The Network Structure of Nanotechnology Research Output of Turkey: A Co-authorship and Co-word Analysis Study[1]

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Abstract

This paper aims to assess the diffusion of nanotechnology knowledge within the Turkish scientific community using co-citation and co-word analysis techniques. We retrieved a total of 10,062 records of nanotechnology papers authored by Turkish researchers between 2000 and 2011 from Web of Science (WoS) and divided the data set into two 6-year periods. We identified the most prolific and collaborative top 15 universities in each period based on their network properties. We then created co-authorship networks of Turkish nanotechnology researchers in each period and identified the most prolific and collaborative top 15 authors on the basis of network centrality coefficients. Finally, we used co-word analysis to identify the major nanotechnology research fields in Turkey on the basis of the co-occurrence of words in the titles of papers. Findings show that nanotechnology research in Turkey continues to increase due to researchers collaborating with their colleagues. Turkish researchers tend to collaborate within their own groups or universities and the overall connectedness of the network is thus low. Their publication and collaboration patterns conform to Lotka's law. They work mainly on nanotechnology applications in Materials Sciences, Chemistry and Physics, among others. This is commensurate, more or less, with the global trends in nanotechnology research and development.

Conference Topic

Country-level studies, Mapping and visualization

Introduction

Nanotechnology is a relatively new field studying materials at atomic levels within the 1 to 100 nanometer (nm) range (one nm is equal to one billionth of a meter, or, 10^{-9}) (Nanotechnology, 2015). It involves physics, chemistry, medicine, and biotechnology, among others, and promises a great deal of innovation for, and benefit to, society as a whole. Turkey identified nanotechnology early on (2003) as one of the eight strategic fields to support and invested considerably in nanotechnology infrastructure and education. It set up several "centers of excellence" in universities for nanotechnology research and development (R&D). Among them are the Research Center for Nanotechnology and Biotechnology of the Middle East Technical University (METU) and the National Nanotechnology Center in Bilkent University. The former is the first such center established with 15M USD government support while the latter is the first largest multi-purpose nanotechnology center established with 70M USD investment. Universities themselves also invested in nanotechnology. Altogether, there are currently more than 20 nanotechnology research centers in Turkey (Bozkurt, 2015;

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[1] This paper is based on the findings of first author's PhD dissertation entitled "Assessing the diffusion of nanotechnology in Turkey: A Social Network Analysis approach." (Darvish, 2014).

Denkbaş, 2015; Özgüz, 2013). The private sector has also invested in nanotechnology in Turkey. Currently, more than 100 companies working in this field and they already developed several nanotechnology products and commoditized them.

In parallel with both government's and private sector's financing of nanotechnology research, several universities initiated multidisciplinary nanotechnology degree programs both at undergraduate and graduate levels (MSc and PhD). The undergraduate and graduate programs of Bilkent University's "Material Science and Nanotechnology", METU's "Micro and Nanotechnology" and Hacettepe University's "Nanotechnology and Nanomedicine" are among them.

The substantial interest and investment in nanotechnology triggered nanotechnology research in Turkey. In fact, Turkey is among the top three countries in the world in terms of the growth rate of nanotechnology research. More than 2,000 researchers are active in this field producing some 2,500 papers in 2014 alone[2] (Bozkurt, 2015, p. 49; Denkbaş, 2015, p. 84; Özgüz, 2013). In this paper, we investigate the development of nanotechnology research in Turkey using bibliometric and Social Network Analysis (SNA) techniques to study the network characteristics of more than 10,000 papers authored by Turkish researchers between 2000 and 2011. We compare the diffusion of nanotechnology research between 2000-2005 and 2006-2011 by measuring the network properties such as degree, betweenness and closeness centrality coefficients of the most prolific and collaborative universities and researchers for each period. We also identify the major nanotechnology research strands in Turkey using co-word analysis.

Literature Review

Information scientists have studied the growth of science and communication using bibliometrics and Social Network Analysis (SNA). While the former deals mainly with the effects of scientific productivity using citation analysis, the latter mainly focuses on the pattern of relationships among scientists. The network composed of co-authorship among scientists is a true indication of their cooperation in research activity.

The "small world" effect is a phenomenon that has been studied by scientists in different fields. This phenomenon conjectures that each member (node) in a society is linked to others (edges) through friends. Literally, every node in a small world is connected through an acquaintance. Newman (2000) found out that average distance from one person to the other by an acquaintance is proportional to the logarithm of the size of the community, implying one of the small world properties. Moreover, he found out that traversing between the two randomly selected nodes of a network takes an average of six steps.

In social contexts, Moody (2004) analyzed the structure of a social science collaboration network over a period. He discovered that collaboration between graduate students in a specific topic creates a small world of scientists and removes restrictions between them. Small world networks may manifest themselves in several shapes and models. Therefore, a good understanding of small world models helps us understand the network characteristics, too. For example, according to Watts (2003) a social network can be categorized as active or passive. Granovetter (1974) studied an active social network from the perspective of finding a job while Burt (1992) looked at such a network as social capital preluding the "rich get richer" phenomenon. In this study, the co-authorship network of structure is represented in a passive sense where the nodes and the edges connecting them are treated as actors and their relationships. Small world models are comprised of clusters or components. Clusters embedded in a network structure reveal a property called "clustering coefficient". According to Watts and Strogatz (1998), one can define a clustering coefficient *C*, which is the average

[2] Search on WoS was carried out on January 11, 2015.

fraction of pairs of neighbors of a node which are also neighbors. That is to say, if node *A* neighbors with node *B* and node *B* is a neighbor of node *C*, then there is a probability that node *A* is also a neighbor of node *C*.

According to Otte and Rousseau (2002, p. 443), betweenness, closeness and degree centrality are well known measures used in analyzing networks. Betweenness centrality is defined as the number of shortest paths going through a node. Thus, a node with high betweenness centrality will have a large impact on the diffusion of knowledge in the network (assuming that knowledge diffusion follows the shortest paths). Centrality is the total number of links that a node has. Degree centrality identifies the most influential node in the diffusion of knowledge in the social network. Closeness measures how far a node is from other nodes in the network structure. Closeness centrality is a measure of how long it will take to diffuse knowledge in a network (Centrality, 2015).

Betweenness centrality plays an important role in the structures of social networks. According to Freeman (2004), the discovery of the structural properties of scientific papers is measured by the betweenness centrality. Actors with a high level of betweenness centrality play a pivotal role in connecting different groups within the network. Betweenness centrality characterizes preferential attachments, cliques, or brokers. Preferential attachments play an important role in network development (Barabasi & Albert, 1999, p. 509). In other words, people in social networks tend to work with well-known people that lead to the concept of "strong and weak ties", characterizing a group of people attached to one node with high centrality. This is called the "star network model" (Moody, 2004; Scott, 2000).

Newman (2000) stated that collaboration among scientists in networks is a good example of showing preferential attachment. As mentioned earlier, if two nodes have high degrees of centrality, the probability of being acquainted with a mutual friend gets higher. Only a small percentage of people in a social network are well connected while the rest are loosely connected (Lotka's law). The productivity of authors in a network resembles Lotka's law in that a small number of researchers publish the majority of papers while large numbers of researchers publish one or two papers (Martin, Ball, Karrer & Newman, 2013). Each group of authors creates a community in which a node with a high degree of centrality is the central node. Therefore, collaboration networks consist of separate clusters representing different scientific fields where they may connect through lower degree connectors. Each community comprises several star networks and these clusters may be connected by a node of lesser degree. Newman (2000) referred to clustering as "community structure".

Co-authorship analysis is used by bibliometricians to track temporal and topological diffusion of scientific publications. Co-authorship stimulates the knowledge diffusion in scientific communities (Chen et al., 2009, p. 192). Thus, co-authorship analysis is used quite often to study the diffusion of innovation and knowledge. For example, Özel (2010) assessed the diffusion of knowledge in business management among academia in Turkey from 1928 to 2010 by studying the co-authorship relationships of academics in business management.

Co-word analysis of texts helps map scientific fields and reveals the cognitive structure of the scientific domain (Chen, 2004). Callon, Courtial, Turner, and Bauin (1983) used the co-word analysis to study the literature over time in terms of the frequencies or co-occurrences of words in titles, abstracts, or more generally, in text. PageRank measuring the popularity of web pages is a similar metric (Page & Brin, 1989). For example, the appearance of a certain author in the references of a corpus of articles reflects the prestige of that author in the network structure.

As we mentioned earlier, the growth rate of nanotechnology research in Turkey is quite encouraging and researchers contribute to the global nanotechnology literature (Kostoff et al., 2006; Kostoff, Koytcheff & Lau, 2007). Although the state of the art of nanotechnology centers and companies has been studied quantitatively (Aydoğan-Duda & Şener, 2010;

Aydoğan-Duda, 2012), their research output in terms of scientific papers has yet to be studied in detail. This is the first such study to investigate the diffusion of nanotechnology in Turkey and the level of collaboration among the most prolific universities and researchers using co-authorship and co-word analysis.

Method

This paper aims to depict the development of nanotechnology in Turkey between 2000 and 2011 by identifying the network structure of nanotechnology papers authored by Turkish researchers and finding out the most productive universities and researchers who help diffuse the nanotechnology knowledge by collaborating with their peers. Social network analysis, co-authorship and co-word analysis tools were used to map the nanotechnology network structure and the collaboration patterns. We attempt to answer the following research questions:

1) Which universities and researchers contribute most to the diffusion of nanotechnology research in Turkey by collaboration?
2) Do co-authorship networks in nanotechnology literature exhibit a "small world" network structure?
3) What are the main nanotechnology research interests of Turkish scholars?

To answer these questions, we retrieved a total of 10,062 records of nanotechnology papers (articles and reviews) from Web of Science (WoS) published between 2000 and 2011 by Turkish authors. We divided the data set into two equal periods (2000-2005 and 2006-2011) to better identify the trends. Almost three quarters of papers (7,398 papers or 73.5%) were published in the second period. Elsewhere, we presented the descriptive statistics for each period on the number of nanotechnology papers published by universities and analyzed the diffusion and adoption of nanotechnology in Turkey by means of the output of the most prolific authors (Darvish & Tonta, 2015). In this paper, we investigate the diffusion of nanotechnology in Turkey by studying the network properties of nanotechnology literature. We first identified the top 15 most prolific universities and authors by means of social network analysis tools. We then identified the scientists with the highest coefficients of centrality in the network structure. We used co-authorship, co-word[3] and factor analyses to track the collaboration patterns and research interests of Turkish nanotechnology scholars between the two periods. We used Bibexcel, VOSviewer, Pajek and Gephi to create files and map the bibliometric data, calculate the properties of the social network structure (e.g., the betweenness, closeness, and degree centralities and the PageRank of each node) and depict the network's features visually.

Findings

Table 1 shows the network properties of the top 15 selected universities in each period (2000-2005 and 2006-2011) ranked by the degree centrality coefficients of their nanotechnology papers. Middle East Technical (METU), Bilkent and Hacettepe Universities are at the pinnacle of the list and they contributed to the network with the highest number of nanotechnology papers. İstanbul Technical (İTU), Erciyes and Kocaeli Universities are at the bottom of the list with the lowest degree centrality coefficients in the 2000-2005 period. Nodes with higher degree centralities participate more in the network than that with the lower ones and the network structure adheres to the small world phenomenon.

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[3]The co-word analysis was conducted based on software: http://www.leydesdorff.net/software/fulltext/index.htm

Table 1. Centrality coefficients of nanotechnology papers of the top 15 universities between 2000-2005 and 2006-2011

2000-2005					2006-2011				
University	# of papers	Degree centrality	Closeness centrality	Betweenness centrality	University	# of papers	Degree centrality	Closeness centrality	Betweenness centrality
Middle East Technical	353	0.523	0.467	0.113	Bilkent	356	0.620	0.588	0.069
Bilkent	183	0.515	0.495	0.124	Gebze Institute of Technology	227	0.603	0.541	0.068
Hacettepe	283	0.401	0.495	0.072	Hacettepe	552	0.574	0.524	0.022
Ondokuz Mayis	65	0.357	0.359	0.041	Middle East Technical	646	0.562	0.511	0.054
Dokuz Eylül	108	0.333	0.393	0.109	Istanbul Technical	481	0.534	0.468	0.031
Gebze Institute of Technology	71	0.314	0.499	0.110	Anadolu	224	0.470	0.379	0.042
Kirikkale	36	0.288	0.457	0.119	Gazi	490	0.457	0.373	0.070
Ege	84	0.276	0.359	0.126	Ondokuz Mayis	309	0.450	0.415	0.067
Abant İzzet Baysal	11	0.252	0.612	0.184	Istanbul	245	0.445	0.394	0.045
Gazi	127	0.244	0.373	0.156	Ege	315	0.431	0.382	0.035
Marmara	64	0.225	0.336	0.215	Ankara	348	0.418	0.363	0.071
Ankara	181	0.224	0.373	0.072	Dokuz Eylül	270	0.323	0.429	0.060
Kocaeli	21	0.218	0.325	0.425	Firat	185	0.317	0.452	0.051
Erciyes	58	0.162	0.466	0.098	Erciyes	166	0.256	0.452	0.049
Istanbul Technical	214	0.109	0.363	0.151	Atatürk	219	0.230	0.316	0.091
Avg		**0.296**	**0.425**	**0.141**	**Avg**		**0.446**	**0.439**	**0.055**

The average degree centrality for the top 15 universities rose from 0.296 in the first period to 0.466 in the second period, indicating an almost 60% increase. Istanbul Technical University's degree centrality increased five times between the two periods, making it one of the top nodes in the second period. Kırıkkale, Abant İzzet Baysal, Marmara and Kocaeli Universities with relatively fewer number of papers did not make it to the top 15 universities in the 2006-2011 period and were replaced by Anadolu, İstanbul, Fırat and Atatürk Universities.

Bilkent University is at the top of the 2006-2011 list with the highest closeness centrality coefficient (0.588) followed by Gebze Institute of Technology (0.541) (which was in the 6th place in the first period). Their high closeness centrality coefficients indicate that sub-networks within the whole network are almost 60% connected. However, their betweenness centrality coefficients are relatively low, which means that the flow of information among sub-clsuters within the whole network is slow. Hacettepe and Middle East Technical Universities are also at the top of the 2006-2011 list. These four universities form a cohesive network structure in 2006-2011. However, the average closeness centrality coefficient stayed almost the same for both periods (0.425 and 0.439, respectively). In other words, it took equally long to spread nanotechnology knowledge for the top 15 universities in each period.

In general, betweenness centrality coefficients are much lower for all universities. In fact, the average betweenness centrality has decreased from 0.141 to 0.055 in the second period, indicating that sub-clusters in the network structure became less connected in the second period for the top 15 universities. Atatürk, Ankara, Gazi, Bilkent, Gebze Institute of Technology and Ondokuz Mayıs Universities have the highest betweenness centrality coefficients in the second period, an indication of relatively higher flow of information among sub-clusters within the network than the rest. Dokuz Eylül, Hacettepe and Ankara Universities have the lowest betweenness centrality coefficients in the first period and Hacettepe, İstanbul Technical and Ege Universities in the second period.

Next, we studied the co-authorship network structures in both periods using social network analysis (SNA) techniques (Fig. 1). SNA enabled us to discern the nodes that might be crucial to the diffusion of nanotechnology knowledge. The network consists of 470 nodes and 1,042 edges in 2000-2005 and 945 nodes and 4,915 edges in 2006-2011. The rates of growth for nodes and edges (ties) increased two- and four-folds, respectively, between the two periods. However, the level of collaboration has not changed so much. There is a minimal change in density (from 0.009 to 0.011) between the two periods, but the network is still quite sparse. Nonetheless, the average degree and clustering coefficients show that clusters within the network are somehow connected for both periods. For example, the average clustering coefficient for 2000-2005 is 0.75, indicating that 75% of the nodes were connected. Since the network has grown in the second period, the rate of connectedness has decreased (0.51), indicating that newly formed clusters were not that cohesive yet.

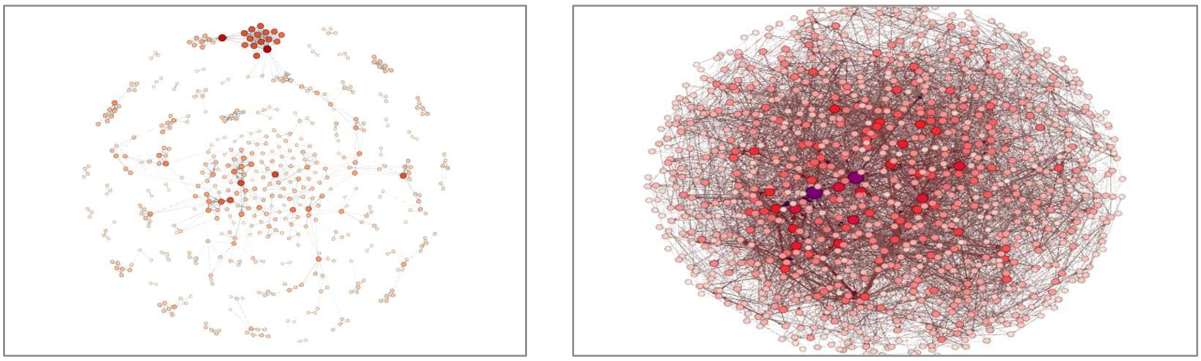

Figure 1. Co-authorship network of scientists working on nanotechnology between: (1) 2005-2011and (r) 2006-2011

The network in the second period adheres to the transitivity relations, indicating that the network at meso level is well connected even though the sub-clusters are not that well connected (especially in the periphery of the network) (Fig. 1). That is to say that there has been some progress in terms of creating new sub-clusters in the co-authorship network, although links among sub-clusters have yet to be formed. In other words, almost all scientists have co-authored with one or more authors in their own cluster but not beyond.

Table 2 shows the top 15 Turkish authors and their affiliations with the highest centrality coefficients (closeness, betweenness, degree, and PageRank) between 2000 and 2005 who contributed to the diffusion of nanotechnology with their scientific papers. Some scientists appear in more than one columns of centrality due to their high collaboration level in the network structure. For example, Yakuphanoğlu F (Fırat University), Yağcı Y and Öveçoğlu MN (İTU), Çelik E (Dokuz Eylül) and Denizli A (Hacettepe) appeared in three columns with high degree (collaborator), betweenness (broker and gatekeeper), and PageRank coefficients (prolific author) while Yılmaz F and Toppare L (METU), Morkoç H (Atatürk), Özdemir I (Dokuz Eylül) and Pişkin E (Hacettepe) appeared at least in two columns out of four (degree, betweenness, closeness and PageRank centralities). They were highly influential in the diffusion of nanotechnology in Turkey between 2000 and 2005.

Table 2. Network properties of the top 15 Turkish authors based on co-authorship degree centralities: 2000-2005.

Rank	Degree centrality	Betweenness centrality	Closeness centrality	PageRank
1	Balkan N (Fatih)	Yilmaz F (METU)	Sarı H (Bilkent)	Ovecoğlu MN (ITU)
2	Teke A (Balıkesir)	Gencer A (Hacettepe)	Sökmen I (Dokuz Eylül)	Çelik E (Dokuz Eylül)
3	Yağci Y (ITU)	Koralay H (Firat)	Kasapoğlu E (Cumhuriyet)	Denizli A (Hacettepe)
4	Yakuphanoğlu F (Firat)	Okur S (Izmir Inst Tech)	Çiraci S (Bilkent)	Hasçiçek YS (Gazi)
5	Ovecoğlu MN (ITU)	Denizli A (Hacettepe)	Aytor O (Bilkent)	Yağci Y (ITU)
6	Çelik E (Dokuz Eylül)	Yavuz H (Hacettepe)	Biyikli N (METU)	Yakuphanoğlu F(Firat)
7	Yilmaz F (METU)	Güneş M (Kirikkale)	Özbay E (Bilkent)	Toppare L (METU)
8	Toppare L (METU)	Yakuphanoğlu F (Firat)	Doğan S (Bilkent)	Yilmaz VT (Ondokuz Mayıs)
9	Doğan S (Bilkent)	Balkan N (Fatih)	Morkoç H (Atatürk)	Pişkin E (Hacettepe)
10	Morkoç H (Atatürk)	Çelik E (Dokuz Eylül)	Sari B (Gazi)	Erkoç Ş (METU)
11	Denizli A (Hacettepe)	Pişkin E (Hacettepe)	Talu M (Gazi)	Kurt A (Koç)
12	Erol A (Istanbul)	Güven K (Erciyes)	Kartaloğlu (Bilkent)	Elmali A (Ankara)
13	Özdemir I (Dokuz Eylül)	Yağci Y (ITU)	Yilgor E (Koç)	Hincal AA (Hacettepe)
14	Turan R (METU)	Ovecoğlu MN (ITU)	Yilgor I (Koç)	Ozdemir I (Dokuz Eylül)
15	Dag O (Bilkent)	Menceloğlu YZ (Sabancı)	Andaç O (Ondokuz Mayıs)	Oral A (Sabancı)

Co-authorship map of the first authors for the first period is shown on the left-hand side of Figure 2. Most of the authors listed in Table 2 are also on the map. Although most authors were from universities with high degree centralities, other authors whose universities did not have high degree centralities were also instrumental in the diffusion of nanotechnology knowledge in the network during the 2000-2005 period (e.g., Yilgor E and Yilgor I from Koç, Koralay H and Yakuphanoğlu E from Fırat, and Kasapoğlu E from Cumhuriyet Universities).

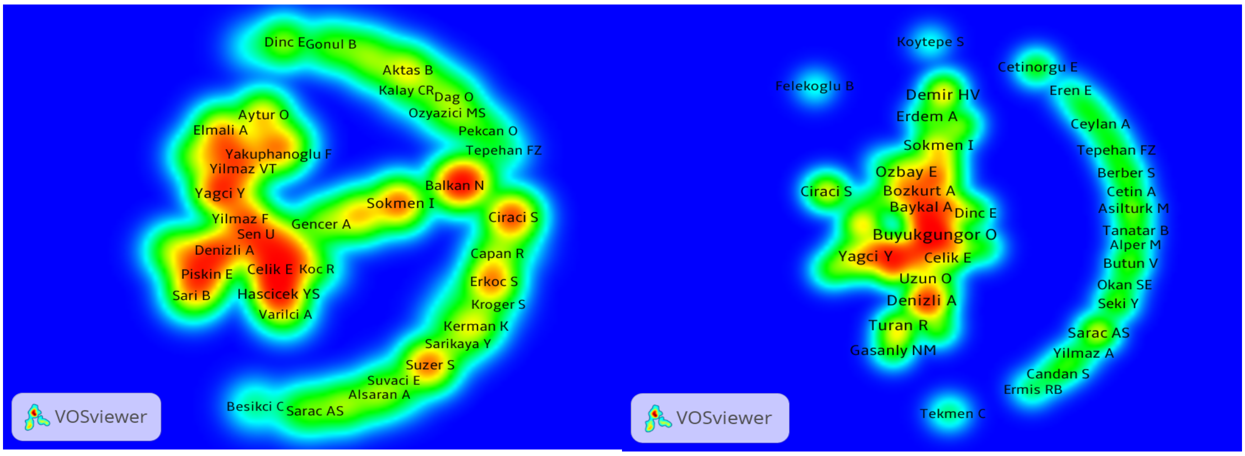

Figure 2. Co-authorship map of Turkish nanotechnology scientists between: (l) 2000-2005 and (r) 2006-2011.

Table 3 shows the top 15 authors who were influential in the diffusion of nanotechnology in Turkey between 2006 and 2011. Interestingly, Büyükgüngör O of Ondokuz Mayıs University has the highest centrality coefficients in all four categories but one (the betweenness centrality) even though he was not in the top 15 authors in the first period. His name appears in the center of the 2006-2011 network of Figure 2 as a prestigious researcher playing an important role in the dissemination of nanotechnology knowledge in the network structure. (His research field is Crystallography.) Similarly, Özçelik S of Gazi University is at the top 15 in all four categories. Six authors appear in at least three columns: Denizli A (Hacettepe), Şahin E (Gazi), Yağcı Y (İTU) and Toppare L (METU) in degree, betweenness and PageRank columns, and Özbay E and Çıracı S (Bilkent) in degree, closeness and PageRank columns. An additional six authors appear in at least two columns: Yeşilel ÖZ (Osmangazi) and Baykal A (Fatih) in closeness and PageRank columns; Yıldız A (Fatih) and Yılmaz F (METU) in degree and betweenness columns; Çakmak M (Koç) in betweenness and PageRank columns; and Turan R (Ege) in degree and PageRank columns.4 It should be pointed out that even though Fatih and Karadeniz Technical Universities failed to have the highest degree centrality coefficients in neither period, some of their scientists (e.g., Yildiz A and Bacaksız E, respectively) played an important role nonetheless in the diffusion of nanotechnology knowledge in the network.

The centrality coefficients of four authors were high in both periods: Yağcı Y (İTU), Denizli A (Hacettepe), and Toppare L and Yılmaz F (METU). They were highly active in spreading the nanotechnology knowledge in Turkey between 2000 and 2011 as prolific authors, collaborators, brokers and gatekeepers, and diffusers.

Table 3. Network properties of the top 15 authors based on co-authorship degree centralities: 2006-2011.

Rank	Degree centrality	Betweenness centrality	Closeness centrality	Page Rank
1	Büyükgüngör O (Ondokuz Mayis)	Yilmaz F (METU)	Büyükgüngör O (Ondokuz Mayis)	Büyükgüngör O (Ondokuz Mayis)
2	Şahin E (Gazi)	Büyükgüngör O (Ondokuz Mayis)	Yeşilel ÖZ (Osmangazi)	Özbay E (Bilkent)
3	Toppare L (METU)	Özçelik S (Gazi)	Demir HV (Bilkent)	Özçelik S (Gazi)
4	Yilmaz F (METU)	Toppare L (METU)	Nizamoğlu S (Bilkent)	Toppare L (METU)
5	Özçelik S (Gazi)	Yağcı Y (ITU)	Çağlar Y (Anadolu)	Denizli A (Hacettepe)
6	Yağci Y(ITU)	Şahin E (Gazi)	İlican S (Anadolu)	Turan R (Ege)
7	Özbay E (Bilkent)	Yildiz A (Fatih)	Çağlar M (Anadolu)	Şahin E (Gazi)
8	Turan R (Ege)	Çakmak M (Koç)	Özbay (Bilkent)	Çıracı S (Bilkent)
9	Çakmak M (Kirikkale)	Şahin O (Dokuz Eylül)	Özçelik S (Gazi)	Yeşilel ÖZ (Osmangazi)
10	Yerli A (Sakarya)	Yilmaz M (Istanbul)	Baykal A (Fatih)	Yağci Y (ITU)
11	Yildiz A(Fatih)	Turan R (METU)	Köseoğlu Y(Fatih)	Sökmen I (Dokuz Eylül)
12	Çetin K (Ege)	Bacaksiz E (Karadeniz Technical)	Toprak MS (Fatih)	Arslan H (Hacettepe)
13	Çiraci S (Bilkent)	Denizli A (Hacettepe)	Çiraci S (Bilkent)	Oskar S (METU)
14	Denizli A (Hacettepe)	Şen S (Yalova)	Durgun E (Bilkent)	Çakmak M (Koç)
15	Sari H (ITU)	Balkan A (Fatih)	Akgol S (Adnan Menderes)	Baykal A (Fatih)

The collaboration network of Turkish scientists who work on nanotechnology seems to be well connected at the micro level but not so much at the macro level. In other words, researchers tend to collaborate within their own sub-clusters (i.e., groups or universities) more often. The frequencies of the total number of publications that first authors contributed to adhere to Lotka's law:

$$f(y) = .2459 \div y^{1.2881} \quad (1)$$

where *f(y)* denotes the relative number of authors with *y* publications (the K-S DMAX = 0.6323) (Rousseau, 1997), indicating that a small number of well-known scientists have stronger positions in the network. As mentioned earlier, although some scientists from smaller universities with the lower degree centrality coefficients have appeared in the network structure as a turning point, one can call them as non-elite authors. However, their impact on knowledge diffusion is remarkable.

[4] Note that some author names with the same initials are affiliated with two different universities in this period (e.g., Çakmak M at both Koç and Kırıkkale Universities and Turan R at both Ege and Middle East Technical Universities). They may well be the same authors who may have moved from one university to the other during this period.

We also carried out a co-word analysis on the words that appear in the titles of articles extracted from WoS to find out the most frequently used terms between 2000 and 2005, and between 2006 and 2010. The first 75 most frequently occurring words in each period were collected, processed and compiled by the software.5 Non-trivial words were eliminated. In order to analyse the word/document occurrence matrix in terms of its latent structure, SPSS software version 16.0 was used to factor analyse the co-occurrence of words. Factor analysis maps each word to a different component (research strand) with the highest factor loading. SPSS created two factors from the list of the co-words. Table 4 and 5 show the output of factors for the periods of 2000-2005 and 2006-2011 along with the loadings of different words in each factor (not all 75 words listed in the tables). According to eigenvalues, the first factor explains 56% of the variance in the entire data set for the period of 2000-2005 while the second one explains the rest of the variance (44%). For the 2006-2011 period, the first factor explains 35% of the variance in the entire data set while the second and third ones explain 33% and 32% of the variance, respectively.

Table 4. Factor analysis of co-words in the titles of nanotechnology papers (2000 and 2005).

Rotated component matrix[a]

Words	Factor 1	Words	Factor 2
CHEMICAL	.999	PLASMA	.999
QUANTUM	.999	TREATMENT	.999
STEEL	.998	CONDUCTING	.990
HYDROGEN	.997	CERAMIC	.982
COPOLYMER	.992	SOL-GEL	.982
FIELD	.992	LAYER	.945
PROPERTIES	.984	OPTICAL	.945
ELECTRICAL	.973	SURFACE	.945

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 8 iterations.

We then produced a normalized cosine extraction of the words and mapped the network structure of co-word analysis in each period using Kamada & Kawai algorithm embedded in Pajek (Fig. 3). Words that appear in both periods belong mainly to Multidisciplinary Science and Materials Science. Represented fields in both periods are as follows: Surface Materials (“Doped”, “Alloy”, and “Plasma”); Chemistry and its subfields (“Coating”, “Crystal” “Catalyst”, and “Sol-Gel”); and Physics (“Quantum”, “Dot” and “Nanotube”). It appears that Turkish nanoscientists work primarily in Material Sciences, followed by Physics and, to some extent, Biotechnology.

[5] We used the software available at http://www.leydesdorff.net/software/fulltext/index.htm to create a normalized cosine symmetric co-occurrence matrix of labels.

Table 5. Factor analysis of co-words in titles of nanotechnology papers (2006 and 2011).

Rotated component matrix[a]

Words	Factor 1	Words	Factor 2	Words	Factor 3
COPOLYMER	.766	STEEL	.673	DOT	.687
COMPLEXES	.697	WELL	.655	MORPHOLOGY	.676
CRYSTAL	.674	AQUEOU	.651	ADSORPTION	.654
THERMAL	.653	ZNO	.642	ENERGY	.644
SPECTROSCOPIC	.650	PARTICLE	.626	PREPARED	.641
CHARACTERISTIC	.643	MATERIAL	.625	QUANTUM	.620
COPOLYMER	.766	TEMPERATURE	.620	ELECTRICAL	.619
METAL	.636	CELL	.618	MODIFIED	.610

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Discussion and Conclusion

In this paper, we assessed the network structure of nanotechnology papers authored by Turkish scientists between 2000 and 2011. We used the social network analysis techniques and studied the network properties from different perspectives. We first identified the top 15 universities for each period (2000-2005 and 2006-2011) on the basis of centrality coefficients. They played pivotal roles in the dissemination of nanotechnology knowledge in Turkey. We then created the co-authorship network of nanotechnology scientists and analyzed the network properties (coefficients of degree, betweenness, closeness centralities and PageRank) of the top 15 authors in each period. We also used the co-word analysis to identify the major nanotechnology research fields in Turkey on the basis of the co-occurrence of words in the titles of papers.

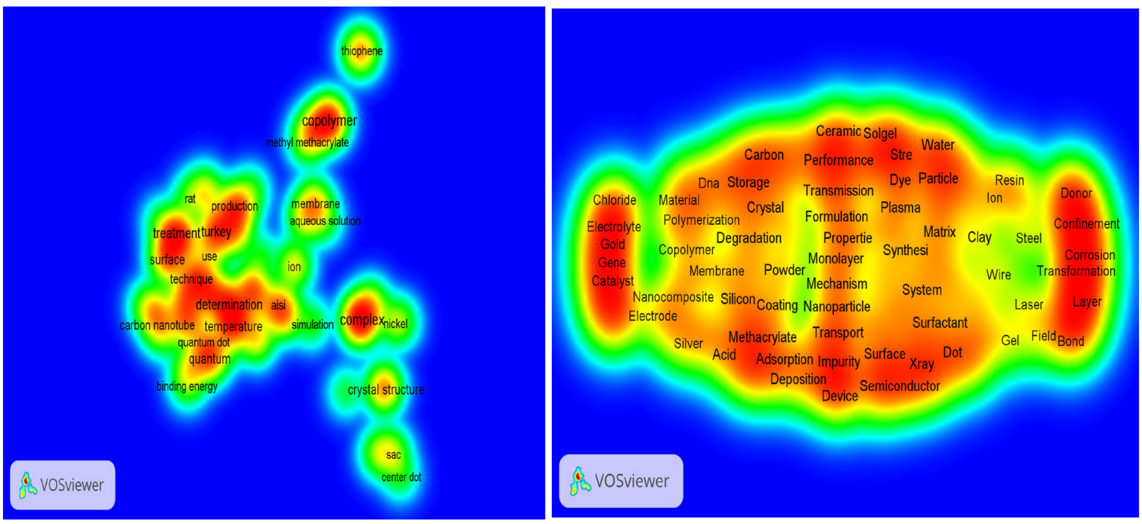

Figure 3. Network of co-word analysis in nanotechnology in Turkey: (l) 2000-2005 and (r) 2006-2011.

Although the number of nodes in the network has increased in the second period (2006-2011), the overall connectedness of the network structures is low. The centrality coefficients of the network structure of the top 15 universities revealed that the social network structure is denser at the micro level than that at the macro level. While the betweenness centrality remained low and the closeness centrality did not change much, the degree centrality increased almost 60% in the second period, which is an indication of the small world phenomenon in the network structure.

The research output of Turkish nanoscientists and collaboration among them conform to some extent to Lotka's law in that a few researchers tend to publish the bulk of nanotechnology papers while the rest are less prolific. This indicates that Turkish scientists tend to work with prolific authors. The taxonomy identified by the co-word analysis shows that Turkish nanoscientists mainly work in Materials Sciences, Chemistry and Physics. Nanotechnology research continues to flourish due to collaborations at the micro level within the Turkish scientific community and the diffusion of nanotechnology knowledge is accelerating. Bibliometric indicators and network properties reported in this research may help policy-makers to understand the interdisciplinary character of nanoscience and nanotechnology better and develop funding mechanisms accordingly.

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