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Collaboration within Engineering Education Research's Community of Practice

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Abstract

Engineering education research (EER) is a relatively young field of inquiry, established with the intent to improve the academic experiences of young and emerging engineers. While many researchers' perceptions of how to improve engineering education stem from traditional classroom experiences, a select group of researchers belong to EER-oriented departments, labs, and research centers. These on-campus resources create a formal bridge between EER-expert networks and offer researchers an opportunity to collaborate with other like-minded individuals. However, researchers lacking access to similar EER resources may be unable to establish connections to engineering education's expert community of practice.

The purpose of this paper is to answer the question "How is collaboration within the EER community of practice impacted by an individual's access to EER resources?" Formal collaborations were catalogued using co-authorship data from publications in the Journal of Engineering Education between the years 2008 to 2012. Influential researchers, collaboration trends, critical brokers, and other hidden structures were analyzed using social network analysis methods. Results of this study found that researchers on campuses lacking formal EER resources are unable to broker connections into EER's expert community of practice. Consequently, these researchers may be unable to adopt best practices from and exchange relevant information with the greater community.

1. Introduction

Research collaboration often occurs between colleagues working within similar as well as different disciplines. Collaboration is known to boost creativity, increase access to relevant skills and knowledge, provide intellectual companionship, and grow researcher network size.[1-3] Through collaborations, social capital is leveraged as a transfer of information and knowledge is facilitated through formal and informal networks.[4] Additionally, future opportunities for collaboration and/or funding are enhanced by growing and strengthening collaborator networks.

Interdisciplinary collaborations give a deeper understanding to complex problems, increase overall research impact, and enable a diverse approach to solving problems and generating new knowledge.[5] However, often research collaboration will take place between individuals within similar networks (such as department, institute, or discipline networks), because researchers from comparable backgrounds are able to relate easily to one another's perspectives. Homophilious partnerships limit researcher interaction with diverse networks and may impede access to relevant knowledge and subsequently inhibit creative thinking.[6]

Interdisciplinary and multidisciplinary collaboration are common themes to research partnerships within engineering education research (EER). Many engineering education researchers are housed in their primary engineering discipline's academic department (e.g. systems engineering, mechanical engineering, or aerospace engineering) and do not share a common interest in EER with their nearby colleagues. This type of multidisciplinary distribution of expertise likely enables and encourages collaboration between engineering education researchers from a variety of backgrounds.[7]

While many of these researchers' perceptions of how to improve engineering education stem from traditional classroom experiences, a select group of researchers belong to departments, labs, and centers primarily devoted to studying EER.[8-10] These programs are increasingly graduating masters and doctoral students with a specific focus in EER. While engineering education departments offer researchers a new opportunity to collaborate with other like-minded individuals, they may also limit researcher motivation to interact outside their known network.[4] Moreover, researchers on campuses lacking formal EER resources may not have access to these "expert" networks due to a deficiency of brokers between communities.[11]

Burt (2004) discusses the roles of brokers in connecting people across groups. In the absence of brokerage, homophily restricts the exchange of novel information and attitudes among a socio-demographically diverse population.[6] Further, unconnected groups are unable to observe the best practices of well-connected expert groups.[11] Brokerage is important to sharing knowledge, synthesizing ideas, and exchanging beliefs between distinct groups.

Previous studies within EER have examined collaboration, with many of these publications focusing on the benefits of academic collaboration, strategies for finding collaborators, and reasons for collaboration.[7, 12-14] One study in particular used scientometrics to investigate the interdisciplinary changes in EER through co-authorship collaboration.[15] Findings from this study revealed an increasingly high degree of disciplinarily diversity in EER related articles.

Hidden structures within formal collaboration networks indicated by co-authorship can be described using social network analysis (SNA) methods. SNA's statistical metrics provide quantitative indicators of significant collaboration patterns within the network, such as centrality, information flow, critical individuals, and clique formation.[16-18] Further, multiple studies have used SNA methods to analyze formal collaboration patterns visible through publication co-authorships.[19-23] Researchers have agreed that co-authorship is a concrete and well documented, if not perfect, indicator of scientific collaboration.[20, 23-24] Within EER, a publically available computational program depicts network maps of co-authorship using bibliometric data.[25] However, there have not been any studies analyzing the impact of an individual's access to EER resources to co-authorship.

The purpose of this paper is to answer the question "How is collaboration within the EER community of practice impacted by an individual's access to EER resources?" Formal collaborations were catalogued using co-authorship data from publications in the Journal of Engineering Education between the years 2008 to 2012. Influential researchers, collaboration trends, critical brokers, and other hidden structures were analyzed using social network analysis methods.

2. Methodology

Data Collection

The Journal of Engineering Education (JEE) is currently the premier journal of the EER community with over 11,000 readers.[26] JEE has an impact factor of 1.925 and articles within the journal have been cited 3,316 times. The 2012 impact factor places JEE fourth out of 38 journals in Education, Scientific disciplines, ninth out of 87 journals in Multidisciplinary Engineering, and sixteenth out of 219 journals in Education and Educational Research.[27] Thus, this paper uses SNA to examine the interdisciplinary nature of JEE publications between the years 2008 to 2012. The data was gathered by means of the Web of Science (WoS) database by Thomson Reuters using the search string "Publication Name=(Journal of Engineering Education) AND Year Published=(2008-2012)." Only full journal articles were included for analysis. The resulting 140 WoS articles were checked for consistency with the articles listed on JEE's website, and missing articles were added to the data set. The final compilation of citations was imported into VantagePoint, a text-mining software.

The listed authors and author affiliations were cleaned using an automatic filter in VantagePoint, and the resulting data set was manually verified. The final data set consisted of 152 articles written by 385 authors belonging to 128 organizations. Table 1 lists the mean, standard deviation, and range for number of publications by author and by organization (i.e. author affiliation).

Table 1. Descriptive statistics for the number of articles per author

Statistic	# Articles per Author	# Articles per Organization
Mean	1.27	2.12
Standard Deviation	0.817	3.72
Minimum	1	1
Maximum	10	37

Methodology

SNA methods use network theory to examine social relationships. By using a network perspective, hidden structures of social relationships are exposed and used to enhance knowledge of social capital's flow and impact.[4,28] On a network map the actors (i.e. population of interest) is represented by nodes. The relation (i.e. social exchange) between actors is represented by an edge connecting associated nodes. The network map for this study can be seen in the Results section of this paper.

A social network can be viewed at many levels.[28] The lowest, simplest perspective is comprised of one actor (ego) and all other actors to which the ego has direct relations (alters). This *egocentric* perspective can be used to generalize close, personal networks of individual actors. At the highest level, the *complete network* uses every relation among all actors to give a macro analysis of the entire network's structure.

This publication uses a sample population to represent a macro view of collaboration within the complete EER network. Publication authors define the network actors, or nodes. Co-authorship associations define the relations between actors, or network edges. Additionally, an egocentric view highlights the close networks of engineering education researchers.

Data Attributes

The purpose of this paper is to answer the question "How is collaboration within the EER community of practice impacted by an individual's access to EER resources?" Thus, the availability of on-campus EER resources is classified using three categories: *EER-academic department*, *on-campus EER center*, or *no on-campus EER resources*.[29]

Table 2 lists the frequencies for organizations, authors, and publications by the availability of on-campus EER resources.

Table 2. Frequency of occurrence by the availability of on-campus EER resources (academic institutions only)

Attribute	# Organizations	# Authors	# Publications
EER-Oriented Department	5	68	51
Eng/STEM Ed Research Center	18	124	62
No On-Campus Resources	90	174	93

Additionally, the type of organization each author was affiliated with is coded using five sub-categories: *university*, *international university*, *non-profit*, *government*, *industry*. However, this publication does not discuss the general implications of the type of organization on co-authorship patterns. A full list of organizations is located in Appendix A.

Dependent Measures

UCINet 6 was used to measure co-occurrences and interactions among author collaborations.[30] Four metrics were identified to characterize the network: *E-I Index*, *Degree Centrality*, *Betweeness Centrality*, and *Effective Size*.

(External-Internal) E-I Index compares the number of ties inside a particular context (or attribute) to those outside that context. The EI Index is calculated as: (external ties – internal ties) / (external ties + internal ties) and ranges from negative one to one. A positive E-I Index indicates the grouping has a higher number of external ties than internal ties.

For this study, a positive E-I Index indicates that authors tend to collaborate with others not located at (i.e. external to) their home institution.

Degree Centrality measures an individual's relative importance within the network by describing how influential, or connected, that individual is to the entire network. This measure allows us to identify the presence and influence of 'critical individuals' in the network; those people who are key coordinators or actors.

For this study, a higher Degree Centrality indicates that an author is more influential to the co-authorship network and tends to be connected to many other co-authors.

Betweenness Centrality quantifies the number of times an individual acts as a bridge along the shortest path between two other nodes. This measure allows us to identify important "brokers" within the network, or individuals who have a unique capability to tie unconnected individuals in the network.

For this study, a higher Betweeness Centrality indicates that an author acts as a bridge between many other authors and is able to broker relationships between otherwise unconnected individuals.

Effective Size is used in egocentric networks to measure an actor's position in a network and is another indicator of important "brokers." As described earlier, The egocentric networks are comprised of one actor (ego) and all other actors to which the ego has direct relations (alters). The effective size of a network is found by taking the number of alters an ego has and subtracting the number of ties that each alter has to other alters or the number of alternate paths. A high effective size indicates that an individual is critical to bridging other nodes, particularly where no alternate connection exists between nodes.

For this study, a higher Effective Size indicates that an author acts as a bridge between many other authors and is able to broker relationships between otherwise unconnected individuals.

3. Results

Network maps were created using NetDraw.[31] Authors (nodes) were coded by color for the availability of on-campus EER resources, and by shape for the type of organization (Table 3). The size of the node represents the number of publications that author published in JEE over the analyzed years, and the thickness of the edges (i.e. line) between nodes represents the number of co-authorships between two connected actors. Figure 1 depicts the network map for the complete network.

Table 3. Node format and associated attribute

Availability of EER Resources (Color)	
Pink	Engineering Education Depart
Blue	STEM Education Research Center
Black	No Resources
Grey/Green	No Code

Type of Organization (Shape)	
Square	University
Down Triangle	Intl University
Circle	Non-Profit
Up Triangle	Government
Diamond	Industry

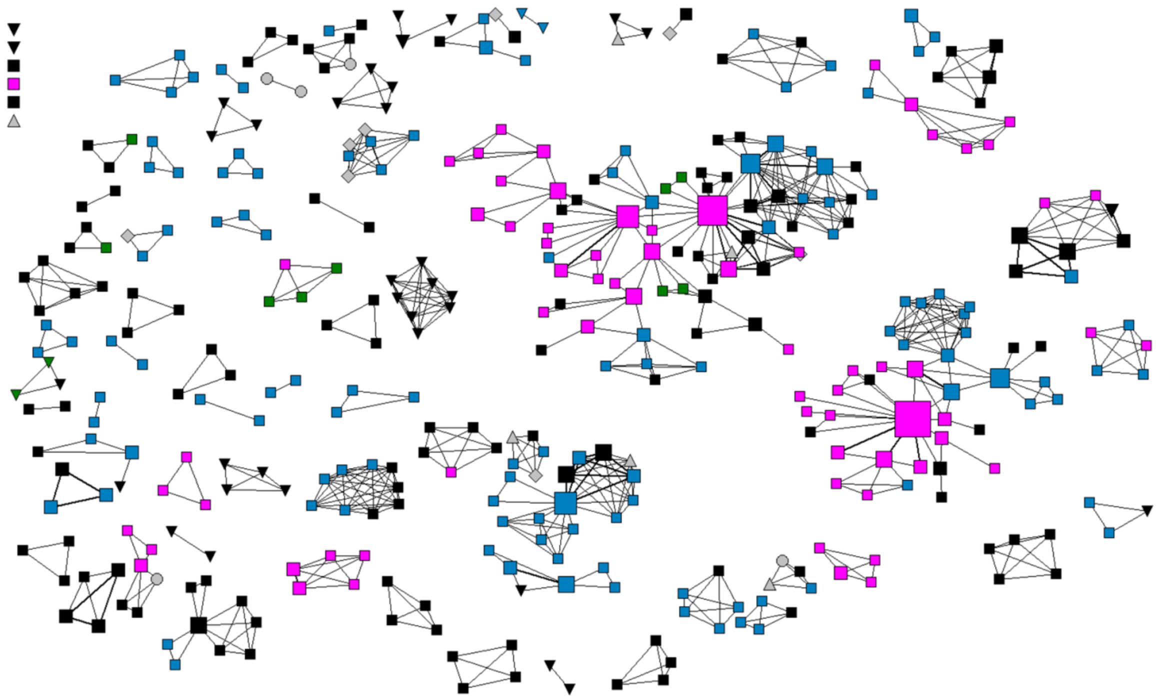

Figure 1. Network Map of Complete Network

E-I Index

The availability of engineering education resources is a significant factor to E-I Index, i.e. the number of publications coauthored with individuals located at the same university versus those publications featuring authors from multiple universities ($F(2, 91) = 9.715$, $p<0.001$). Further, a Tukey Multiple Comparisons test shows that a difference in means exists between authors with an engineering education department and those who do not have an engineering education department (Figure 2). Authors affiliated with an engineering education department have a significantly lower E-I Index, however the positive index value reflects that most authors tend to collaborate outside their collocated network.

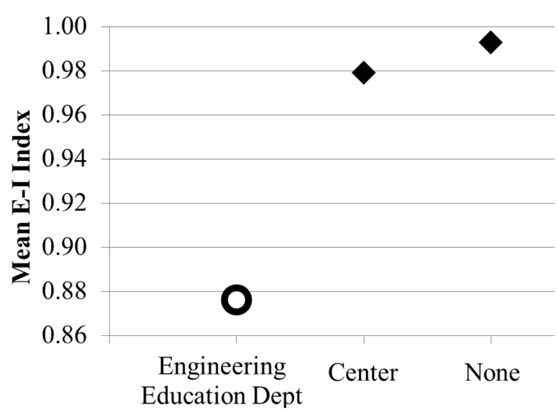

Figure 2. E-I Index by Availability of EER Resources

Centrality

The availability of EER resources, was not a significant factor to Degree Centrality ($F(2, 363)=0.830$, $p>0.05$). However, ranking authors by their Degree Centrality demonstrates that highly ranked authors are primarily housed on campuses with access to either an engineering education department or a STEM education research center (Table 4)

Table 4. Authors with the top 10 Degree Centrality measures

Author	**University**	**EER Resources**	**# JEE Articles**	**Normalized Degree Centrality**
Ohland, Matthew W	Purdue University	Department	8	2.517
Finelli, Cynthia J	University of Michigan	Center	5	1.736
Sheppard, Sheri D	Stanford University	Center	4	1.736
Borrego, Maura J	Virginia Tech	Department	10	1.563
Chen, Helen L	Stanford University	Center	3	1.215
Diefes-Dux, Heidi A	Purdue University	Department	5	1.215
Long, Russell A	Purdue University	Department	3	1.215
Carpenter, Donald D	Lawrence University	None	3	1.128
Harding, Trevor S	Calif Polytech State Univ	None	3	1.128
Lichtenstein, Gary	Stanford University	Center	3	1.128

An examination of Betweenness Centrality shows that the availability of EER resources is a significant indicator ($F(2, 332)=11.204$, $p<0.001$). Further, a Tukey Multiple Comparisons test shows that a difference in means exists between authors affiliated with an engineering education department and those not affiliated with an engineering education department (Figure 3). Authors affiliated with an engineering education department have a larger Betweenness Centrality, indicating the presence of individuals who have a unique capability to broker relationships between unconnected individuals in the network.

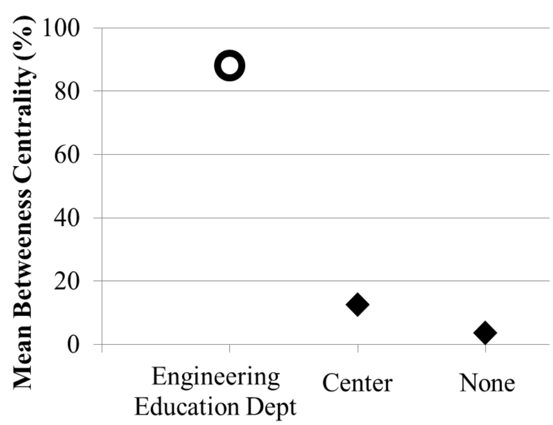

Figure 3. Plot of Betweeness Centrality by the availability of EER resources

A network map organized by university illustrates an interesting trend in network centrality (Figure 4). Authors without access to EER resources tend to be located toward the edge of the network map and have a more clustered relationship with few brokering individuals. Universities with engineering/STEM education research centers are further to the center of the circle, with a few individuals holding the ability to broker relationships between universities. Finally, the most central universities typically have an engineering education department.

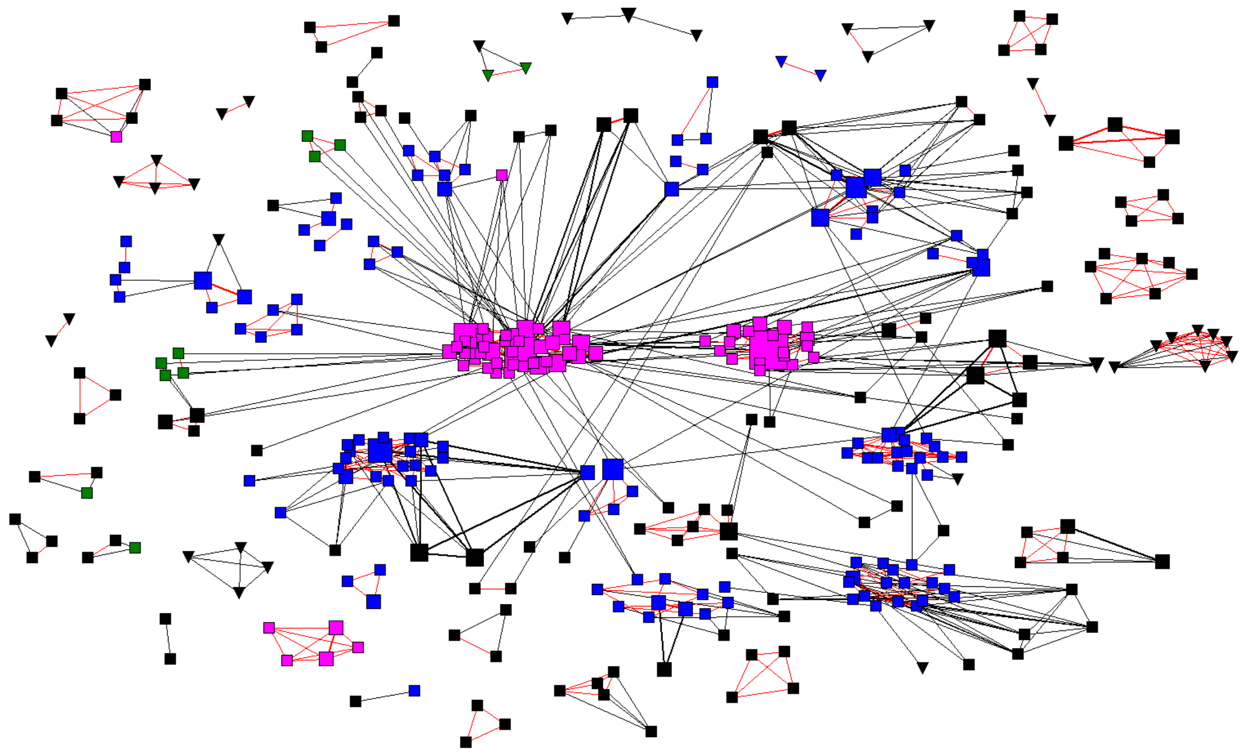

Figure 4. Network map, grouped by university (red lines indicate collaboration within university)

Effective Size

Examining the egocentric network, the availability of EER resources is significant to an ego's effective size (F(2, 332)=8.53, p<0.001). Further, a Tukey Multiple Comparisons test shows that a difference in means exists between those with an engineering education department and those who do not have an engineering education department. Figure 5 shows that individuals on campuses with engineering education departments have a greater mean Effective Size than those with only a research center or those with no resources, indicating the presence of individuals who have a unique capability to broker relationships between unconnected individuals in the network.

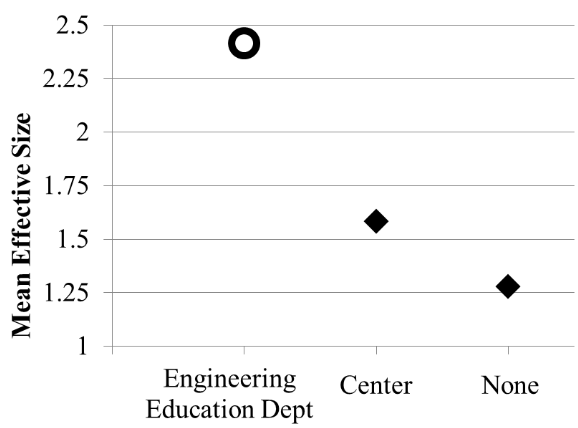

Figure 5. Effective Size by the availability of EER resources

Figure 6 depicts a visual comparison of ego networks grouped by availability of EER resources. The left image shows the ego network for those universities with engineering education departments and the right image shows the ego network those universities without engineering education departments. These maps illustrate that the universities with engineering education departments have several individuals who are important to brokering relationships and collaborations, while those on campuses without an engineering education department typically have a more clustered relationship with few critical individuals.

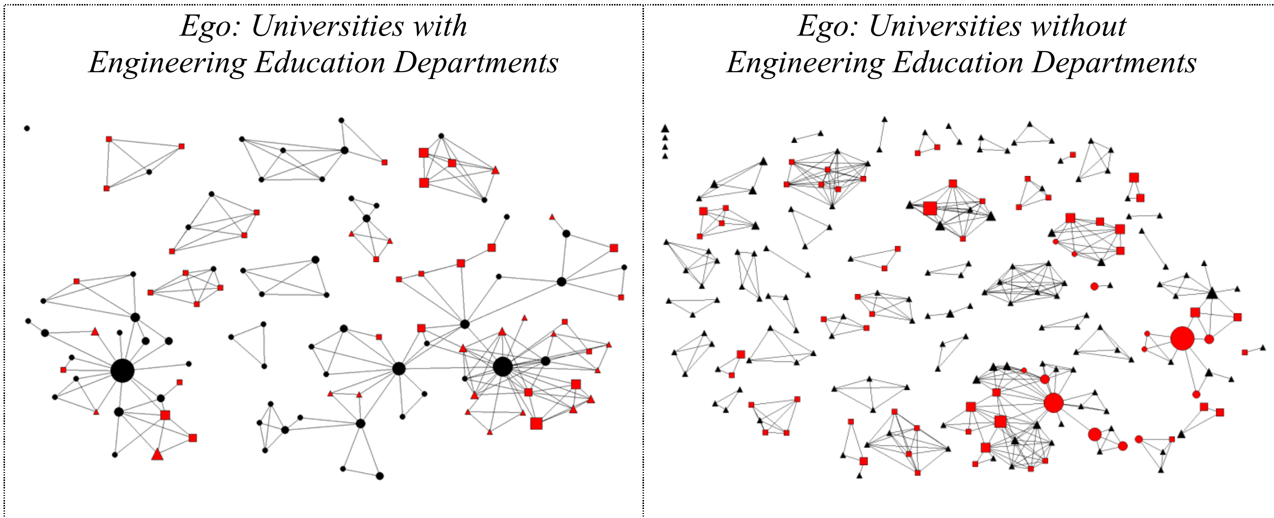

Figure 6. A visual comparison of ego-networks for differing levels of access to EER resources (ego=black nodes, alters=red nodes)

4. Discussion and Conclusions

The multidisciplinary distribution of EER expertise enables and encourages collaboration between engineering education researchers from a variety of backgrounds. While many of these researchers' perceptions of how to improve engineering education stem from traditional classroom experiences, a select group of researchers belong to departments, labs, and centers primarily devoted to studying EER. Institutions with an engineering education department typically have a high research production and greater impact within the field of EER. While only 5% of the analyzed academic organizations have an engineering education department, those same institutions comprised 19% of the authors and 25% of the publications found in JEE from 2008-2012. The fifty-one JEE articles published by individuals affiliated with engineering education departments have been collectively cited 291 times, or approximately 5.7 citations per paper. Authors not affiliated with an engineering education department are cited at a lower rate with only 4.7 citations per paper.

Authors affiliated with an engineering education department are typically central and influential collaborators within EER. However, results of this study found that researchers on campuses lacking formal EER resources may not have adequate access to this "expert" network and lack the ability to broker connections into EER's expert community of practice. Consequently, these researchers may be unable to adopt best practices from and exchange relevant information with the greater community.

Researchers not affiliated with an engineering education department may have difficulty accessing EER's expert network due to the limited number of researchers belonging to engineering education departments. Thus, the EER community must create opportunities for researchers without access to formal EER resources to collaborate with other researchers. One potential solution may be to look at the current engineering education multi-day workshops/symposiums, such as the National Effective Teaching Institute, How to Engineer Engineering Education, and Making Academic Change Happen, and create a similar event that will compliment these by serving as an open forum for collaboration. The intent of the multi-day event would be to create an open forum for the discussion and exchange of ideas between innovative instructors and engineering education researchers. The symposium would act as a bridge and connect instructors actively reshaping courses at their home institution with prominent EER practitioners. The instructors would be encouraged to collaborate with engineering education researchers to improve their course design as well as formally examine and disseminate information about the impact of the implemented changes.

While the discussed research focuses on formal collaborations typified by JEE articles, informal collaborations and mentorship networks were not included in the analysis. Thus, a future study will use surveys to examine informal collaboration and mentorship networks in EER. Results from this future study will assist the engineering education community in creating effective programs for supporting unconnected researchers, particularly researchers independently performing engineering education research within their specific discipline.

Acknowledgements

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Appendix: Organization Attributes

Availability of EER Resources	
1	Engineering Education Department
2	Engineering or STEM Education Research Center
3	No On-Campus Resources

Basic Carnegie Classification	
RU/VH	Research Universities (very high research activity)
RU/H	Research Universities (high research activity)
Bac/A&S	Baccalaureate Colleges--Arts & Sciences
Master's L	Master's Colleges and Universities (larger programs)
DRU	Doctoral/Research Universities
Spec/Eng	Special Focus Institutions--Schools of engineering
Bac/Diverse	Baccalaureate Colleges--Diverse Fields
Master's M	Master's Colleges and Universities (medium programs)

Organization	Org Type	Carnegie Classification	Eng Ed Resources	Num Records	Num Authors
Aalto University	Intl Univ		3	1	1
American Association for the Advancement of Science	Non-Profit			1	1
American Institutes for Research	Non-Profit			1	1
Arizona State University	University	RU/VH	2	6	11
Association of State & Territorial Health Officials	Non-Profit			1	1
Beijing University Aeronautics & Astronautics	Intl Univ		3	1	1
Boeing	Industry			1	3
Boston College	University	RU/H	3	1	2
Brigham Young University	University	RU/H	2	1	1
Bucknell University	University	Bac/A&S	3	1	3
California Polytech State University San Luis Obispo	University	Master's L	3	5	4
California State University-Fullerton	University	Master's L	3	2	1
Carnegie Foundation for the Advancement of Teaching	Non-Profit			1	2
Carnegie Mellon University	University	RU/VH	2	6	5
Central Queensland University	Intl Univ		3	1	1
City University Hong Kong	Intl Univ		3	1	1
Clarkson University	University	RU/H	3	1	4

Organization	Org Type	Carnegie Classification	Eng Ed Resources	Num Records	Num Authors
Clemson University	University	RU/H	1	1	1
Colorado School of Mines	University	RU/H	2	7	5
Colorado State University	University	RU/VH	3	1	2
CUNY City College	University	Master's L	3	2	2
Curtin University Australia	Intl Univ		3	1	1
Dartmouth College	University	RU/VH	3	1	1
Duke University	University	RU/VH	3	1	4
East Carolina University	University	DRU	3	1	1
Education Designs Inc	Industry			1	1
Education Northwest	Industry			1	1
Fairleigh Dickinson Univ	University	Master's L	3	1	1
Florida State University	University	RU/VH	3	1	4
Franklin W. Olin College of Engineering	University	Spec/Engg	3	3	3
George Mason University	University	RU/H	3	1	1
George Washington University	University	RU/VH	3	1	3
Georgia Institute of Technology-Main Campus	University	RU/VH	3	2	7
Harvard University	University	RU/VH	3	1	1
Hewlett Packard Corp	Industry			1	1
Howard University	University	RU/H	3	1	1
Illinois Institute of Technology	University	RU/H	3	1	1
Indiana University-Main Campus	University	DRU	3	1	1
Indiana University-Purdue University-Fort Wayne	University	Master's L	3	1	1
Iowa State University	University	RU/VH	3	1	1
Korea Fdn for the Adv of Science & Creativity	Intl Gov			1	1
Lawrence University	University	Bac/A&S	3	3	1
Linkoping University	Intl Univ		3	1	2
Loughborough University	Intl Univ		2	1	2
Marshall University	University	Master's L	3	1	1
Massachusetts Institute of Technology	University	RU/VH	2	1	1
Miami University-Oxford	University	RU/H	3	1	1
Michigan State University	University	RU/VH	2	1	1
Ministry of Educ, Culture, Sports, Science & Tech	Intl Gov			1	1
Minnesota State University-Mankato	University	Master's L	3	1	1
Nanyang Tech University	Intl Univ		3	2	2
National Academy of Engineering	Government			1	1
National Pingtung University of Science & Technology	Intl Univ		3	2	1
National Science Foundation	Government			1	2

Organization	Org Type	Carnegie Classification	Eng Ed Resources	Num Records	Num Authors
National Taiwan University of Science & Tech	Intl Univ		3	1	2
Natural Sciences & Eng Research Council	Government			1	1
North Carolina State University at Raleigh	University	RU/VH	3	1	1
Northeastern University	University	RU/H	3	1	4
Northwestern University	University	RU/VH	3	4	8
Ohio State University Main Campus	University	RU/VH	1	2	5
Oklahoma Baptist University	University	Bac/Diverse	3	1	1
Oklahoma State University Main Campus	University	RU/H	3	1	1
Old Dominion University	University	RU/H	3	1	1
Oregon State University	University	RU/VH	2	2	4
Pennsylvania State University-Main Campus	University	RU/VH	2	8	17
Pepperdine University	University	DRU	3	1	1
Purdue University Main Campus	University	RU/VH	1	37	42
Research Triangle Educational Consultants	Industry			2	1
Rose-Hulman Institute of Technology	University	Spec/Engg	2	4	4
Rowan University	University	Master's L	3	1	2
Saint Louis University Main Campus	University	RU/H	3	1	1
Seattle Pacific University	University	Master's L	3	1	1
Shanghai University	Intl Univ		3	1	1
Simmons College	University	Master's L	3	1	1
Stanford University	University	RU/VH	2	7	9
Suffolk University	University	Master's L	3	1	1
Technion - Israel Institute of Technology	Intl Univ		3	1	1
Temasek Polytech	Intl Univ		3	1	7
Texas A&M University	University	RU/VH	3	2	2
Texas Tech University	University	RU/H	2	2	3
The University of Alabama	University	RU/H	3	1	1
The University of Tennessee Martin	University	Master's M	3	1	1
The University of Texas at Austin	University	RU/VH	3	1	1
The University of Texas Pan American	University	Master's L	3	1	1
Tufts University	University	RU/VH	3	2	4
Tuskegee University	University	Bac/Diverse	3	1	1
United States Military Academy	University	Bac/A&S	3	1	1
Universidad de La Laguna	Intl Univ		3	1	2

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Universidad de La Rioja	Intl Univ		3	1	4
Universidad Politécnica de Valencia	Intl Univ		3	1	1
University of Alberta	Intl Univ		3	1	1
University of Auckland	Intl Univ		3	1	1
University of Colorado at Boulder	University	RU/VH	3	2	2
University of Connecticut	University	RU/VH	3	2	4
University of Florida	University	RU/VH	3	3	3
University of Georgia	University	RU/VH	3	1	3
University of Houston	University	RU/VH	3	1	4
University of Louisville	University	RU/VH	3	1	1
University of Manitoba	Intl Univ		3	1	2
University of Maryland-College Park	University	RU/VH	3	1	1
University of Massachusetts Amherst	University	RU/VH	3	1	2
University of Melbourne, Australia	Intl Univ		3	1	1
University of Michigan Ann Arbor	University	RU/VH	2	9	19
University of Missouri Columbia	University	RU/VH	3	4	3
University of Nebraska Lincoln	University	RU/VH	3	1	2
University of Nevada-Reno	University	RU/H	3	1	1
University of New Hampshire Main Campus	University	RU/H	2	1	2
University of New Mexico Main Campus	University	RU/VH	3	2	1
University of Notre Dame	University	RU/VH	3	1	3
University of Oklahoma Norman Campus	University	RU/VH	2	4	8
University of Pittsburgh	University	RU/VH	2	3	6
University of Pretoria	Intl Univ		3	1	1
University of Rochester	University	RU/VH	3	1	1
University of San Diego	University	DRU	3	2	2
University of South Dakota	University	RU/H	3	1	1
University of South Florida-Tampa	University	RU/VH	3	2	2
University of Sydney	Intl Univ		3	1	2
University of Vermont	University	RU/H	3	1	3
University of Washington Seattle Campus	University	RU/VH	2	8	18
University of Wisconsin Madison	University	RU/VH	3	3	5
Urban Institute	Industry			1	1
Utah State University	University	RU/H	1	1	1
Vanderbilt University	University	RU/VH	3	3	3

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Virginia Commonwealth University	University	RU/VH	3	1	1
Virginia Polytechnic Institute & State University	University	RU/VH	1	16	19
Washington State University	University	RU/VH	2	5	8
Western Washington University	University	Master's L	3	1	1
Xi'an University of Architecture & Tech	Intl Univ		3	1	1