VOLUMEN 35, NÚMERO EXTRA | Selección de Trabajos Presentados a REF | PP. 123-130
ISSN 2469-052X (en línea)

Redes de coautoría en la investigación en educación en electromagnetismo

Coauthorship networks in electromagnetism education research

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Resumen

Este artículo de investigación explora los patrones y características de colaboración entre investigadores en el campo de la educación en electromagnetismo utilizando datos bibliométricos y relacionales de múltiples revistas revisadas por pares. El estudio revela que la coautoría es predominante en el campo, con la mayoría de los artículos escritos por parejas o tríos de investigadores. El análisis de redes sociales indica un alto coeficiente de agrupamiento promedio, lo que significa que los investigadores en educación en electromagnetismo presentan a sus coautores entre sí, expandiendo así el círculo social dentro del campo. Sin embargo, la red también exhibe una estructura fragmentada, con varios subgrupos que colaboran de forma independiente. La presencia de estudiantes en los componentes conectados es relativamente baja, lo que indica una comunidad de investigación madura impulsada principalmente por profesores universitarios. Además, las características estructurales de la red de coautoría no varían significativamente entre los investigadores de múltiples revistas y aquellos de una sola revista. Este estudio destaca la importancia del análisis de redes sociales para comprender la colaboración científica y sus implicaciones para la difusión del conocimiento dentro de una estrecha comunidad de investigación en la educación en física.

Palabras clave: Análisis de redes sociales; Investigación en enseñanza de la física; Colaboración científica; América Latina.

Abstract

This research paper explores the collaboration patterns and characteristics among researchers in the field of electromagnetism education research using bibliometric and relational data from multiple peer-reviewed journals. The study reveals that coauthorship is predominant in the field, with most papers coauthored by pairs or trios of researchers. The social network analysis indicates high average clustering coefficient meaning researchers in electromagnetism education introduce their coauthors to each other, expanding the social circle within the field. However, the network also exhibits a fragmented structure, with several subgroups collaborating independently. The presence of students in connected components is relatively low, indicating a mature research community driven mainly by university professors. Moreover, structural features of the coauthorship network do not vary significantly between researchers from multiple journals versus a single journal. This study underscores the importance of social network analysis in understanding scientific collaboration and its implications for knowledge diffusion within a narrow research community within physics education research.

Keywords: Social network analysis; Physics education research; Scientific collaboration; Latin America.

La evaluación del presente artículo estuvo a cargo de la organización de la XXIII Reunión Nacional de Educación en Física

I. INTRODUCTION

Recent research in the electromagnetism education research (EER), both in Brazil and internationally, has focused on overcoming some classical problems in the educational and pedagogical scope. Among them, the traditional teaching with the conception of passive students stands out (Fontes and Rodrigues, 2022), leading to demotivation in the classroom (Lavor and Oliveira, 2022). Additionally, are evident challenges the lack of connection between electromagnetic theory and its practical applications in everyday life (Moraes and Viana, 2021), and the difficulty of students in understanding fundamental concepts of electricity and magnetism, mainly aggravated due to the involved mathematical complexity (Santos, Araújo, and Silva, 2022). These issues have been widely recognized and discussed in various areas of EER, including papers in journals, conference papers, and dissertations and theses. The community of researchers in this area has been making continuous efforts to overcome these difficulties. In the reported practices of electromagnetism teaching, the presence of both information and communication technology (ICT) and experimentation as mediational resources for teaching this discipline is common. These resources not only contribute to the teaching of scientific concepts but also assist the student's development as a social and cultural agent (Fontes and Rodrigues, 2022) and have already been extensively studied in specialized literature reviews (see Matos et al., 2019; Gonçalves and Goi, 2021).

In this context, we identify a research gap in EER. Previous works have addressed specific issues related to electromagnetism teaching practices. However, so far, no studies have investigated how this group of scholars is organized around collaboration. Therefore, the present study aims to investigate to what extent researchers of papers in EER are embedded in a collaborative network. Specifically, our research question is: *to what extent do researchers collaborate in the production of knowledge about electromagnetism teaching, and what are the characteristics of this collaboration?*

To answer these questions, we will use sociological concepts and metrics derived from graph theory. Thus, we position the current work in a tangential sphere to electromagnetism teaching, as we will examine it from this unique perspective. We believe that this approach will enrich the knowledge already built by previous research, providing a complementary view and expanding the understanding of EER.

II. CONCEPTUAL FRAMEWORK

Social network analysis (SNA) is a broad theoretical perspective, comprised of a set of theories and methods that serves various fields of knowledge, from social sciences to natural sciences (Freeman, 2004). Its goal is to provide insights into the investigation of social structures and the relationships between their agents. In general, SNA is based on the intuitive notion that the relationships between social actors, as well as their patterns of configuration, influence the behavior and actions of the individuals involved. Thus, SNA is considered a multidisciplinary research field focused "on the study of interdependence, in the molecular dimension of social life and not in the atomistic dimension of social life" (Higgins and Ribeiro, 2018, p. 40). In our study, we aim to investigate a specific intellectual network: scientific collaboration. Although scientific collaboration occurs in many different contexts (Katz and Martin, 1997), we specifically focus on coauthorship, which is the most common form of assessing scientific collaboration. Coauthorship establishes a formal link between at least two researchers who share authorship of a scientific publication, and their collaboration network represents a knowledge network related to specific aspects of scientific research practice (Fontes and Rodrigues, 2023), also describing the structure of knowledge (Newman, 2004). It is widely acknowledged that scientific collaboration, in the form of coauthorship, is a real phenomenon in modern scientific research influenced by factors such as increased productivity and professionalization of fields, pursuit of interdisciplinary research, and training of new researchers through scientific guidance in graduate programs (Hayashi et al., 2012).

Currently, SNA is commonly examined through concepts from graph theory, with numerous metrics used depending on the object of study, network type, and research question. These metrics need to be interpreted by the researcher, as their meanings change according to the types of networks analyzed (Scott, 2012). A graph is composed by vertices (or points) and edges (or lines). In our analysis, the vertices always represent researchers-authors of the analyzed papers, and the edges that connect them always represent a coauthorship. Thicker edges represent a higher intensity of collaboration. We evaluated the interconnectedness of the network by the concept of *average degree centrality*, one of the most direct measures of collaboration networks, representing the average degree of the vertices. A degree of a vertices is the number of other vertices to which it is connected. The interconnectedness of the network was also assessed by the *average clustering coefficient*. This coefficient represents the average density of connections in the immediate social circle of each researcher. Essentially, it measures the probability that two coauthors of a particular researcher have collaborated with each other (Newman, 2004). We also explored the concept of *connected components* to identify sets of researchers working in isolation from each other, indicating subgroups of the network connected to each other but disconnected from the rest of the network. Finally, we used the concept of *betweenness centrality* to count the number of researchers in a position of power, as they lie in the middle of the path between other researchers in the EER network. This measure indicates their potential to mediate the flow of information in the network and can be associated with the role of broker for vertices with high betweenness centrality (Bottero and Crossley, 2011). Together, these concepts provide a comprehensive picture of the structure of the research community centered around the specific theme of electromagnetism education.

III. SAMPLE, METHODS AND PROCEDURES

The empirical data that underpins the analysis in this study is derived from two stages[1]: i) papers on electromagnetism education research in different peer-reviewed Brazilian journals; and ii) papers on electromagnetism education research in the journal Revista de Enseñanza de la Física (REF). The methodological procedures for stage i) have already been conducted and described in another work with a different scope. In other words, part of the methodological procedures to select the papers that comprise the corpus of this study is described in detail in another publication (see Fontes and Rodrigues, 2021). Therefore, we will only highlight the most relevant aspects of this process.

First, using the public online platform "Qualis-Periódicos", we selected A1 or A2 classified journals in the areas of Education or Teaching (evaluation from 2013-2016) that had a scope in physics teaching or science teaching and that allowed full-text searching on their respective websites. The list of the eight consulted journals and the distribution of papers by year and journal can be found in Fontes and Rodrigues (2021). The search for papers used the descriptors *electromagnetism*, *magnetism*, *electricity*, *electric*, and *electrical* within the entire text. We considered papers published between 2000 and 2019, resulting in 46 papers from different journals. Second, for stage ii), we followed the same search procedures, using the same descriptors in the search engine of REF, covering the period between 2000 and 2022, and identified 43 papers.

In total, 89 papers published in journals were considered for analysis. Figure 1 schematically represents the flowchart of the processes involved in collecting the data.

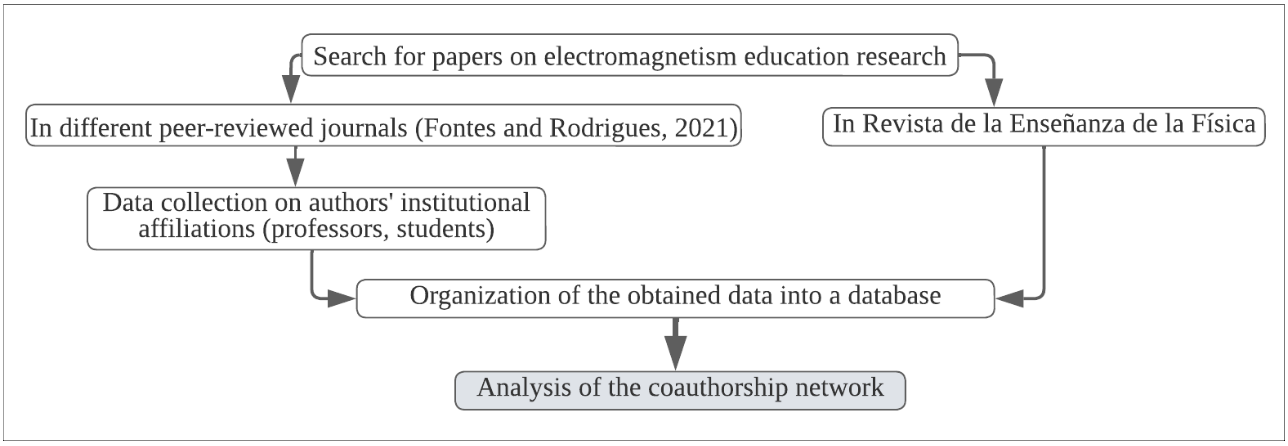

FIGURE 1. Flowchart depicting the methodological steps of the data collection process for the creation of coauthorship networks.

The collection of authors' institutional affiliations was obtained through the Lattes curriculum (Mena-Chalco et al., 2014). Authors who were enrolled as undergraduate, master's, or doctoral students at the time of paper publication were categorized as students. Conversely, authors employed as professors at higher education institutions were classified as professors (PhD-level). The network analysis was conducted using Gephi software version 0.9.7.

IV. RESULTS

In total, 220 different researchers (vertices) were identified, among which 2 had papers without coauthorship, resulting in 264 coauthorships (edges) found. The average number of authors per paper is 2.8, with the majority of papers (75%) having 2 or 3 authors. Only 6 (6.7%) of the papers were published without coauthorship. The average degree centrality of the network is 2.4, indicating that, on average, each researcher is connected to 2.4 other researchers. Figure 2 illustrates the coauthorship network among the researchers in the field of EER.

[1] The data are available from the corresponding author, upon reasonable request.

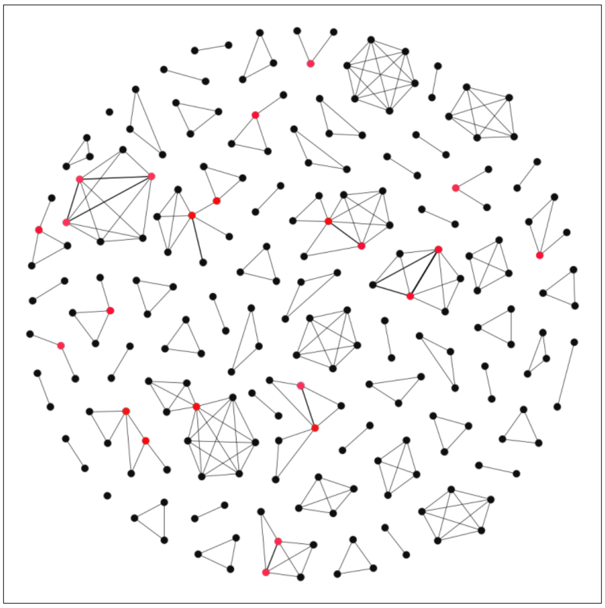

FIGURE 2. Electromagnetism education research coauthorship network. Vertices highlighted in red represent researchers with betweenness centrality.

The EER network consists of 220 researchers organized into 66 connected components. Some researchers exhibit higher degree centrality than others, as evident from the distribution of edges in Figure 2. The highest degree centrality is 8, and the 218 researchers with at least one collaboration may be divided as follows:

- 3 researchers with more than 5 coauthors
- 18 researchers with 5 coauthors
- 23 researchers with 4 coauthors
- 32 researchers with 3 coauthors
- 87 researchers with 2 coauthors
- 55 researchers with 1 coauthor

Figure 3 illustrates the division of the coauthorship network among EER researchers based on the multiple journals (Figure 2a) and on single journal (Figure 2b).

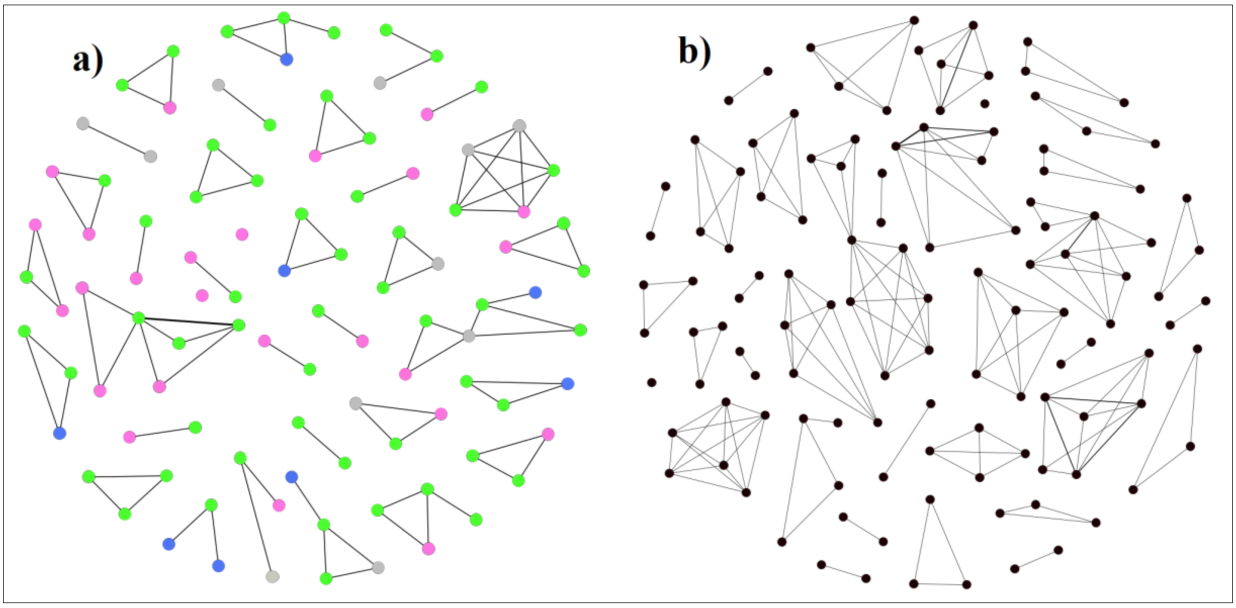

FIGURE 3. Coauthorship network on electromagnetism education research in a) multiple journals; and b) single journal. In the left figure, the points are colored according to their affiliation: green points represent university professors, pink points represent students, blue points represent other affiliations, and gray points indicate that institutional affiliation could not be retrieved.

Among the 99 authors who make up the network in Figure 3a, the following distribution of institutional affiliation was observed at the time of paper publication: 55 were university professors; 25 were students (mostly graduate students); 8 had other affiliations; and in 11 cases, Lattes curriculum data could not be found. The values for the network metrics are presented in Table I.

TABLE I. Metrics evaluated for the networks in electromagnetism education research.

Metrics	Multiple journals network (Figure 3a)	Single journal network (Figure 3b)	Full network (Figure 2)
Coauthors (vertices)	99	121	220
Coauthorships (edges)	92	169	264
Average degree centrality	1.9	2.8	2.4
Average clustering coefficient	0.89	0.95	0.92
Connected components	34	35	66
Vertices with betweenness centrality	10 (10%)	11 (9%)	23 (10%)

It is worth noting that only 10% of the vertices have betweenness centrality. This occurs because, regardless of the network considered, approximately 90% of the points are trivially connected without the need for intermediation.

V. DISCUSSION

In this study, we analyzed bibliometric and relational data from the network of researchers in the field of electromagnetism education, gathered from various peer-reviewed journals. Firstly, we observed that both the average number of authors per paper (2.8) and the prevalence of collaboration in pairs or trios (2 or 3 authors per paper) in EER align with findings reported in other areas or thematic scopes within scientific education (see Souza, Barbastefano and Lima, 2012; Zervas et al., 2012; Anderson, Crespi and Sayre, 2017). Secondly, a vast majority of papers, 83 out of 89 (93%), resulted from coauthorship. It is widely recognized that coauthored publications are on the rise globally, influenced by several factors inherent to the scientific community, such as pressure for publication from funding agencies and universities, combination of different expertise (Campbell and Simberloff, 2022), and international collaboration studies (Yang, Oldac and Nkansah, 2023). This trend is not limited to specific fields but extends across various research domains. Empirical analyses conducted in broad knowledge areas, such as Biology, Physics, and Mathematics (e.g., Newman, 2004), as well as wider fields like Humanities and Health Sciences (e.g., Mena-Chalco et al., 2014), have consistently reported these collaborative practices. Moreover, this collaborative pattern is also apparent in niche areas, such as electromagnetism education research, as observed in our study.

A notable aspect of the EER network is the researchers' tendency to introduce their collaborators to one another. High values for the clustering coefficient, as discussed by Newman (2001), are associated with papers coauthored by three or more authors. However, this alone cannot explain the high clustering coefficient values, given that approximately half of the papers involve only one or two authors. Therefore, we propose that researchers in electromagnetism education actively introduce their coauthors to create new scientific collaborations and expand the social circle within the field. Additionally, the EER network's high average clustering coefficient, combined with a heterogeneous distribution of degree centrality, results in a fragmented network structure. The presence of numerous connected components indicates that researchers predominantly collaborate within smaller groups and work in relative isolation from the rest of the network (see Figure 2). As a consequence of this phenomenon, the network lacks central actors who could significantly influence the flow of knowledge by occupying intermediary or privileged positions among other researchers (Bottero and Crossley, 2011). Notably, these findings hold true regardless of the approach used to analyze the EER network, whether it involves a sample obtained from multiple journals (Figure 3a) or from a single journal (Figure 3b). The fragmented nature of the EER network and the absence of central researchers show the decentralized nature of collaboration in this field. This sheds light on the structure of scientific collaboration in electromagnetism education research, highlighting the diverse and independent collaborative practices that contribute to the development and dissemination of knowledge within the field.

One explanatory element for the fragmentation into different subgroups within the EER network could be the diverse epistemological preferences of researchers, leading them to adopt various theoretical frameworks. Fontes and Rodrigues (2021) highlighted the existence of numerous theoretical frameworks that underpin research in electromagnetism education. Among 32 papers that were oriented by specific theoretical perspectives, they identified at least 14 different frameworks, including History and Philosophy of Science, inquiry-based teaching, Cultural-Historical Theory, among others. Therefore, while all members of the EER network share a common interest in electromagnetism education, the diversity in theoretical approaches contributes to understanding the phenomenon of sparse collaboration within the specific research field.

Furthermore, an interesting observation is that the presence of students within the connected components of the EER network is less than 38% (Figure 3a). This indicates that in the subgroups of researchers, students play a less prevalent role, while university professors are prominently represented. This percentage is notably lower compared to the coauthorship network in physics education research that was analyzed by Fontes and Rodrigues (2023). In that study, the authors examined the coauthorship network formed by researchers engaged in mapping overviews in physics education research, regardless of their specific thematic area. Their findings revealed that almost all connected components in that network were composed of students. In a sense, this difference suggests a certain level of maturity in the field of EER, where the majority of research is conducted by researchers with well-established institutional ties, such as teaching positions at universities. It indicates that EER is primarily driven by experienced scholars and not heavily reliant on postgraduate research, which was observed in the mapping-type research within physics education (see Fontes and Rodrigues, 2023).

Lastly, it is worth highlighting that while the specific networks of EER shown in Figure 3 exhibit many similarities, there are some differences in the average degree centrality between researchers who published in Brazilian journals and those who published in the Revista Enseñanza de la Física (see Table I). On average, the EER network represented by the Revista Enseñanza de la Física appears to be more collaborative. Its average degree centrality is comparable to that of egocentric networks of research group leaders (see Leite et al., 2014). However, the reasons for this discrepancy are not entirely clear, as the content analysis of the papers does not reveal characteristics that justify such a difference. Both networks seem to revolve around similar issues and share the same objectives, such as overcoming conceptual learning difficulties in electromagnetism teaching. This observed difference may be better understood by examining specific institutional and research dynamics within the countries involved. Future research might benefit from analyzing more data to gain further insights into this issue and its underlying factors.

VI. CONCLUSION

Considering the research guiding question, *to what extent do researchers collaborate in the production of knowledge on electromagnetism education, and what are the characteristics of this collaboration?* we have learned some valuable lessons.

First, collaboration is a predominant activity in EER, with a particular emphasis on producing work in pairs or trios. Second, EER exhibits resemblances not only in bibliometric characteristics but also in topological aspects to other scientific networks that analyze coauthorship within thematic scopes. It is noteworthy that such similarities can also be observed when comparing EER networks from multiple sources (in the Brazilian context) and a single source (in the Argentine context). Especially notable is the absence of a comprehensive giant component in the investigated network. We believe that, in a broader sense, physics education research is structured more around epistemological scopes than thematic scopes, as illustrated in this study focusing electromagnetism education. To gain further insights, future research could examine the extent to which researchers contribute scientifically to different thematic scopes of physics within the context of physics education research. It is essential to emphasize that the analysis of scientific collaboration through coauthorship represents just one approach for investigating the knowledge structure of a scientific community, which can be complemented by other investigations, such as citation analysis.

Third, from the perspective of coauthorship, collaboration in EER appears to be organized by a balance of weights and counterweights. On one hand, the lower presence of students and the higher presence of university professors per connected component may indicate a certain maturity of the research area. On the other hand, the dataset evaluation suggests that researchers might make more occasional contributions, which could pose challenges in addressing more persistent issues in electromagnetism education. This aspect is crucial to consider for the research community

Lastly, social network analysis provides valuable insights into the structural forms and implications for the diffusion of knowledge generated by a collective. In this regard, SNA is adept at analyzing relational phenomena such as scientific collaboration, which are often overlooked in traditional literature reviews or theoretical works on scientific communities.

ACKNOWLEDGMENT

This work was supported by the National Council for Scientific and Technological Development – CNPq under Grant 140901/2022-1.

REFERENCES

Anderson, K. A., Crespi, M. & Sayre, E. C. (2017). Linking behavior in the physics education research coauthorship network. *Physical Review Physics Education Research*, 13(1), 010121. DOI: 10.1103/PhysRevPhysEducRes.13.010121

Bottero, W. & Crossley, N. (2011). Worlds, fields and networks: Becker, Bourdieu and the structures of social relations. *Cultural sociology*, *5*(1), 99-119. DOI: 10.1177/17499755103897

Campbell, S. E. & Simberloff, D. (2022). Forty years of invasion research: more papers, more collaboration... bigger impact?. *NeoBiota*, 75, 57-77. DOI: 10.3897/neobiota.75.86949

Fontes, D. T. M. e Rodrigues, A. M. (2021). Fundamentação teórica no ensino de eletromagnetismo: uma revisão da literatura em periódicos nacionais. *Caderno Brasileiro de Ensino de Física*, 38(2), 965-991. DOI: 10.5007/2175-7941.2021.e72040

Fontes, D. T. M. e Rodrigues, A. M. (2022). Experimentação e tecnologia como suporte à prática dos professores de física. In J. Rink, A. A. Viveiro, A. S. Neto, M. E. Andrade (Eds.), *Pesquisas e experiências em ensino de ciências e educação ambiental* (274-289). Itapetininga, São Paulo, Brasil: Hipótese.

Fontes, D. T. M. e Rodrigues, A. M. (2023). Uma análise de rede para as pesquisas do tipo mapeamento em Ensino de Física. *Ensino e Tecnologia em Revista*, 7(1), 364-378. DOI: 10.3895/etr.v7n1.16709

Freeman, L. C. (2004). *The development of social network analysis: a study in the sociology of science*. Canada: Empirical Press.

Gonçalves, R. P. N. e Goi, M. E. J. (2021). Experimentação no ensino de química na educação básica: uma revisão de literatura. *Revista Debates em Ensino de Química*, 6(1), 136-152.

Hayashi, C. R. M. *et al.* (2012). Análise de redes de colaboração científica entre educação especial e fonoaudiologia. *Revista Interamericana de Bibliotecología*, 35(3), 285-397.

Higgins, S. S. e Ribeiro, A. C. (2018). *Análise de redes em ciências sociais*. Brasília, DF: Enap.

Katz, J. S. & Martin, B. R. (1997). What is research collaboration? *Research policy*, 26(1), 1-18. DOI: 10.1016/S0048-7333(96)00917-1

Lavor, O. P. e Oliveira, E. A. G. (2022). Discutindo eletrostática através de uma sequência de ensino investigativa. *Revista de Enseñanza de la Física*, 34(1), 85–91. DOI: 10.55767/2451.6007.v34.n1.37944

Leite, D. *et al.* (2014). Avaliação de redes de pesquisa e colaboração. *Revista da Avaliação da Educação Superior*, 19(1), 291-312. DOI: 10.1590/S1414-40772014000100014

Matos, J. D. V. *et al*. (2019). Aprendizagem significativa por meio do uso de TICs: levantamento das produções da área de ensino de 2016 a 2018. *Revista Novas Tecnologias na Educação*, 17(1), 466-475.

Mena-Chalco, J. P., Digiampietri, L. A., Lopes, F. M. & Cesar, R. M. (2014). Brazilian bibliometric coauthorship networks. *Journal of the Association for Information Science and Technology*, 65(7), 1424-1445.

Moraes, R. B. e Vianna, D. M. (2021). As interações verbais entre estudantes sob a perspectiva latouriana em uma oficina investigativa sobre magnetismo com cinescópios. *Revista de Enseñanza de la Física*, 33(2), 73–80. DOI: 10.55767/2451.6007.v33.n2.35177

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *Proceedings of the national academy of sciences*, 98(2), 404-409. DOI: 10.1073/pnas.98.2.404

Newman, M. E. J. (2004). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the national academy of sciences*, 101(1), 5200-5205. DOI: 10.1073/pnas.0307545100

Santos, B. M., Araújo, L. M. e Silva, K. W. A. (2023). Jogo de cartas sobre espectro eletromagnético e suas aplicações: relato de experiência na formação inicial de professores. *Revista de Enseñanza de la Física*, 35(1), 95–108. DOI: 10.55767/2451.6007.v35.n1.41393

Scott, J. (2012). *What is social network analysis?*. Bloomsbury Academic.

Souza, C. G., Barbastefano, R. G. e Lima, L. S (2012). Redes de colaboração científica na área de química no Brasil: um estudo baseado nas coautorias dos artigos da revista Química Nova. *Química Nova*, 35(4), 671-676. DOI: 10.1590/S0100-40422012000400003

Yang, L., Oldac, Y. I. & Nkansah, J. O. (2023). What makes scientists collaborate? International collaboration between scientists in traditionally non-central science systems. *Higher Education Research and Development*. DOI: 10.1080/07294360.2023.2218803

Zervas, P. *et al.* (2014). Studying research collaboration via co-authorship analysis in the field of TeL: the case of Educational Technology & Society Journal. *Educational Technology & Society*, 17(4), 1–16.