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How did academic collaboration occur in research on STEM attitudes and careers?

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Abstract

This study aims to examine the co-authorship relationships established between researchers working on STEM career interests, STEM professions, and STEM attitudes by creating a social network. For this purpose, the articles scanned in the web of science index between 1983 and 2023 were filtered. After the filtering process, a total of 6371 articles constituted the sample of this research. In our study, the relationships established between 10989 authors, 237 universities, and 121 countries in the co-authorship network were visualized and existing connections were modeled. As a result of the collaborations between the authors in the network, prominent communities were found with the Louvain algorithm. Other network metrics such as weighted degree centrality, closeness degree centrality, and betweenness degree centrality were calculated and visualized using Gephi software. The findings obtained as a result of the analysis revealed the characteristic patterns of scientific collaborations in the social network, prominent authors in the field, universities, and countries.

Keywords: Social Network Analyses; STEM Career; STEM Occupation; Stem Vocation.

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1. Introduction

As a reflection of the growing interest in STEM careers, scientists, societies, universities, and government agencies are encouraged to develop scientific careers and engage students in STEM careers (Clarke, Sharma, & Schiller, 2019). One of the main goals of the recent global education reform has been to develop a qualified workforce in STEM fields and to increase the number of people who have careers in these fields (Dou et al., 2019; Karahan, Kara, & Akçay, 2021). However, despite the continuous and rapid increase in the need for employment in STEM-related fields, the workforce capacity to meet these positions has not been reached yet (Höffler, Köhler & Parchmann, 2019; Makhlouf & Mine, 2020). This situation reveals the need for research to determine the variables that affect students' attitudes toward STEM (Huang et al., 2022; Göktepe Körpeoğlu & Göktepe Yıldız, 2022). To meet the need for a stem workforce, students' interest and attitudes toward STEM disciplines should be increased and students should be directed to choose these areas (Hiğde & Aktamış, 2020). Determining the attitudes toward STEM will contribute to making the necessary arrangements to increase the workforce potential that countries will need in the future (Kennedy, Quinn, & Taylor, 2016; Dou, Cian & Espinosa-Suarez, 2021; Villanueva Baselga et al.,2022).

On the other hand, one of the important problems of science is how to identify new fields and needs, trend research topics, and the patterns between them, thus predicting discoveries (Kang et al., 2021; Plasman & Gottfried, 2022). Social network analysis, which is an approach based on the idea that "the whole is not just the sum of the parts that make up the whole" for the solution of these and similar problems, has been used in network research in social and behavioral sciences since the mid-1930s (Wasserman & Robins, 2005: 1). It is a method that is frequently applied in many fields such as anthropology, social psychology, communication, economics, and mathematics (Freeman, 2004). There are many opinions that social network analysis can be used in the analysis of relationships (Hanneman & Riddle, 2005). Social network analysis justifies intuitions about the structural ties that bind social actors together (Freeman, 2004).

Social network analysis is an approach that enables to reveal of the existing patterns in the relations of the actors of that community with each other to understand the structure of a community. Social networks are of particular interest to researchers as they reveal important communication patterns between authors in scientific studies. One of the primary tasks of social network analysis is community mining or detection (Umadevi, 2014). While SNA provides powerful, descriptive, and statistical measures for interpreting networks (Wasserman & Faust, 2009), network diagrams allow to visualization of relational patterns that affect individual or community behavior (Newman, 2001). Co-authoring networks can be used to explore international cooperation models (Melin & Persson, 2005). While analysis of co-authoring networks is used to rank the most influential authors in the co-author network or to identify the most suitable reviewers for a paper or to predict future research collaboration (Savić et al,2015), community detection in these networks reveals characteristic patterns of scholarly collaboration and author helps to understand the identity organization of the society (Aung, & Nyunt, 2020) effectively automates the synthesis process that takes time in literature reviews while revealing the developments in the field in the process (Cowhitt, Butler, & Wilson, 2020).

1.1. Purpose of study

This study aims to examine the co-authorship relationships established between researchers working on STEM career interests, STEM professions, and STEM attitudes by creating a social network. As a result of all these, the research questions of our study on scientific collaborations in research on STEM attitudes and careers are as follows.

Q1- How was the Intensity of Collaboration by Years, based on Author, Institution, and Countries?

Q2- As of 2023, the prominent communities cover how much of this density?

Q3- Who are the top 10 authors who play a key role in terms of degree centralization, betweenness, and closeness centrality in prominent communities?

Q4 – Which are the 10 countries that play a key role in terms of degree centralization in prominent cooperation clusters and what are the development values of the last 10 years?

2. Materials and Methods

We accepted the condition of a joint article between any two authors in the field of STEM professions as a scientific collaboration sign. We assumed that the joint article between the two authors constituted a collaboration between the institutions of those authors at the time they published the article and also between the countries where the institutions are located.

2.1. Procedure

We determined the number of citations received by common publications as a power factor that highlights the relationship. According to those rules, we have generated graph nodes that represent the author, affiliation, and countries; as graph edges represent the collaboration between authors, affiliations, and countries for the STEM vocational co-authorship network (SVCN). We analyzed the SVCN and obtained the results by using Gephi software. Gephi is open-source software for developing networks and analysis (Bastian, Heymann, & Jacomy, 2009). We analyzed the nodes over the years and in-depth, by their centralization value which is one of the generally accepted SNA metrics. We focused on Weighted Degree Centrality, Betweenness Centrality, and Closeness Centrality to understand the collaboration.

We ranked the authors, institutions, and countries using weighted degree centralization, which is used to examine the strength of the relationships between nodes as influence value in the network (Opshl, Agneessens, & Skvoretz, 2010). We used the betweenness centrality to determine the mediator authors which positions in the middle of different collaboration groups. Betweenness centrality is a fundamental metric in social network analysis and shows the importance of nodes in a graph and the shortest paths through them in terms of intersection (Riondato & Kornaropoulos, 2014). In a collaboration community, we wished to determine the closest author to the other authors in a collaborative way. Thereafter, we used closeness centrality. Closeness centrality is an important metric in social network analysis that measures how close a node is to all other nodes in the graph (Okamoto, Hen, & Li, 2008). To have a macro view of the graph we determine communities embodied by the authors that collaborate closely by using the Louvain algorithm. The Louvain algorithm is a simple, heuristic method for finding communities in large networks (Blondel, Guillaume, Lambiotte & Lefebvre, 2008). We acquired the density parameters of the collaboration network and evaluated them over the years. Graph Density, another metric, gives the integrity of nodes in a network (Zervas, Tsitmidelli, Sampson & Chen, 2014).

3. Results

3.1. Q1: Change of Graph Density by Years

The metrics showing the density of collaboration of authors, institutions, and countries are given below. According to the data in Table 1, the number of entities such as author institution or country, total collaboration, and density values of those entity networks by years are shown.

Table 1

Network Density Metrics

Year	Total Author Collabo-ration	Author Quantity	Author Density	Total Institution Collabo-ration	Institution Quantity	Institution Density	Total Country Collabo-ration	Country Quantity	Country Density
2022	10400	2234	0.0042	8498	694	0.0353	1200	61	0.6557

2021	9528	1797	0.0059	6747	533	0.0476	726	46	0.7014
2020	6922	1527	0.0059	4452	444	0.0453	519	52	0.3914
2019	7640	1700	0.0053	7040	419	0.0804	383	44	0.4049
2018	8148	1460	0.0077	7259	412	0.0857	386	39	0.5209
2017	5971	1272	0.0074	4456	349	0.0734	261	31	0.5613
2016	4713	1009	0.0093	5028	305	0.1085	824	34	1.4688
2015	4974	872	0.0131	3074	288	0.0744	120	24	0.4348
2014	2669	667	0.0120	3188	219	0.1336	132	20	0.6947
2013	2383	655	0.0111	2660	243	0.0905	90	17	0.6618
2012	1444	416	0.0167	1981	148	0.1821	20	10	0.4444
2011	1710	428	0.0187	1651	163	0.1250	71	13	0.9103
2010	882	183	0.0530	758	83	0.2227	5	4	0.8333
2009	171	88	0.0447	68	40	0.0872	33	12	0.5000
2008	227	73	0.0864	133	37	0.1997	6	5	0.6000
2007	109	59	0.0637	31	18	0.2026	3	2	1.0000
2006	190	55	0.1279	206	33	0.3902	1	2	0.3333
2005	137	42	0.1591	57	31	0.1226	1	3	0.1000
2004	22	14	0.2418	10	10	0.2222	1	2	1.0000
2003	17	11	0.3091	6	5	0.6000	1	10	0.3333
2003	1	2	1.0000	1	2	1.0000	1	0	0.0000
2002	13	10	0.2889	31	17	0.2279	1	2	0.1667
2001	10	6	0.6667	4	2	4.0000	1	2	1.0000
2000	7	8	0.2500	6	6	0.4000	1	2	1.0000
1999	8	10	0.1778	49	18	0.3203	1	2	1.0000
1998	15	9	0.4167	3	3	1.0000	1	2	1.0000
1997	3	3	1.0000	6	4	1.0000	1200	61	0.6557
1996	4	5	0.4000	1	2	1.0000	726	46	0.7014
1995	10	11	0.1818	3	6	0.2000	519	52	0.3914
1994	13	15	0.1238	2	4	0.3333	383	44	0.4049
1993	1	2	1.0000	6	4	1.0000	386	39	0.5209
1992	10400	2234	0.0042	8498	694	0.0353	261	31	0.5613
1991	9528	1797	0.0059	6747	533	0.0476	824	34	1.4688

3.2. Q2: Modularity Quantities and the Density as of 2023

We identified 10 Communities with a total density of more than 10% of the whole graph. The highest and lowest average centrality values in terms of centrality metrics of the member authors belonging to these communities are shown in Table 2. Also, Figure 1 visualizes communities.

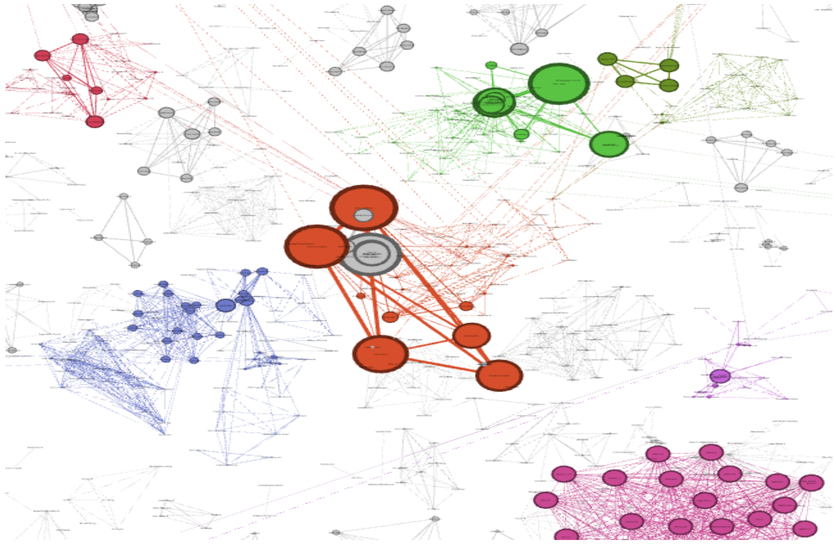
Table 2

Modularity Metrics of the Author Networks

Community Number	Graph Density %	Author Quantity
603	2.19	81
77	1.65	61
612	1.27	47
221	0.84	31
412	0.81	30
607	0.78	29
545	0.76	28
649	0.73	27
239	0.7	26
262	0.68	25

Figure 1

Communities in Author Network



3.3. Q3: Top 10 Authors and Their Centrality Values

Among all modules, Table 3 shows the first 10 prominent authors in terms of weighted degree, betweenness, and closeness centrality.

Table 3

Network metrics of Top 10 Authors

Author Name	Weighted Degree Centrality	Betweenness Centrality	Closeness Centrality
Brown, Elizabeth R.	20754	168.916667	0.276712
Diekman, Amanda B.	19659	2852.25	0.31962
Cheryan, Sapna	19409	45	1
Hazari, Zahra	18707	1032.933333	0.552846
Clark, Emily K.	17000	3.25	0.248157
Johnston, Amanda M.	14304	0	0.246944
Sonnert, Gerhard	13128	249.866667	0.43871
Sadler, Philip M.	12188	185.2	0.43038
Tai, Robert H.	11972	255	0.407186
Steinberg, Mia	11547	0.25	0.247549

3.4. Q4: Top 10 Country, Their Centrality Values

The current degree centralism and weighted degree centralization values between 2012 and 2022 of the 20 countries that stand out in terms of weighted degree centralism are shown in Table 4.

Table 4

Network metrics of Top 10 Countries over the past 10 years

Country	Weighted Degree	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
USA	29738	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
England	8038	719	1913	1051	2118	2846	3484	3727	3123	2842	5515	449
Australia	7716	363	528	1927	557	248	130	323	186	1175	1805	148
Canada	7250	0	176	95	22	164	711	1155	335	1064	1108	287
Germany	6142	8	971	0	579	968	208	27	82	452	3460	68
France	5786	96	400	0	536	269	2633	183	201	370	183	204

Switzerland	5163	0	0	4920	0	36	454	42	47	0	1	10
Scotland	4585	2	96	4077	161	262	0	0	224	188	24	17
Netherlands	3842	0	0	0	0	4239	0	0	9	8	304	17
Italy	3569	0	48	1630	0	258	13	924	50	166	37	36

4. Discussions

The results of the distribution of graph density values according to years, which we obtained as a result of our study, showed that the appetite for academic collaboration increased based on authors, universities, and countries in studies conducted in the field of STEM professions and careers. As a result of the analysis, a decrease was observed in graph density compared to previous years. This is because, on the one hand, it leads to an increase in the entry of new researchers into the field, the number of researchers, and the possibility of collaboration, on the other hand, it reveals a low density due to the inability of collaboration networks to develop at the same pace. In this study, we observe that the field has developed with different accelerations in different periods from the study of the STEM career that started in 1983 to the present day. Particularly after 2002, the accelerated movement grew and grew, and by the end of 2022, it exceeded 10,000 annual collaborations. However, when we look at the institutions and countries that are the pioneers of this acceleration, we see that the USA takes the lead. We think that the systematic review of the other activities of the countries that are the pioneers of academic collaboration in the field of STEM professions and comparing them with each other will have a complementary effect on the continuation of this study.

When the communities formed within the scope of the organization of the academic collaboration network are examined, it is seen that the prominent communities dominate more than 10% of the network and include the most successful authors and publications. In light of these findings, it is clear that academic cooperation provides advantages in producing quality scientific outputs and in the continuation of research. However, it has been observed that among the prominent communities, collaboration communities are weak or not realized compared to the collaborations within themselves. In particular, community number 221 is a closed network, and it has been observed that the collaboration provided in a successful publication with multiple authors highlights the community and therefore the authors. An in-depth examination of the cooperation between these cooperation clusters working in the same field can be carried out as a continuation of this research, and developing strategies for the formation of these collaborations will make great contributions to the progress of the field.

When the prominent authors among the communities are examined, we see that the authors in community number 612 have the highest weighted degree of centrality and betweenness centrality. These authors are highly valued for their work and collaborations, as well as for their potential to form partnerships among many different groups of authors. It has been observed that the closeness centrality of the authors who can access large committees and produce high-quality products and collaborations is lower than the authors who have produced quality products in closed groups. This shows that the local activity of an active author in a community in a collaborative network is independent of its global activity. As a result, although researches and collaborations in the field of STEM professions are on an increasing trend, collaboration groups should tend to cooperate with other communities besides collaborating within themselves. By examining the activities of universities and countries that increase their cooperation activities outside of their academic studies, user feedback can be provided to the field and more efficient global collaborations can be established. In the establishment of global collaborations, new research can be made by selecting representative members of the communities within the existing network and examining the working areas in depth, and this developing research field can be more beneficial for the welfare of both societies. can be provided to produce various academic outputs.

5. Conclusion

The importance of STEM education is increasing in terms of attracting students' interest in science, technology, engineering, and mathematics and enabling them to pursue careers in these fields. Increasing the workforce potential in STEM fields for countries and structuring studies to ensure that STEM professions are preferred is necessary for both national and international competition. Since the network was created using strong relational data, major communities in the co-authoring network were identified.

The structure of these communities was examined with social network analysis, which is an interdisciplinary field of study, and the authors who were influencers in the communities were determined. It is thought that the study will provide foresight to researchers who conduct a literature review and bibliometrics analysis on STEM careers, STEM professions, and STEM attitude fields in terms of revealing prominent authors, universities, and countries in these fields and will create a source from an abroad perspective.

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