AC 2012-4392: A QUANTITATIVE STUDY OF COLLABORATION PATTERNS OF ENGINEERING EDUCATION RESEARCHERS

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A Quantitative Study of Collaboration Patterns of Engineering Education Researchers

Abstract
Academic collaboration is vital to advancing rigorous scholarship in engineering education. Despite its significance recognition among scholars and the government, prior studies have revealed that engineering education researchers still work in isolation in their academic activities. However, the overall collaboration patterns and what factors contribute to the breadth of collaboration remain largely unknown. In this paper, we reveal the collaboration patterns among engineering education researchers based on bibliographic data analysis. We select 7,732 NSF awards related to engineering education from EHR-DGE, EHR-DRL, EHR-DUE, and ENG-EEC. We then develop a keyphrase extraction algorithm to determine the main research topics of an award and utilize a name disambiguation system to precisely identify co-authorship. Our findings show that EER awardees collaborate more than researchers in the general disciplines of engineering and education. Also, average number of awardees per award is highly correlated with the number of awards. We further identify three categories of research topics that show different patterns in terms of level of collaborative engagement. We believe that our research results will provide comprehensive and insightful understanding of collaboration patterns within the engineering education research community. It also benefits the research community by offering information perhaps necessary to promote collaboration in certain areas in engineering education.

1. Introduction

Importance of communication and collaboration has always been emphasized in academia. There are appeals for more intensive collaboration across disciplines and domains with wider sharing of research data, results, and other resources. For example, National Academy of Engineering (NAE)[1] asks for more interdisciplinary knowledge and cross-disciplinary collaboration in engineering to address future grand challenges. In 2003, National Institutes of Health (NIH) has issued new policies[2] to impose the implementation of research data sharing on NIH grantees funded $500,000 or above a year. National Institute of Standards and Technology (NIST) established a Scientific Data Lifecycle Management Working Group[3] in 2009 to harness digital data and improve data dissemination. National Science Foundation (NSF) also announced policy changes[4] in 2011 to enforce dissemination and sharing of research results by requiring all grant applicants include a plan of data management in any proposal submitted.

In Engineering Education Research (EER), academic collaboration has also been known as a critical factor in improving research quality and increasing researchers' job satisfaction[5]. Another study recognized the significance of collaboration between researchers in engineering education (ENE) and educational research[6]. In contrast to the highlighted benefits of scholarly collaboration, ENE scholars have still been identified as working in isolation based on their academic publication pattern[7]. There is only a limited degree of collaboration in the form of co-authorship in academic publications, grants, and other types of professional activities in EER.

Prior studies have revealed primary strategies researchers used to identify collaborators[5] and their behavioral changes after collaboration[8]. However, few efforts have investigated the overall collaboration pattern and why some scholars tend to collaborate.

There are many factors that influence a researcher's collaboration decisions such as fields of study, awareness of other academic work, levels of competition, perceived usefulness of collaboration, and work ethics. Among these possible factors, fields of study have been recognized as the most significant characteristic in determining researchers' collaboration decisions[9]. Even though there are increasing amounts of co-authored publications, such collaborative research varies radically in discipline[10,11].

In this study, we focus on how fields of study within engineering education influence researchers' collaboration patterns. Our study answers the following research questions:

1. What is the overall collaboration pattern in EER as opposed to engineering and education? How are these patterns correlated with the breadth of collaborations we observe?
2. Do certain research topics in engineering education tend to emphasize collaboration more than the others?

To begin addressing these questions through a preliminary pilot study, we examine 7,732 NSF grant proposals relevant to engineering education and analyze their topics and co-authorship. Since author-supplied keyword is rarely available with NSF proposals, we implement a key-phrase extraction algorithm to determine key terms of each proposal based on the title and abstract. We also resolve author name ambiguity to ensure accuracy of bibliographic data analysis. Our research results will provide comprehensive and insightful understandings of collaboration patterns for the EER community based on the funding information available from NSF. It helps engineering education scholars identify potential collaborators and also benefits the research community by offering information perhaps necessary to promote collaboration in certain areas in engineering education. In section 2, we review literatures about collaboration studies and bibliographic data analysis. Section 3 presents the method we used to collect and analyze data. Section 4 demonstrates our findings and section 5 presents the future work.

2. Literature review

2.1 Scientific collaboration in engineering education

There is an on-going debate over what activities should be considered as scientific collaboration and how to measure it. Co-authorship is the most widely used variable to measure scientific collaboration. In studying research collaboration, Pao identified the correlation between co-authorship with funding status and revealed that the majority of publications were contributed by only a small group of productive authors[12]. Lee and Bozeman counted number of collaborators based on co-authorship on publications and studied its correlation with scientific productivity. However, some scholars challenge the reliance on only co-authorship for studying and measuring scientific collaboration. Katz and Martin listed scenarios where co-authorship became a misleading measure of research collaboration[13]. Laudel identified six types of research collaborations and compared formal communication channels such as co-authorship with invisible ones such as acknowledgement in terms of how they reward researchers[14]. Although co-authorship is arguably a partial measure of scientific collaboration, scholars generally agree that it is the most tangible and well-documented form of collaboration[15,16]. Therefore, the present study follows this classic proxy measure for quantifying academic collaboration.

The intensity of research collaboration depends on various factors. Some argued that geographical and institutional boundaries largely influenced scholars' collaboration patterns but acknowledged that appropriate facilities such as new communication technology might reduce such impacts[17,18]. Therefore, one research strand is to analyze academic collaboration at international[19–21] and institutional level[17]. Besides studying collaboration at a macro level, the majority of research collaboration studies focus on individual collaboration and their results showed the variation of academic collaboration in discipline[10,11]. The present study has the same objective on revealing differences in research collaboration caused by the nature of the research topics but with a particular focus on engineering education.

Recent studies have attempted to study research collaboration in engineering education. Borrego and Newswander revealed that academic collaboration can improve research quality and increase scholars' satisfaction in conducting research[5]. They also identified major strategies ENE scholars used to find collaborator[5]. Some recognized the significance of collaboration between researchers in engineering education and those in educational research[6]. Another study presented how engineering faculty's teaching approach could be changed as a result of extensive engagement in collaborative activities with learning scientists[8]. These three studies based their arguments on participants' and authors' perceptions, whereas another line of research analyzed collaboration based on bibliographic data. Borrego combined bibliographic data analysis with faculty interviews to reveal the isolation of engineering education scholars[7] in academic publications. None of the existing study has examined how fields of study may affect the collaboration pattern, which as mentioned earlier, is one of the most influential factors in research collaboration.

2.2 Bibliographic data analysis in EER

Recent studies in EER have started to analyze bibliographic data for revealing trends and status. Jesiek et al.[22,23] have drawn upon articles in international journals and conference proceedings to characterize the international difference in the state of EER in terms of main research areas, institutional infrastructure, research strategies, funding sources, and publication outlet. Beddoes et al.[24] chose a similar approach to analyzing academic publications and studying international patterns but had a particular focus on gender/women related topics. Other than studying international issues, a line of research examine closely articles published in specific publication venues and offers an in-depth review of their archives. Wankat[25] examined the JEE articles over 1993-2002 and identified main research areas, topical trends, and source of financial support. Borrego[7] analyzed four ENE coalitions to present the status of population studied, major methodologies, and the type of contributions. In contrast to studying specific journals and conferences, some scholars aim to characterize the overall picture of the whole EER area. Osorio[26] summarized the current state of EER literatures by providing an overview of overall author profiles, sources of support, type of documents, main subjects, and major publication venues. Madhavan et al.[27] provided an intuitive data gateway called iKNEER for ENE researchers to explore large-scale publications and iKNEER has provided users insights in the form of statistics and visualizations. These studies all share a similar approach of relying on bibliographic data analysis or meta-analysis of ENE publications with the last study focusing on ultra-scale data. However, none of the existing research has focused on presenting collaboration patterns in the EER community.

3. Methodology

Figure 1 illustrates the process of sampling relevant awards and analyzing the award data. First, we acquire metadata of all 338,470 NSF grant proposals from 1976 to 2011 that are public available on *nsf.gov*. Based on a proposal's category and abstract, we select grants related to EER. Each selected proposal is assigned five weighted key phrases by a word-frequency-based extraction algorithm. A scholar's research area is determined by all his/her awarded grants. We then combine scholars' collaboration on proposals with their fields of study to reveal the scientific collaboration patterns in EER.

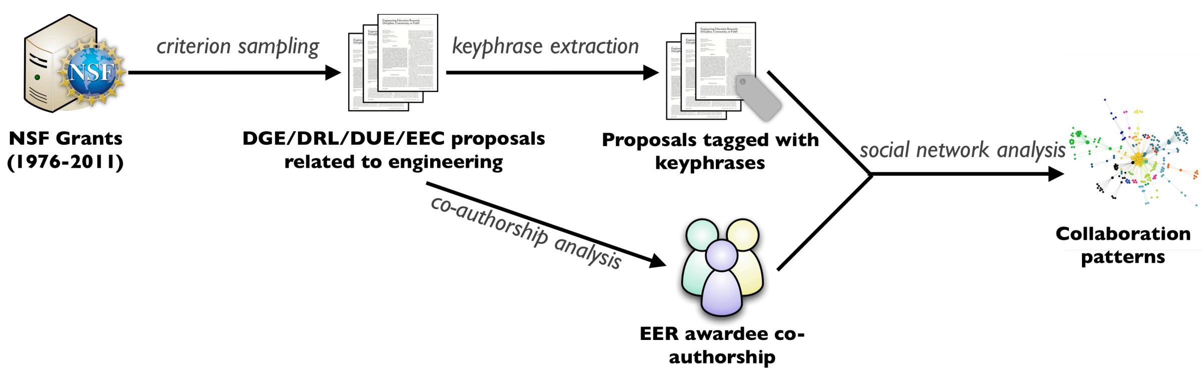


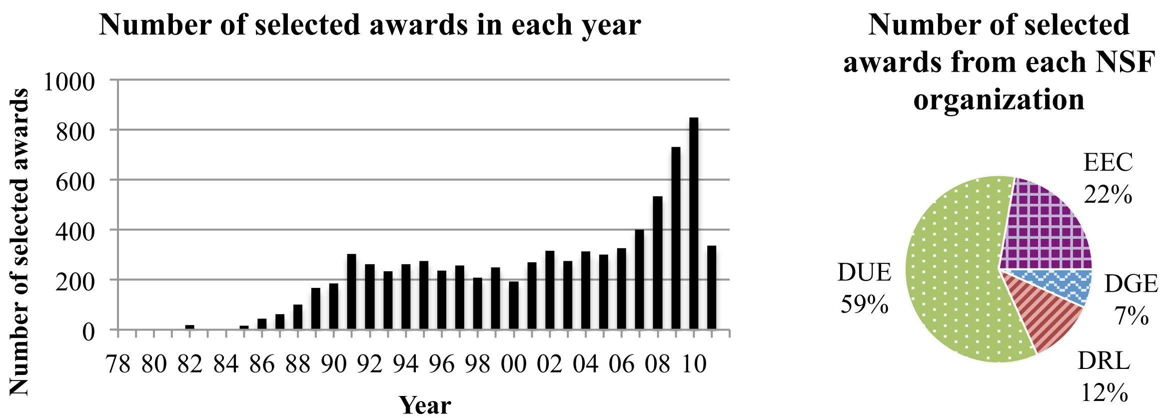
Figure 1. The workflow of analyzing the collaboration patterns based on EER grant proposals.

3.1 Sampling awards

We use criterion sampling to select NSF awards that are relevant to engineering education research. An award is selected if it meets all of the following criteria:

(1) It is an NSF award granted between 1976 and 2011 available on *nsf.gov*. NSF has digitized and published grants as early as 1976. Grant data in 2011 are complete but those in 2012 are not included;
(2) It is under the Division of Graduate Education (DGE), Division of Research on Learning in Formal and Informal Settings (DRL), Division of Undergraduate Education (DUE), or Engineering Education Center (EEC) organization. These four organizations are selected based on the categories of the past and active grants awarded to engineering education researchers at two major institutions in the EER community; and
(3) The proposal abstract or title must contain the keyword 'engineer' or 'engineering'. This is to ensure the relevance to engineering education since projects in DGE, DRL, and DUE are likely to address educational challenges in other non-engineering domains.

Based on these criteria, we select a total of 7,732 grant proposals over 1978-2011 with no award available in 1976, 1977, and 1980, as illustrated in Figure 2(a). Among all these proposals, there are 517 proposals from DGE, 894 from DRL, 4,603 from DUE, and 1,718 from EEC, as shown in Figure 2(b). The metadata downloaded from *nsf.gov* contains the following fields: title, abstract, PI, co-PI, awarded institution, award revision date, active period, award amount, directorate, NSF organization, and NSF program. Note that NSF does not make proposal full texts available to the public.



(a) **(b)**

Figure 2. Number of selected NSF awards **(a)** by year over 1978-2011 and **(b)** from each NSF organization

3.2 Key phrase analysis

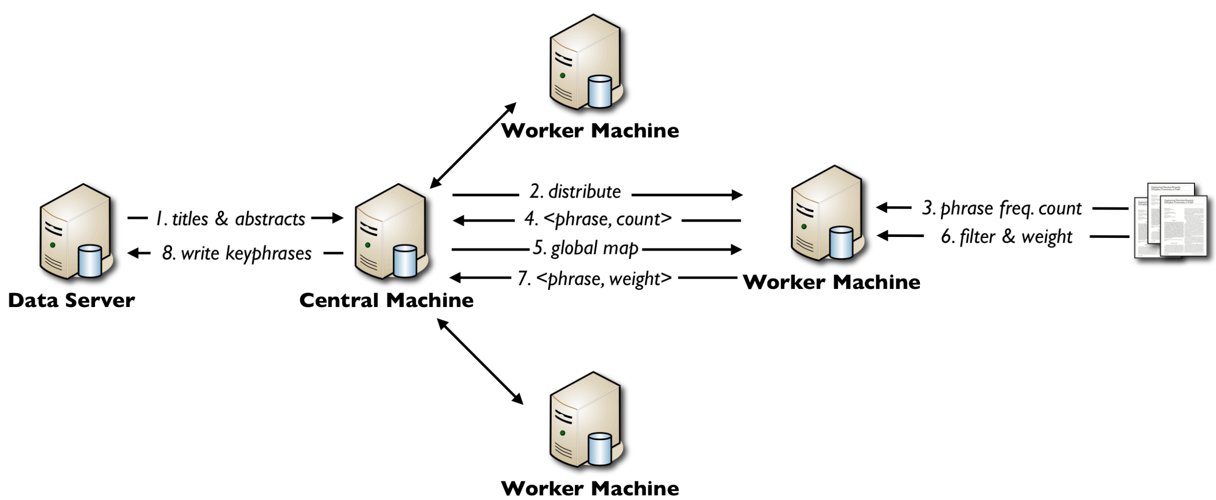


Figure 3. The GenEx keyphrase extraction algorithm implemented in a distributed manner.

In bibliographic data analysis, author-supplied keywords are widely used to define the research topic of a given study. However, keywords are not available in the NSF award data and therefore we implement a distributed key phrase extraction algorithm based on GenEx[28] to determine the main research areas of an award. As illustrated in Figure 3, the algorithm starts with the central machine dividing the selected awards evenly into *n* groups and distributing them to *n* worker machines. Each machine counts the phrase frequency of the title and abstract of each proposal. In this study, a phrase is defined as a sequence of no more than 4 words. The central machine aggregates the phrase-frequency pairs from each worker machine and sends this global database back to the worker machines. By comparing a phrase's counts in an award with its frequency over all awards, each phrase is weighted and filtered based on its weight using the parameters defined in GenEx[28]. As a result, high-frequency stopwords such as *the, of, is* will be filtered because these words are common in most of the documents. Topical phrases such as *community college* are selected because they are mentioned frequently in a small set of documents while rarely appear in other documents. The ten phrases with the highest weights are selected as the key phrases of an award.

3.3 Co-authorship analysis and name disambiguation

For NSF awards, co-authorship refers to the collaborative relationship between PI and co-PI of the same award and between PI's of a collaborative project. There are two major challenges in precisely identifying such collaboration: award ambiguity and author name ambiguity. The award ambiguity problem happens when the same collaborative proposals have different titles written by different PI's and therefore are mistakenly viewed as separate awards. To resolve the ambiguous awards, we apply the well-known token-based disambiguation algorithm based on the Levenshtein Distance. Two awards are considered to be the same collaborative research when (1) they fall into the same NSF directorate and organization, (2) their titles are at least 80% similar token-wise, (3) both award titles contain the word *collaborative* or its variations, and (4) they have different PI and awarded institutions.

The second type of ambiguity is author name ambiguity, where researchers use different variations of their names in applying grants. Without recognizing such cases, one individual may be viewed as multiple scholars, which leads to incorrect analysis of the collaboration pattern. Similar to award disambiguation, we develop a program to compute the similarity between author names based on multiple entities: full name, email, affiliation, and past awards.

3.4 Identifying collaboration patterns

Based on the awards' keyphrases and co-authorship, an NSF awardee's research interests are defined as a collection of keyphrases from all his/her awards. To address the research questions proposed earlier, we focus on the following measures:

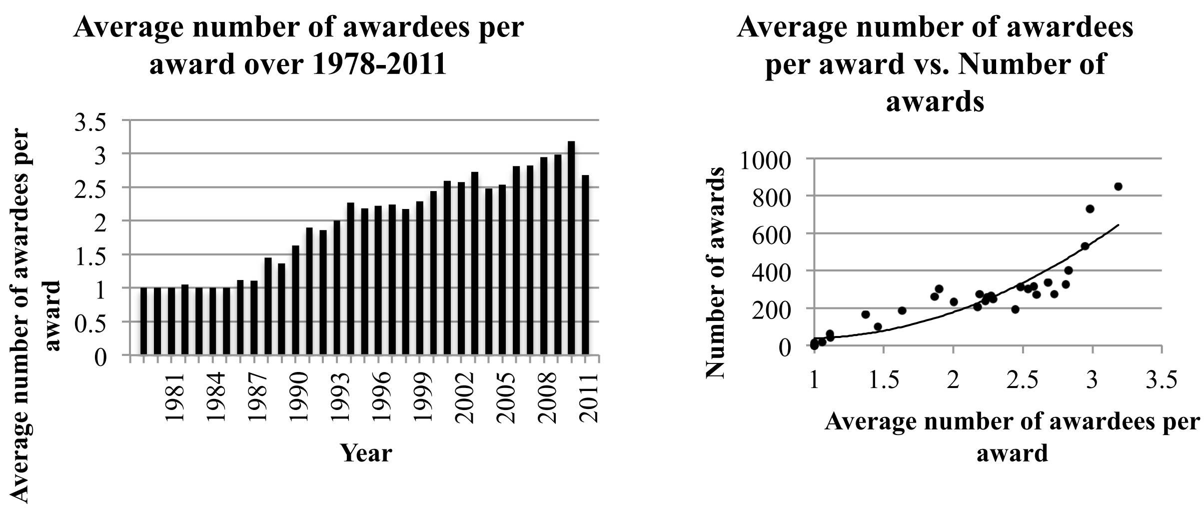
1. An awardee's number of collaborators;
2. Average number of awardees per award;
3. An awardee's research interests;

We sort all the awardees by their collaborative width and group them into four. We derive the measure of collaborative width from Stein and Blaschke's study[29]: an awardee's collaborative width is defined as the sum of the number of collaborators in each of his/her award. That means, if an awardee collaborates with the same scholar in multiple awards, this collaborator will be counted multiple times.

4. Collaboration patterns

4.1 Overview

After name disambiguation, the 7,732 selected awards involve 7,412 distinct awards and 13,176 distinct awardees. There are 2.59 awardees per award on average with the highest number of 15 authors collaborating on one award. Based on the selected awards, a total of 1,276 (9.7%) NSF awardees have no collaborators and 2,102 (16.0%) awardees have only one collaborator. These numbers characterize the basic collaborative status of EER and we further compare them to the general engineering and education disciplines. In the Engineering (ENG) directorate, there are 1.53 awardees per award among 48,980 grants awarded by NSF, whereas in the Education and Human Resources (EHR) directorate, 2.21 awardees per award among 31,167 grants. The broad ENG and EHR directorates not only include all the 7,732 EER-related awards selected in this study, but they also cover many other projects that address engineering or educational challenges. As an emerging cross-disciplinary domain with mixed characteristics of engineering and education, engineering education stands out as having significantly more academic collaboration than average as opposed to other areas in these two disciplines.



(a) **(b)**

Figure 4. (a) The growth of average number of awardees per award over 1978-2011 and **(b)** the average number of awardees per award is highly correlated with he number of awards

Figure 4(a) presents the number of authors per award in each year over 1978-2011. Combining it with the number of awards in Figure 2(a), we observe a positive correlation between these two variables. In Figure 4(b), each data point represents a year over 1978-2011 and within each year, the point is plotted based on the average number of awardees per award for the corresponding year in Figure 4(a) and the number of awards for the corresponding year in Figure 2(a). We use a hierarchical regression model to determine their relationship. In the first model, we regress number of awards on average number of awardees per award and the model is significant, $F(1,32) = 100.73$, $p < .001$. Then we add the quadratic term of average number of awardees per award as a predictor in the second model. The improvement is significant, $F_{-incremental}(1,30) = 8.98$, $p < .01$. Therefore, average number of awardees per award is highly correlated with the number of awards.

4.2 Research topics and collaboration tendencies

As mentioned in Section 3.4, we divide awardees into four groups based on their number of collaborators. We use Group 1 to denote the group of awardees that collaborate most intensively and widely, whereas Group 4 includes the least collaborative awardees. Table 1 shows each group and its corresponding number of collaborators and number of awardees. Such a division strategy aims to avoid separating awardees with the same number of collaborators into two groups while trying to make the number of awardees even in each group. The top 50 research topics in each group are listed in Appendix A. Based on the popular topics in groups of different collaborative width, we identify three categories of topics: (1) Topics that receive consistent attentions across groups; (2) Topics that are popular within one or two groups but become radically less popular in other groups; and (3) Topics that fluctuate or show no clear pattern.

Table 1. Awardee groups and the corresponding number of collaborators and number of awardees

Group No.	1	2	3	4
Num. of collaborators	5 - 50	4	2 - 3	0 - 1
Num. of awardees	2,232	3,395	4,171	3,378

First, regardless of levels of scholars' engagement in collaboration, the following topics gain almost the same extent of attention from scholars: *course, curriculum, undergraduate, mathematics,* and *instruction*. Second, there are many areas that show a clear tendency to only one or two groups. For example, projects related to *laboratory, computer, technology, software, design,* and *equipment* are more likely to be conducted by scholars with fewer collaborators. On the contrary, grants about *graduate, IGERT, community colleges, nanotechnology, integrate, NUE, workforce,* and *interdisciplinary* are very unlikely to be awarded to researchers working in isolation and are most likely to be given to Group 2 awardees. However, Group 2 has less often studied problem spaces in *industrial* and *electrical* than other groups. Topics about *degree* are prone to be examined by Group 2 and Group 3, whereas *experience* is favored by Group 1 and Group 4. There are also areas that do not demonstrate a clear pattern: *REU, mentoring, manufacturing, hands-on,* and *module.*

4.3 Implications

The results in Section 4.1 are consistent with a prior study conducted by Borrego[7], who argued that many ENE researchers were working in isolation. Our finding also shows that about 25% of NSF awardees working in ENE have no or only one collaborator on NSF proposals. However, we further propose that ENE awardees tend to collaborate more as opposed to awardees in other areas of engineering and education. This informs education researchers and engineering researchers who plan to conduct EER studies of the expectation of more collaboration and thus allow them to be better prepared prior to joining the EER community. Also, our result shows that average number of awardees per award is highly correlated with the number of awards. Our finding based on the NSF funding source complements a prior study[30] showing that professors with more industrial funding collaborated more. Although causation remains unknown, such a relationship between funding and collaboration may help funding agencies adjust their investment strategy in the future and help researchers identify potential collaborators.

Patterns recognized in Section 4.2 demonstrate the status of popular EER topics in how much they require or foster collaboration. This can become a guideline for funding agencies such as NSF to make investment decisions on EER. Program officers may want to look more closely at proposals with very few authors if what the proposals investigate has been studied usually by a large group of scholars and vice versa. Similarly, researchers may form a team of appropriate size based on the kind of project they are doing. Our findings about academic team size in conducting research in given areas can also be incorporated with scholars' publications to determine the correlation between team size and academic productivity[31].

5. Conclusion

In this paper, we reveal the collaboration patterns among engineering education researchers based on bibliographic data analysis on 7,732 NSF awards. We apply a keyphrase extraction algorithm to determine the main research areas of an award and utilize a name disambiguation system to precisely identify co-authorship. Our findings show that EER awardees are more collaborative than other researchers in the general disciplines of engineering and education. Also, average number of awardees per award is highly correlated with the number of awards. We further reveal three categories of research topics that show different patterns across different level of collaboration engagement. Our future study aims to incorporate bibliographic data in journals and conference proceedings and less formal academic collaborative activities. We also plan to compare findings in the present study with scholars' perceived collaboration patterns and strategies. Understanding the academic collaboration in the EER community helps recognize the gap in the development of a certain area and foster a collaborative environment for community members to communicate research innovations.

6. Acknowledgement

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Appendix A

Rank	Group	Group 2	Group 3	Group 4
1	courses	graduate education	courses	laboratory
2	curriculum	igert	laboratory	courses
3	experience	courses	curriculum	engineering
4	reu	curriculum	scholarships	undergraduate
5	scholarships	scholarships	mathematics	reu
6	undergraduate	nanotechnology	undergraduate	students
7	engineering	interdisciplinary	engineering	experience
8	mathematics	undergraduate	instructional	curriculum
9	education	trainees	community college	program
10	community college	community college	student	computer
11	students	mathematics	igert	industrial
12	instructional	integrative	programs	technology
13	graduate education	nue	education	scholarships
14	program	education	graduate education	education
15	igert	experiences	computer	instruction
16	modules	computer	experience	mathematics
17	interdisciplinary	student	reu	equipment
18	integrated	college	interdisciplinary	mechanical
19	college	departments	modules	materials
20	laboratory	engineering	industrial	design
21	faculty	engineers	technology	software
22	nanotechnology	technology	design	teaching
23	retention	disciplinary	academic	concepts
24	computer	instructional	retention	faculty
25	mentoring	academic	manufacturing	skills
26	manufacturing	modules	degree	manufacturing
27	industrial	retention	engineers	school
28	nue	scholars	concepts	college
29	technology	degree	skills	physics
30	academic	teaching	learning	engineers
31	engineers	laboratory	teachers	activities
32	k-12	concepts	scholars	electrical
33	electrical	workforce	faculty	majors
34	teaching	majors	technical	modules
35	learning	skills	college	instrumentation
36	teachers	technical	high school	academic
37	degree	innovative	software	community college
38	skills	introductory	equipment	high school
39	summer	learning	hands-on	mentoring
40	success	gk-12	professional	teachers
41	scholars	stem	electrical	learning
42	high school	faculty	recruitment	experiments
43	workshops	recruitment	nue	department
44	concepts	graduates	careers	introductory
45	hands-on	fellows	departments	summer
46	participants	sustainable	nanotechnology	projects
47	award	support	activities	degree
48	stem	industrial	majors	testing
49	workforce	programs	interactive	participants
50	professional	school districts	teaching	retention