Intellectual Structure Of Stem Education In Educational Research

Mutlu Tahsin ÜSTÜNDAĞ
Gazi University, Gazi Faculty of Education,
Computer Education and Instructional Technologies, Turkey
mutlutahsin@gmail.com

Haydar YALÇIN
İzmir Katip Çelebi University,
Faculty of Humanities and Social Sciences,
Information Management and Technologies, Turkey
haydar.yalcin@gmail.com

Erhan GÜNEŞ
Ahi Evran University, Faculty of Education,
Computer Education and Instructional Technologies, Turkey
guneserhan@gmail.com

ABSTRACT
The aim of this research is to put forward the intellectual structure of STEM (Science, Technology, Engineering and Mathematics) education concept in educational research. STEM education has emerged as a highly accepted paradigm in education especially in the USA and European countries in recent years. The theoretical substructure of STEM education that is seen as an important factor in attaining the expected qualities in human profile for the changing conditions of the 21st century has started to be formed. STEM education prioritizes team study and interdisciplinary approach. It is of great importance to put forward the intellectual structure of STEM education, that will play an important role in training people for the conditions of the present day, for better comprehension by the researchers, curriculum developers and practitioners. Moreover, when the literature on this concept is investigated, lack of comprehension of the concept and vision is seen. For this reason, the investigation of the development and current status of STEM education will contribute to literature in terms of understanding the intellectual structure of the concept. The dataset of the study is composed of all types of studies in at least one of the categories of Education & Educational Research and "Education, Scientific Disciplines" published in Web of Science (WoS). Basing on WoS categories the relationship of the concept with other disciplines have been examined and visualized with web graphics on the accessed publications. It has been possible to refer to which focus the scientific data has been developed nourishing via the journals by mapping the journals in the dataset as citation giving and citation attaining. In addition to these, contribution of disciplines and countries to STEM education has been compared.

Keywords: Scientometrics, STEM education, knowledge diffusion

INTRODUCTION
In recent years STEM education that is shaped by science, technology, engineering and mathematics disciplines altogether has emerged as a new paradigm instead of a traditional science education. Bybee (2010b) defines STEM education as "although focusing on science and mathematics disciplines including technology and engineering fields". For Dugger (2010) STEM education which advocates the integration of information and skills on science, technology, engineering and mathematics fields by including engineering design processes into science education aims to educate students as individuals who are open to communication, systematical thinkers, creative, possessing ethical values and ones who can present the most convenient solutions to problems by directing them to cooperation to different disciplines like an engineer. Lacey and Wright (2009) sees STEM education -that aims to attain individuals the required knowledge and skills to see the problems with an interdisciplinary point of view- important for leadership in scientific field and economic growth.

The responsibility of countries to raise and train the individuals according to the necessities of today's fast changing and developing technology brings forward a must. Because qualified human resource means a strong economy. At this point it can be said that individuals should attain skills such as critical and analytical thinking, investigate, inquiry, problem solving and decision making. It is a reality in the competitive business World that

countries producing information and technology establish superiority on the other countries in economic and social domains. Furthermore, technology education or technology literacy is of great importance at this point. Sanders (2008) states this situation as: "*Technology education has a key role to play in integrative STEM education, and could play a significant role in twenty-first century American education if it can demonstrate relevance in this way.".* Miaoulis (2009) points out that today when the country economies are determined by information and innovations it is very important to train engineers and scientists and increase science and technology literacy. The reality that qualified human resource can only be achieved via qualified education proves itself day by day. Countries producing information and technology place great importance to their people's mathematics and science educations. For these reasons, in the USA necessity for a science education based on engineering design has been emphasized (Çavaş, Bulut, Holbrook & Rannikmae, 2013). In a science education based on engineering design, the design process correlate with the real life. Furthermore, this kind of education provides the learners to realize that there is more than one solution to problems and understand the importance of cooperative work (Ercan & Bozkurt, 2013; National Research Council, 2012).

It is possible to say that there is hereupon an apparent critical concentration in countries that pay attention to STEM education. At this point the report written by Marginson, Tytler, Freeman, and Roberts (2013) titled *STEM: country comparisons: international comparisons of science, technology, engineering and mathematics (STEM) education*" shows that some countries have started to receive the fruits of this education. The emergence of these kinds of comparison and evaluation reports show that there has been some amount of concentration in STEM education. However, some studies in the literature reveal that although some countries have comprehended the philosophy of STEM education, they have not realized it fully or there is still need to research on this concept. The study conducted by Brown, Brown, Reardon, and Merrill (2011) starts as follows: *"Many in the field of technology education have embraced STEM education, but there is a lack of understanding of STEM education in schools.".* These statements imply that there is a need for the serious support of the academic community for the practitioners in schools and model practices that will help the comprehension of STEM education that is coherent with the internal dynamics and cultures of each country. To shortly summarize the study and its results we can say that the study aimed to find out whether teachers, students and school principals could comprehend STEM education or not. A questionnaire composed of open-ended questions have been used as data collection tool as well as observations and interviews have been conducted. According to the findings of the study it has been seen that STEM education has not been comprehended. Another result is that STEM education has no vision. Yet another study has been carried out by Breiner, Harkness, Johnson, and Koehler (2012). The title of the study summarizes the situation best by stating "*What Is STEM?".* The results of the study titled "*A Discussion About Conceptions of STEM in Education and Partnerships"* indicated that there is not a consensus on STEM concept. Bybee (2010a) has tried to set forth a 2020 vision for STEM education. This study implies that there is still much more to be done. Yet it is seen in literature that there is a need for understanding STEM education and concept. When we examine the situation in our country, STEM education should be defined specific to our country within the scope of the aims in 2023 Vision and Ministry of National Education (MEB) strategic documents (Çorlu, Adıgüzel, Ayar, Çorlu, Özel, 2012). However, studies on STEM education in our country seem to be in the preparation phase. The findings of the study conducted by Marulcu and Sungur (2012) indicate that studies on STEM education are in the preparation phase even in teacher training system and teacher candidates are not prepared to STEM education.

As seen from the literature that there is not a concept integrity but also lack of vision; this study is thought to contribute to this field. And as revealing the intellectual structure of STEM concept will help STEM concept and STEM education to be better understood and offer a solution and guidance for researchers and practitioners shows the importance of this study. It would be useful to include some research done in this context. The study conducted by Greenseid and Lawrenz (2011) investigated a less studied field; they studied the usage of citation analysis on the influence of program evaluations in STEM education. Their citation analysis has been focused on three STEM education program evaluations' products. The aim of the study was comparing the influence of the STEM education evaluations. In analyzing the citations; single-level Poisson regression analysis, content analysis and network analysis have been conducted. With the purpose of whether citation data usage is functional in comprehending the evaluation impacts; the result has been although with limited extent, methods of citation data analysis supports the comprehension of the influence of extensive scale and multi-site STEM education and evaluation fields.

Another research by Assefa and Rorissa (2013) titled "*A bibliometric mapping of the structure of STEM education using co-word analysis"* sought to define the structure that underlies STEM education and its main areas as well as the relationship between them by using co-word analysis, visualization and bibliometric mapping tools. The authors used co-occurrence analysis in order to organize bibliometric maps. With this "word

association method" there has been a significant relationship between word that "co-occur" has been figured. Composed of two databases 7265 documents have formed the data of the study.

We are in the opinion that an increase in the studies that will help better understanding of STEM education concept in literature will provide better formation and practices of the concept in the future.

THE AIM OF THE STUDY

The aim of this research is to put forward the intellectual structure of STEM (Science, Technology, Engineering and Mathematics) concept in educational research. The investigation of the emergence, development and current situation of the concept will contribute to the literature in terms of understanding the intellectual structure of the concept. Our research questions that will serve for this aim are as follows:

1. How is the distribution of STEM research according to countries?
2. How is the distribution of STEM research according to WoS categories?
3. How is the distribution of STEM research according to WoS research domains?
4. How is the distribution of keywords WoS and the authors give to STEM researches?
5. What are the prominent disciplines that STEM researches nourish from?
6. From which disciplines is the knowledge dissemination in STEM researches provided?

METHOD

In this research the current situation of STEM education research in WoS publications has been tried to be put forward; so it is a descriptive research. In descriptive research the situations are presented wholly and exactly as far as possible (Fraenkel, Wallen and Hyun, 2014)

The Dataset of the Study

The dataset of the study was obtained by querying from Web of Science (WoS). "Topic research" code that makes searches in abstract, title and key words of the publications in WoS was used. At this stage it was seen that the concept "STEM" is used frequently in field of medicine. For this reason in order to exclude the publications in medicine field NOT=(TS=("stem cell") statement was added to the query. The final version of the query to reach the dataset is thus: (TS=("Science, Technology, Engineering and Mathematics" OR "STEM" or "STEM EDUCATION") AND TS=(education)) NOT=(TS=("stem cell")). Via this query all types of publications in SCI-E, SSCI, A&HCI, CPCI-S, CPCI-SSH and ESCI indexes between 1945 and 2016 were accessed. The total number of the accessed publications is 1985. First, the accessed 1985 publications were analyzed via "Vantage Point" and "SciMAT" software and publications that have no relation with STEM education or those published in the field of medicine were filtered and a separate dataset was formed from publications that have at least one of the "Education & Educational Research" and "Education, Scientific Disciplines" categories. The final number of the publications was 908. In all the analyses and visualizations dataset that has been composed of these 908 study was used.

Data Analysis

As the dataset of the study was very big and complex, data mining techniques were used in the analysis of the data obtained. One of the definitions of data mining in literature has been made by Larose (2014) as "the process of discovering useful patterns and trends in large datasets". Bibliometric analysis was used in the study for providing to seeing the trends and patterns. According to Pritchard (1969) bibliometrics is "the application of mathematical and statistical methods to books and other media of communication". Glanzel (2003) states that in bibliometric studies of scientific publications the information types to be used are as follows: title of the journal, authors' names, corporate addresses, references used, type of the documents, publication title, abstract, keywords, acknowledgements and subject headings. Again for Glanzel (2003) bibliometric method has been widely used for research management and science policy for more than 10 years. Data of the study has been analyzed via "Vantage Point" and "SciMAT" software and "Pajek" software has also been used for analysis results.

FINDINGS

This study sought answers to six questions. Findings of these six research questions were presented with separate titles according to their orders in the aim section.

1. How is the distribution of STEM research according to countries?

Concerning the research question, Figure 1 is presented:

Figure 1. Distribution of STEM Research According to Countries

The publication distribution according to the country published in, according to author address is seen in Figure 1. It is possible to state that North America countries are pioneers for STEM studies according to Figure 1. They are seen to be followed respectively by European countries, Australia and Turkey. When the literature is examined, the starting time of the USA for STEM education studies go back to 1990s and have accelerated since the last decade.

2. How is the distribution of STEM research according to WoS categories?

Created by using Aduna algorithm, when Figure 2 is examined it is seen that the biggest cluster of WoS categories related to STEM education are respectively *Education & Educational Research* and *Education, Scientific Disciplines*. When the relations of the publications with other categories are investigated it is easily observed that they are related with many WoS categories.

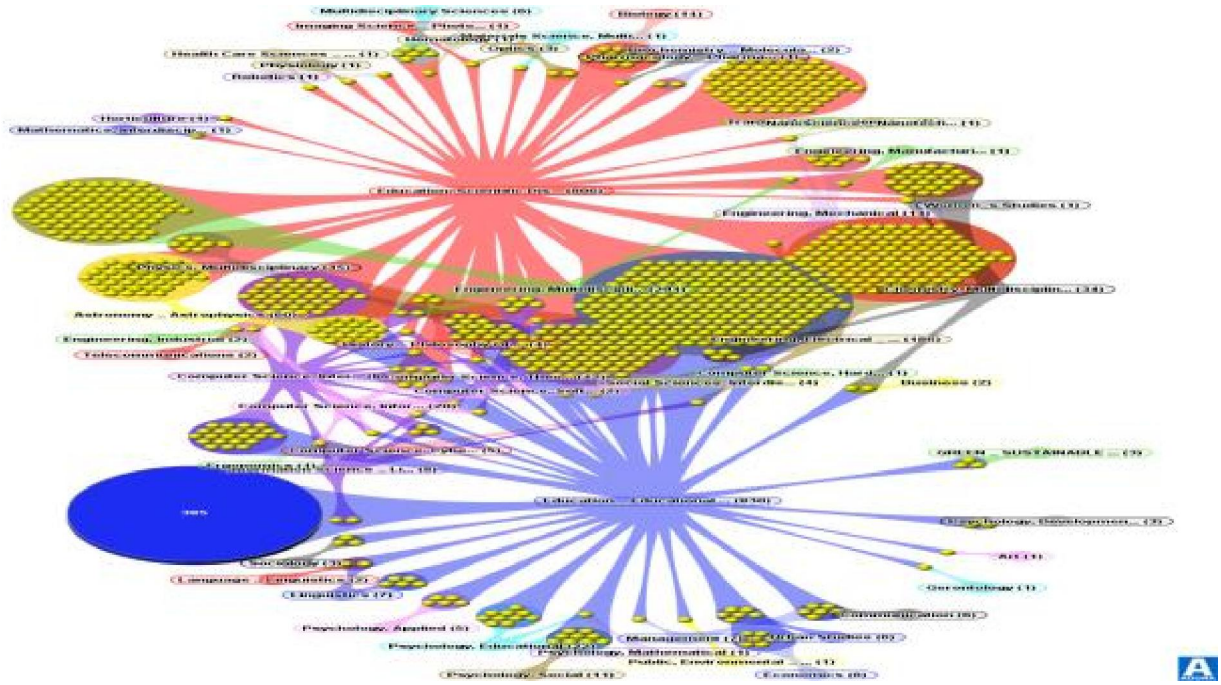

Figure 2. The Distribution of STEM Research According to WoS Categories and the Relationship Status (Aduna Alg.)

When Figure 3, created by Pajek, is examined the categories and the proximity to the center can be seen more clearly:

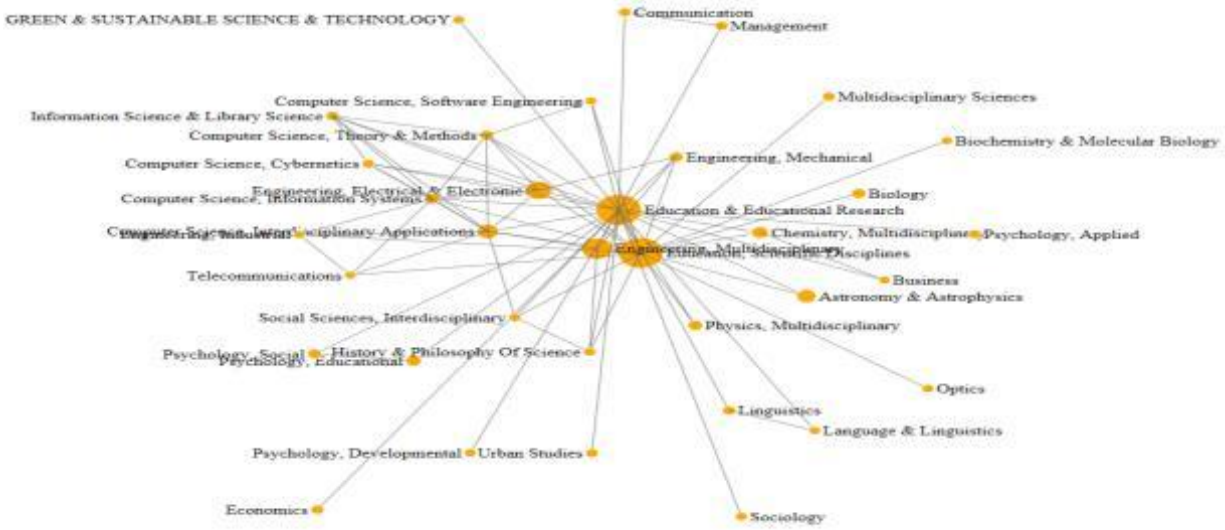

Figure 3. The Distribution of STEM Research According to WoS Categories and the Relation Status (Pajek)

When Figure 3 is analyzed again *Education & Educational Research* ile *Education, Scientific Disciplines* Categories show themselves. Just beside them appears *Engineering, Multidisciplinary* category as the biggest node. We could say that they are followed respectively by the other categories of *Engineering* fields with *Astronomy & Astrophysics, Interdisciplinary Applications, Computer Science, Cybernetics, Information Management, Social Sciences* categories. These all reveal how large amount of discipline STEM concept addresses and studies. In other words, it is possible to say that the concept that is thought to be about just 4 disciplines is in fact examined by researchers studying in many disciplines.

3. How is the distribution of STEM research according to WoS research domains?

It is possible to say after the analysis of STEM education studies in WoS according to the research domains with Figure 4 created by Aduna algorithm that, studies indexed under *Education & Educational Research* study field are published more in journals that are indexed in *Science* ve *Technology Research, Astronomy & Astrophysics* study fields. Cluster with the largest ratio of publication is again seen to belong to journals in *Education & Educational Research* research domains.

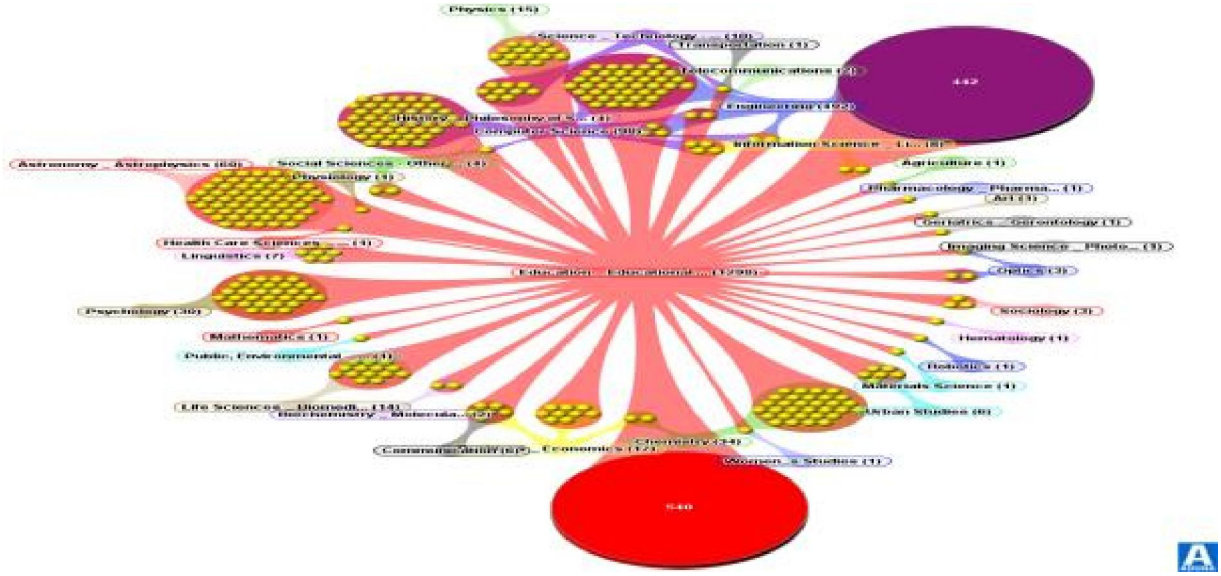

Figure 4. The Distribution of STEM Research According to WoS Research Domains and The Relationship Status (Aduna Alg.)

Figure 5 prepared by using Pajek in the analyses is presented to closely examine the relationship among WoS research domains:

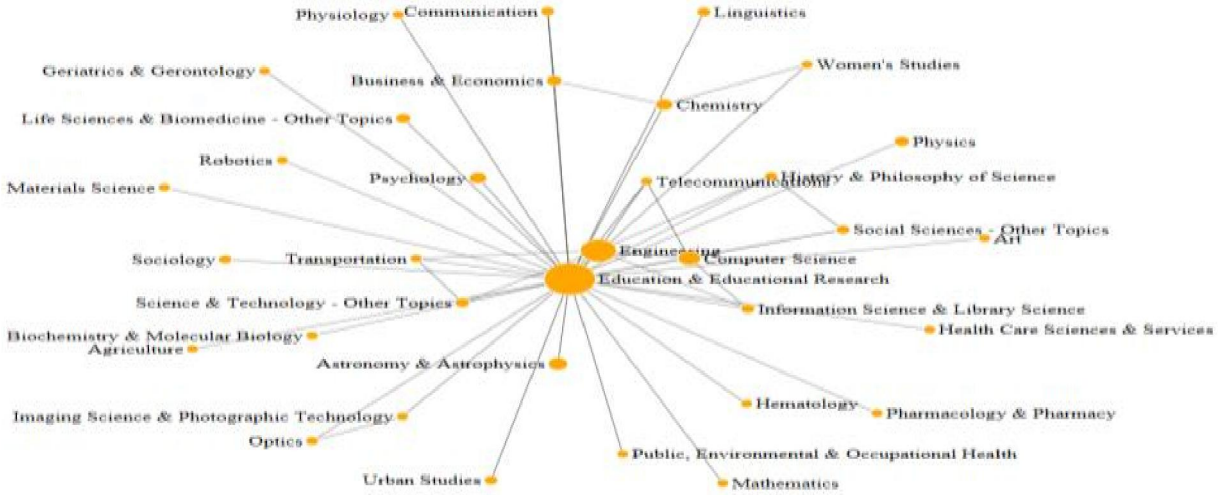

Figure 5. The Distribution of STEM Research According to WoS Research Domains and The Relationship Status (Pajek)

Education & Educational Research research domain could be possibly stated as the biggest node in the center when Figure 5 is examined. It is followed respectively by *Engineering, Computer Science, Astronomy & Astrophysics* and *Psychology.*

4. How is the distribution of keywords WoS and the authors give to STEM research?

The visual created by Aduna algorithm related with the key words WoS gives to the studies is presented in Figure 6:

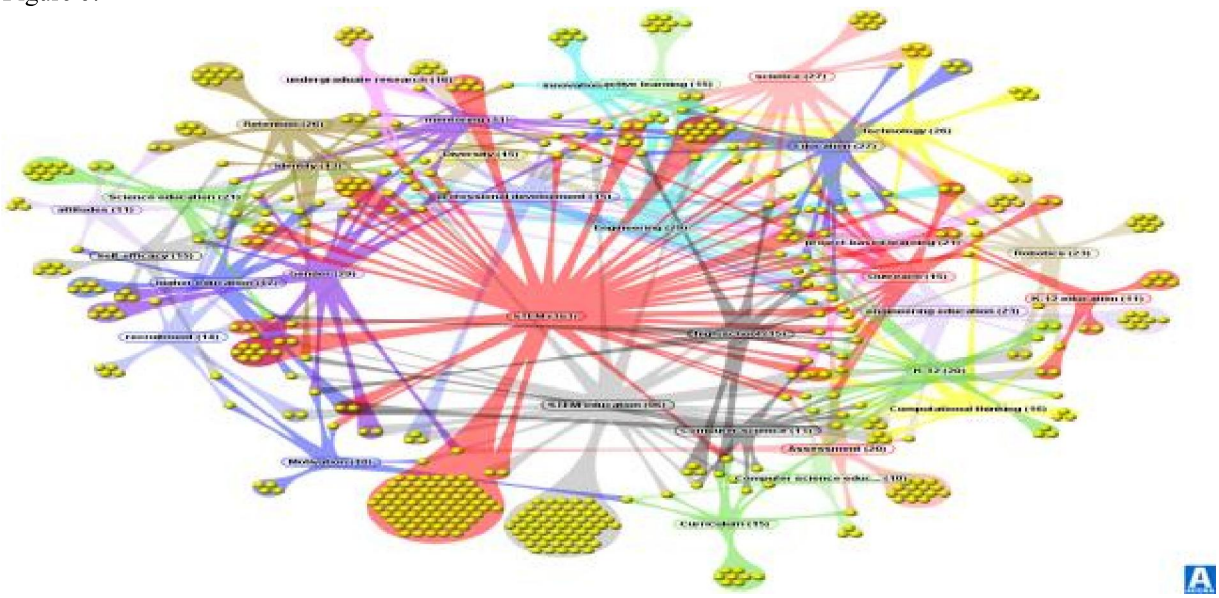

Figure 6. The Distribution of Keywords WoS Gives To STEM Research (Aduna Alg.)

It is seen that research fields such as *science education, higher education, motivation, robotics, computational thinking, innovation active learning* and *curriculum* will increasingly have a research field in the forthcoming period when Figure 6 is examined and STEM field is closely looked at. It is again possible to state that the field is in a close relationship with disciplines such as *computer science, technology, engineering* and etc. considerably.

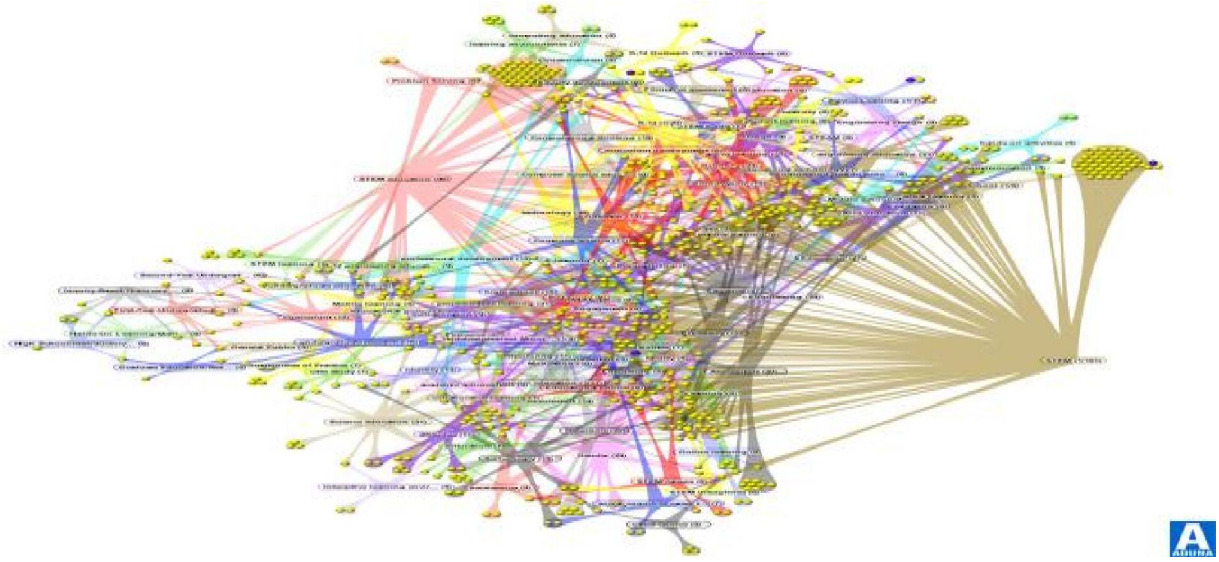

Figure 7. The Distribution of Keywords (100+) The Authors Give to STEM Research (Aduna Alg.)

When Figure 7, illustrating the keywords given to the articles by the authors, is examined it is seen that the starting point of all articles in STEM field is STEM. When we examine how the discipline is shaped under STEM we see that the studies are stated with rather different words. A more systematic way is seen to be followed in classifying the studies the keywords of which are given by WoS.

5. What are the prominent disciplines that STEM research nourish from?

Journal based science map is one of the scientific presentation methods provided by Sci2 program depending on University California San Diego science map system. This map has been created by using 2001-2010 Web of Science and 2001-2008 SCOPUS dataset. There are 13 main research fields on the map. The main aim of the map is to demonstrate which research fields do the journals in the examined dataset focus on. Circle caliber in the presentation illustrates the size of the publication in the research field.

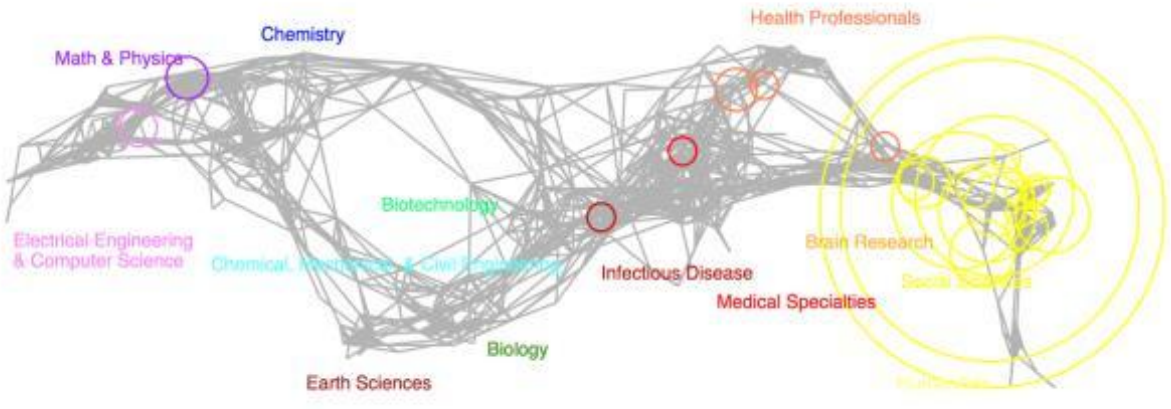

Figure 8. Prominent Disciplines That Nourish STEM Research (Journal Reconcile)

Even though science, engineering, mathematics fields seem to be the top priority for STEM education; the number of the publications towards social sciences and human sciences attract attention as concepts about psychology like cognitive structure, perception, self-realization and etc. still have an important place in educational practices. It is possible to say that the volume stems from the journals oriented towards psychology and educational sciences. In addition to the journals towards social and human sciences, it is observed that a remarkable publication volume has started also in journals published in especially Mathematics and Physics (Figure 8).

6. From which disciplines is knowledge dissemination in STEM researches provided?

Binary map presentation has been developed for the aim of visualizing the citation process in the scientific journals according to the database format included in CiteSpace software. The visual design covers the journals in 2011 Journal Citation Report (10.546 journals). Dual binary map is composed of two sub-maps. Map in the right side expresses the publications cited whereas the map in the left side expresses the publications that give citations. Scientific research fields are clustered with VOS or Blondel Algortym for specifying the study fields. Publications in the general presentation dataset form connections towards the cited journals according to their citation numbers and frequency in the dataset. Whether this flow is meaningful or not can be controlled via the help of normalized Z-values.

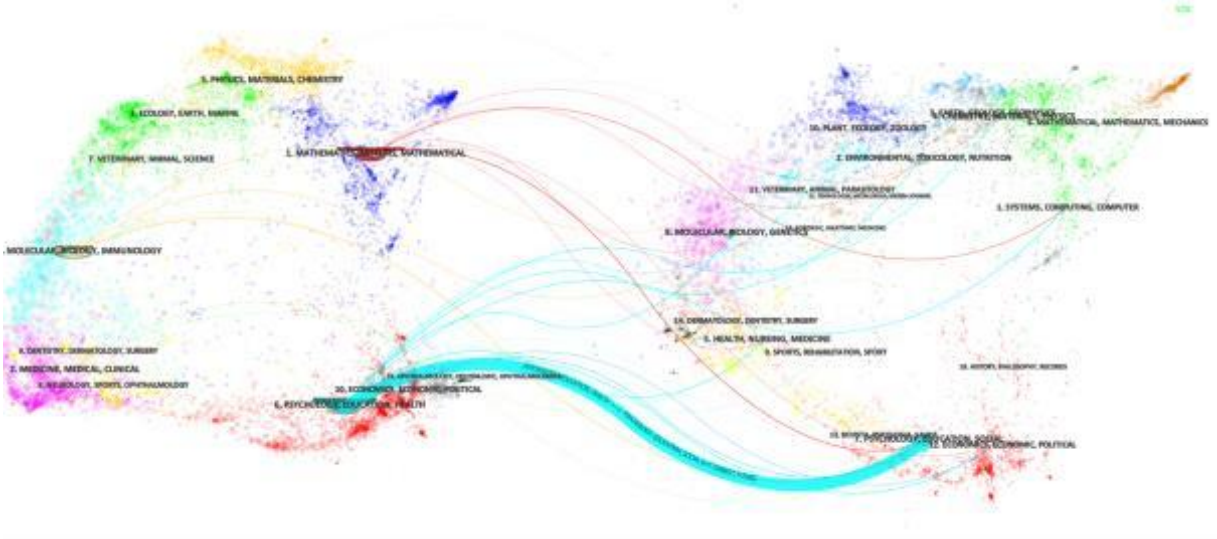

Figure 9. Knowledge Dissemination of STEM Researches

It is observed from the visualization made for the aim of knowledge dissemination to STEM field that there is a knowledge dissemination towards *psychology, education* and *social science* field from *psychology, education* and *health* field. In other words; in forming STEM literature *psychology* and *health* literature especially nourishes *psychology, education* and *social science* fields.

CONCLUSIONS

Among the results of our research; the first is that even though STEM field seems to be related with four fields, as a result of our analyses, arising by the basic principles and methods used in STEM education, the intensive effect of concepts that are directed to psychology's investigation areas can be reported. According to another result it is possible to state that basic distinctive qualities about STEM field has not arisen yet. However, the fact that publications about the concept are still published in especially social and human sciences journals could be a guiding information for decision and policy makers. Yet it is possible to say that this information is important for researchers and graduate students in order to follow the related literature.

Being able to visualize the subject fields, the related literature nourishes from could be guiding in determining the competences needed to give the training stated in the literature. On the other hand, it is obvious that it will contribute to see whether STEM education has developed as it should be or is following the traditional ways as seen in the other education literatures. The quantitative contribution to the related literature is seen to be made from the USA and it is possible to state that the studies go back to the beginning of 90s.

In our study we have tried to provide the big Picture of the field by putting forward the intellectual structure of the field. Among the future research to be conducted, especially on which sub-subjects are concentrated via the analyses made in article abstracts should be established. Moreover, with citation analysis studies, determining the basic reading list towards the field and identifying the Pioneer author and institutions of the field could be provided.

REFERENCES

Assefa, S. G., & Rorissa, A. (2013). A bibliometric mapping of the structure of STEM education using co-word analysis. *Journal of the American Society for Information Science and Technology, 64*(12), 2513-2536.

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics, 112*(1), 3-11.

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher, 70*(6), 5-9.

Bybee, R. W. (2010a). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher, 70*(1), 30-35.

Bybee, R. W. (2010b). What is STEM education? *Science, 329*(5995), 996-996. doi:10.1126/science.1194998

Çavaş, B., Bulut, Ç., Holbrook, J., & Rannikmae, M. (2013). Fen eğitimine mühendislik odaklı bir yaklaşım: ENGINEER projesi ve uygulamaları. *Fen Bilimleri Öğretimi Dergisi, 1*(1), 12-22.

Çorlu, M. A., Adıgüzel, T., Ayar, M. C., Çorlu, M. S., & Özel, S. (2012). *Bilim, teknoloji, mühendislik ve matematik (BTMM) eğitimi: Disiplinler arası çalışmalar ve etkileşimler.* Paper presented at the X. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresi, Niğde, Turkey.

Dugger, W. E. (2010). *Evolution of STEM in the United States.* Paper presented at the 6th Biennial International Conference on Technology Education Research, Queensland, Australia.

Ercan, S., & Bozkurt, E. (2013). *Expectations from engineering applications in science education: decision-making skill.* Paper presented at the The International Organization for Science and Technology Education (IOSTE); IOSTE Eurasian Regional Symposium & Brokerage Event Horizon 2020 Symposium Antalya, Turkey.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2014). *How to design and evaluate research in education* (9 edition ed.): McGraw-Hill New York.

Glanzel, W. (2003). Bibliometrics as a research field. A course on theory and application of bibliometric indicators. (Course Handouts). Retrieved from http://nsdl.niscair.res.in/jspui/bitstream/123456789/968/1/Bib_Module_KUL.pdf.s.

Greenseid, L. O., & Lawrenz, F. (2011). Using citation analysis methods to assess the influence of science, technology, engineering, and mathematics education evaluations. *American Journal of Evaluation, 32*(3), 392-407.

Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. *Monthly Labor Review, 132*, 82-118.

Larose, D. T. (2014). *Discovering knowledge in data: an introduction to data mining*: John Wiley & Sons.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: country comparisons: international comparisons of science, technology, engineering and mathematics (STEM) education. Final report* (0987579800). Australian Council of Learned Academies, Melbourne, Vic. Retrieved from http://hdl.handle.net/10536/DRO/DU:30059041

Marulcu, İ., & Sungur, K. (2012). Fen bilgisi öğretmen adaylarının mühendis ve mühendislik algılarının ve yöntem olarak mühendislik-dizayna bakış açılarının incelenmesi. *Afyon Kocatepe Üniversitesi Fen Bilimleri Dergisi, 12*(1), 13-23.

Miaoulis, I. N. (2008). Engineering the K-12 curriculum for technological innovation. Retrieved from http://legacy.mos.org/NCTL/docs/MOS_NCTL_White_Paper.pdf

National Research Council [NRC] (2012). *A Framework for k-12 science education: practices, crosscutting concepts, and core ideas*. Washington DC: National Academic Press.

Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of documentation, 25*, 348-349.

Sanders, M. (2008). STEM, STEM Education, STEMmania. *Technology Teacher, 68*(4), 20-26.