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# Scholarly Collaboration In Engineering Education: From Big-Data Scientometrics To User-Centered Software Design

Hanjun Xian
*Purdue University*

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Is approved by the final examining committee:

Krishna Madhavan                           Sean Brophy
_____
                  Chair
Monica Cox

Niklas Elmqvist

Mihaela Vorvoreanu

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Approved by Major Professor(s): ___Krishna Madhavan_____

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Approved by: Robin Adams                                          10/29/13
                      Head of the Graduate Program                              Date

SCHOLARLY COLLABORATION IN ENGINEERING EDUCATION: FROM
BIG-DATA SCIENTOMETRICS TO USER-CENTERED SOFTWARE DESIGN

A Dissertation

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of

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To Xingyu, my dear wife for her support; Shier and Jinhua, my parents, for giving me

courage and confidence; and Leo, my little one, for keeping me moving forward.

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ABSTRACT

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Engineering education research has grown into a flourishing community with an-ever increasing number of publications and scholars. However, recent studies show that a significant amount of engineering education knowledge retains a clear disciplinary orientation. If the gaps in scholarly collaboration continue to be prevalent within the entire community, it will become increasingly difficult to sustain community memory. This will eventually inhibit the propagation of innovations and slow the movement of research findings into practice.

This dissertation studies scholarly collaboration in the engineering education research community. It provides a clear characterization of collaboration problems and proposes potential solutions. The dissertation is composed of four studies. First, the dissertation recognizes gaps in scholarly collaboration in the engineering education research community. To achieve this goal, a bibliometric analysis based on 24,172 academic articles was performed to describe the anatomy of collaboration patterns. Second, the dissertation reviews existing technologies that enhance communication and collaboration in engineering and science. This review elaborates and compares features in 12 popular social research network sites to examine how these features support scholarly

communication and collaboration. Third, this dissertation attempts to understand engineering education scholars' behaviors and needs related to scholarly collaboration. A grounded theory study was conducted to investigate engineering education scholars' behaviors in developing collaboration and their technology usage. Finally, a user-centered software design is proposed as a technological solution that addresses community collaboration needs.

Results show that the engineering education research community is at its early stage of forming a small-world network relying primarily on a small number of key scholars in the community. Scholars' disciplinary background, research areas, and geographical locations are factors that affect scholarly collaboration. To facilitate scholarly communication and collaboration, social research network sites have been adopted by scholars in various disciplines. However, engineering education scholars still prefer face-to-face interactions, emails, and phone calls for connecting and collaborating with other scholars. Instead of connecting to other scholars online, the present study shows that scholars develop new connections and maintain existing connections mainly by attending academic conferences. Some of these connections may eventually develop into collaborative relationships. Therefore, one way to increase scholarly collaboration in engineering education is to help scholars better network with others during conferences. A new mobile/web application is designed in this dissertation to meet this user need.

The diffusion of innovation theory and the small-world network model suggest that a well-connected community has real advantages in disseminating information quickly and broadly among its members. It allows research innovations to produce greater impacts and to reach a broader range of audiences. It can also close the gap between

scholars with different disciplinary backgrounds. This dissertation contributes to enhancing community awareness of the overall collaboration status in engineering education research. It informs policy making on how to improve collaboration and helps individual scientists recognize potential collaboration opportunities. It also guides the future development of communication and collaboration tools used in engineering education research.

CHAPTER 1.    INTRODUCTION

1.1    <u>Statement of the problem</u>

Engineering education research (EER) has grown into a large research community with an ever-increasing number of publications and scholars. However, recent studies showed that a large number of scholars must work in isolation (Borrego, 2007; Madhavan, Xian, Vorvoreanu, et al., 2010). In addition, engineering education scholars were not well informed about the research innovations of other scholars (Borrego, Froyd, & Hall, 2010; Wankat, 2011). Because the findings drawn from these existing studies were based on a small scholar population of the community, it remains unclear whether the entire EER community is experiencing the same fragmentation of scholarship. Nor is it explored what contributes to the fragmentation status. If this kind of fragmentation is prevalent within the EER community, sustaining community memory (Marshall, Shipman III, & McCall, 1995) becomes extremely difficult. Eventually, it will inhibit the propagation of community opinions on research work. Therefore, it is essential to study the entire EER community and to analyze the collaboration network among all engineering education scholars.

Given the possible need to increase scholarly communication and collaboration, a number of pioneering efforts have recently been attempted. As traditional face-to-face communication (such as workshops) continues to play a key role in promoting academic

collaboration and innovation diffusion (Felder & Brent, 2010; Simpson et al., 2010; Streveler & Smith, 2006), Web 2.0 virtual environments offer an innovative and efficient solution to achieving similar goals. The increasing popularity of such Web 2.0 platforms for research purposes has influenced the entire academia (Codina, 2009; Nentwich, 2010; Watters, 2011). The EER community is no exception. Nevertheless, the Web 2.0 technologies per se do not guarantee the success of a tool in enhancing communication and collaboration among engineering education scholars. Features that contribute to scaffolding scholarly communication and collaboration in existing sites need to be examined closely to explain how these sites aid scholars' communicative activities.

Although social networking sites seem to help scholarly communication and collaboration, scholars typically remain reluctant to adopt Web 2.0 applications for academic use (Procter et al., 2010). Engineering education researchers hold a similar attitude towards adoption of such new Web 2.0 applications (Malik et al., 2011). The seemingly effective Web 2.0 solution fails to reach and influence the target audience. This fact implies a greater need to develop a better understanding of how engineering education scholars develop collaboration and their technology usage.

Understanding of engineering education scholars' collaborative behavior and technology usage related to collaboration yields design implications of new collaboration tools. An example tool is proposed to show how to translate engineering education scholars' needs and behaviors into a software design. The tool is compared with other competitive technologies, such as the social networking tools for research discussed earlier, in order to demonstrate its unique advantages. With these advantages presented to

the research community, this tool becomes more likely to be adopted within the EER

community itself.

## 1.2    Overview of the dissertation

The present dissertation aims to study scholarly collaboration in EER and to

propose a user-centered software designed to increase collaboration. To achieve this goal,

the dissertation is composed of four interrelated studies:

- CHAPTER 2: Anatomy of scholarly collaboration in engineering education:

  a big-data bibliometric analysis. The quantitative analysis of large-scale

  bibliographic data aims to both clarify and analyze the problem of scholarly

  collaboration in EER. This study characterizes the overall status of

  collaboration in EER, recognizes gaps in collaboration, and elaborates on

  factors that influence scholarly collaboration in EER.

- CHAPTER 3: A review of communication and collaboration features in

  social research network sites. This study aims to explore possible

  technological solutions necessary for enhancing communication and

  collaboration in EER.

- CHAPTER 4: Understanding engineering education scholars' research

  collaboration and their technology usage: a grounded theory study. This

  study identifies factors that are truly essential to the engineering education

  scholars as they manage their networks and collaborate in research. This

  study then explains why existing Web 2.0 solutions have not been widely

  adopted.

- CHAPTER 5: A user-centered software design to enhance scholars'
  experiences in making connections during academic conferences. This
  chapter elaborates design of a new collaboration tool based on scholars'
  needs. It further discusses the proposed tool's advantages over existing
  solutions.

The present dissertation presents a macro view of scholarly collaboration within EER and an in-depth analysis of how individual scholars develop collaborations. In pursuit of technological solutions to increasing scholarly collaboration, the present dissertation proposes a new collaboration tool with feasible and executable details based on the user needs. The proposed collaboration tool is based on a scientific and formal study of the market gap and user needs.

CHAPTER 2.     ANATOMY OF SCHOLARLY COLLABORATION IN
ENGINEERING EDUCATION: A BIG-DATA BIBLIOMETRIC ANALYSIS

## 2.1     Introduction

Understanding collaboration structures within any problem space is a data intensive

endeavor. Even to derive a partial characterization of the collaboration networks

prevalent within the engineering education research community requires data at such

large scales making such an effort extremely difficult. The difficulties of large-scale data

analysis include computational challenges and dealing with significant data noise.

Therefore new methodologies are required to perform these analyses. In this paper, the

author attempt a big-data bibliometrics characterization of the engineering education

research problem space. Bibliometrics refers to methods used to quantitatively evaluate

publications, scholars, journals, institutions, and larger population steps based on

large-scale publication metadata (Borgman & Furner, 2002). While there is some general

understanding of big-data bibliometrics among engineering education research (EER)

scholars (Johri, Wang, Xiaomo, & Madhavan, 2011; Madhavan, Xian, Johri, et al., 2010;

Xian & Madhavan, 2012), the techniques presented in this paper and the literature

surrounding this big-data approach add a completely new perspective to begin mapping

the engineering education research space. The fundamental question when undertaking

such studies is:    "Why should we even attempt to characterize the nature of

collaboration within a problem space?" The author will begin to address this question next.

As a newly emerging discipline, engineering education has quickly evolved into a large research community with a growing number of academic publications, scholars, publication venues, and funding streams. For instance, as the most inclusive annual conference in engineering education, *American Society for Engineering Education Annual Conference Proceedings* (ASEE) had 529 papers published in 1996. This number rapidly increased to 1,722 in 2011. Similarly, the number of *Frontiers in Education* (FIE) papers has increased from 270 in 2000 to 440 in 2011. From 1991 to 2009, the number of scholars publishing in FIE rose from 231 to 1,003 (Madhavan, Xian, Vorvoreanu, et al., 2010). Also, new publication venues, such as *Advances in Engineering Education* (AEE), have emerged over the last decade. Based on an awards search on *nsf.gov*, National Science Foundation (NSF) invested approximately $2.5 million on projects related to engineering education (with "engineering education" mentioned in abstracts) in 1991. Again this number grew to about $234 million in 2011.

Similar to other interdisciplinary fields, the engineering education research community also features a high diversity in scholars' knowledge background and research interests. Wankat (2004) (2004) reported that the authors of the *Journal of Engineering Education* (JEE) had come from a variety of engineering and non-engineering disciplines, without a single discipline dominant. Also, as of 2012, ASEE categorizes conference proceedings papers into 51 divisions, from highly discipline-related topics (such as aerospace and architectural engineering) to

cross-disciplinary foci (such as computers in education, design in engineering education, and educational research and methods).

The diversity in scholarship in EER implies neither inter-disciplinarity nor a higher degree of scholarly communication and collaboration. A significant amount of engineering education knowledge retains a clear disciplinary orientation and rarely reaches audiences from other disciplines. As a recent study revealed, engineering educators in different disciplines seldom communicated and collaborated with each other (Wankat, 2011). Scholars tend to read and cite articles that describe practices in their same engineering discipline because the context and solutions sound more familiar and applicable. The disciplinary barrier leads to silos and limited cross-fertilization in EER (Wankat, 2011). While the increasing publication production and diverse scholarship signal a flourishing community, this growth makes it increasingly difficult to understand the epistemic nature of knowledge generated in this problem space. It is exactly for these reasons that understanding collaboration patterns and networks is critical.

## 2.2   Research questions and an overview of the study

While there have been calls for more collaboration within the engineering education community (Jamieson & Lohmann, 2009; Jesiek, Borrego, & Beddoes, 2008; Wankat, 2011), the underlying topology of the collaboration networks within the engineering education research space has never been systematically explored. Prior studies either focus on elaborating on a very limited scope of the community or propose general remedies for the community fragmentation without relying on a large body of literature (Madhavan, Xian, Johri, et al., 2010). Comprehensive data coverage (if not total) is essential in characterizing the complete network structure among engineering

education scholars. This essentially moves the problem of understanding the topology of collaboration networks underlying engineering education research into the realm of big data. Although it has been recognized that a variety of factors such as the scholars' fields of study (Birnholtz, 2007; Tuire & Erno, 2001; Xian & Madhavan, 2012) and geographic locations (Tuire & Erno, 2001) (Jesiek, et al., 2008; Tsui, Nifadkar, & Ou, 2007) affect collaboration, little is known about exactly how these factors contribute to scholarly collaboration in EER. This paper aims both to characterize the status of scholarly collaboration in EER and to study factors that influence collaboration among engineering education scholars. In particular, the following questions are to be answered:

1. What are the main characteristics of scholarly collaboration in the entire EER space over 2000-2011?

2. How do factors, such as scholars' disciplinary background, research areas, and geographical locations, affect scholarly collaboration structures in the EER space?

To answer these questions, a bibliometric analysis is conducted based on papers in the top EER journals and conference proceedings over 2000-2011. A total of 24,172 papers and 29,116 unique authors are included. Since these authors are used in the present study to represent the entire engineering education scholar population in the U.S. and to a good extent other parts of the globe, the rest of this paper refers to them as engineering education scholars. A social network analysis is performed to characterize the network topology of the overall scientific collaboration network. These scholars are grouped by their disciplinary background, research areas, and geographical locations respectively. To automate scholar grouping, only scholars located in the U.S. are included in the geography-based analyses. Other analyses do not limit the data scope to only the

U.S. scholars. For each grouping criterion, again a social network analysis is applied to measure collaboration within and between groups of scholars.

The analysis performed in the present study is the first attempt to quantitatively analyze academic collaboration within the EER community based on unprecedentedly large-scale bibliometric data. The data scale may not seem as large as those in typical big data problems such as understanding the network topology among Twitter users (Kwak, Lee, Park, & Moon, 2010). However, in investigating scholarly collaboration particularly in EER, the data scale in the present study is unprecedentedly large and methods used in this study demonstrate many properties that are unique to dealing with big data problems. For example, computation times and computational infrastructural requirements for many parts of this study are significant and are in the realm of big data. A discussion about the scope of these infrastructural requirements is outside the scope of this study. Therefore, the author argues that this big data approach to EER community structures is in itself a new methodological contribution to the field of engineering education research. Findings in this study could enhance community awareness of the overall collaboration status in EER, inform policy making on how to improve collaboration, and help individual scientists to recognize potential collaboration opportunities.

## 2.3    Theoretical framework and related work

The present study is guided by the diffusion of innovations theory and the small world network theory, which are both briefly introduced in this section. The diffusion of innovations theory highlights the importance of scholarly communication and collaboration in advancing science. Further it recognizes factors that affect adoption of new knowledge. This echoes the focus on scientific collaboration and the study of factors

that influence scholarly collaboration in the present study. The small world network

theory characterizes a network model that mimics numerous real-world social networks,

including academic networks. This theory is referenced in the present study to guide the

selection of network measures. Furthermore, the ideal small world network model is used

as a benchmark to identify potential issues in the community structure in the EER

community. Any deviations from the small world network model are indicative of

structural problems that inhibit flow of information in the community. These deviations

are also critical to identify lapses (or holes) in the network structure that could place

unnecessary burden for capacity building on a few individuals within the community.

### 2.3.1    Diffusion of innovations

As a pioneer and major contributor to the formation of this theory, Rogers (2003)

synthesized diffusion research and proposed a comprehensive theory concerning the

diffusion of innovations. In his book, Rogers defined diffusion as "the process in which

an innovation is communicated through certain channels over time among the members

of a social system" (Rogers, 2003, p. 5). He further defined innovation as "an idea,

practice, or object that is perceived as new by an individual or other unit of adoption"

(Rogers, 2003, p. 12). The diffusion of innovations theory has been used to analyze a

variety of technological changes (Jaffe, Newell, & Stavins, 2003) in industry, such as the

adoption of automated teller machines (Sinha & Chandrashekaran, 1992), smartphones

(Kim, Seoh, Lee, & Lee, 2010), and mobile banking services (Laukkanen, Sinkkonen,

Kivijärvi, & Laukkanen, 2007).

In addition to focusing on the study of the adoption of technologies and commercial

products, the diffusion of innovations theory can also be used to explain the process of

scientific advancement. Based on the philosophy of science, scientific progress relies largely on scholars' awareness of others' achievements and scholars' self coordination. As a leading philosopher of science, Kuhn (1996) offered the analogy of science as a puzzle-solving game and proposed the notion of "paradigm shift" to denote the revolutionary stage when a sufficient amount of anomalies cannot be explained by the current paradigm. Both revolutionary science and normal science (Kuhn, 1996) rely on the presence of coordination among scientists, which has been identified as an imperative factor in advancing science. In describing the Republic of Science, Polanyi (2000) argued that scientific problems would be exhausted in the absence of results achieved by others. Therefore, the most efficient organization of scientific progress was the self-coordination of independent initiatives within the sight of others' achievements. In order to explain how scientists from different specialties form a joint opinion, Polanyi (2000) posited that each scientist gained overlapping competencies that qualified him/her for multiple groups, which cumulatively formed networks and chains to cover the whole science. This ideal model echoed Campbell's fish-scale model of omniscience (Campbell, 1969), where each narrow specialty overlapped with its neighboring specialties.

Not only do the above theories highlight the significance of scientific communication and collaboration in advancing science, but the fundamental assumptions in this theory also offer guidelines on how to diffuse innovations in scientific communities. According to Rogers (2003), there are five stages of adopting innovations: knowledge, persuasion, decision, implementation, and confirmation. Scholars' disciplinary background and research areas make understanding innovations within another domain a challenge, particularly in interdisciplinary fields such as engineering

education. When lacking a proper understanding and acknowledgement of academic work by other scholars, scholars are unlikely to take further steps to seek additional knowledge, implement the knowledge gained, and finally adopt new knowledge. The discrepancy between scholars' personal backgrounds and innovations found in other domains introduces the uncertainty of relative advantage, incompatibility, complexity, and low trial ability (Rogers, 2003, pp. 229-265). As a result, scientific collaboration is unlikely to happen. Based on the diffusion of innovations theory along with related studies reviewed in Section 2.3.2, the present study focuses on studying scholarly collaboration in EER and characterizes how geographical location, disciplinary background, and research area influence the collaboration network topology.

### 2.3.2   Diffusion of innovations in EER

The problem of insufficient diffusion of innovation within the EER community has been widely recognized. A recent small data bibliometric study based on engineering education journal papers revealed that engineering educators in different engineering disciplines rarely communicated and collaborated with each other (Wankat, 2011). Papers in disciplinary engineering education journals, such as *Chemical Engineering Education,* were rarely citing or cited by papers in general engineering education journals such as *Institute of Electrical and Electronics Engineers* (*IEEE) Transactions on Education* (Wankat, 2011). Borrego et al. (2010) also found that EER academic publications had a very limited effect on influencing engineering departments' adoption of EER innovations. Instead, engineering department chairs relied on colleagues and word of mouth to uncover innovations (Borrego, et al., 2010). The collaboration network among FIE authors produced by Madhavan et al. (2010) demonstrates that significant capacity

building starting to happen within engineering education. But the same work also shows that there is a divide between a core EER group and the wider engineering community.

Besides the lack of communication across engineering disciplines, another gap between practice and research has also been recognized as an additional major problem within the EER community. According to the innovation cycle of educational practice and research (Booth, Colomb, & Williams, 2008), educational research findings should guide and improve educational practices. In response, educational practices should ideally identify questions to be explored in research studies. In reality, however, engineering practitioners rarely read EER publications, nor do they formally report feedback on practice to the research community (Adams & Felder, 2008). Engineering education researchers, on the other hand, do not represent ideas and results in terms that can be easily understood by educators, nor can they engage educators in evaluating research innovations (Fincher, 2009). Determining whether a scholar is more research-oriented or practice-oriented for all engineering education scholars is infeasible. Therefore, this attribute is excluded in the present study.

There are other factors that further influence academic collaboration and innovation diffusion, such as the scholars' geographic locations (Jesiek, et al., 2008; Tsui, et al., 2007; Tuire & Erno, 2001), research areas (Tuire & Erno, 2001; Xian & Madhavan, 2012), culture (March, 2004), and language (March, 2004), as identified by other disciplines. Unfortunately, while culture and language are important factors, these factors are almost impossible to determine and are beyond the scope of our big-data bibliometric analyses.

Bringing coherence to a fragmented EER community could require revolutionary changes in infrastructures that support both effective scholarly communication and the diffusion of research innovations across organizations and disciplines. Besides attending conferences such as ASEE and FIE, U.S. scholars have also organized and evaluated the impact of varied workshops, such as the NSF Design Workshop Series (Simpson, et al., 2010), Rigorous Research in Engineering Education workshops (Streveler, Smith, & Miller, 2005), and National Effective Teaching Institute (Felder & Brent, 2010), to promote collaboration among engineering education practitioners with similar interests. All of these efforts aim to help scholars develop social ties, which are recognized as essential in diffusing information across different social groups (Granovetter, 1973).

Despite the significant effect of face-to-face interactions on building social ties and diffusing innovations, such interaction is greatly limited by both time and geospatial location. Connecting sparse social networks within the EER community can also be realized through means that exert fewer constraints. Authors have made early attempts (Madhavan, Xian, Johri, et al., 2010; Madhavan, Xian, Vorvoreanu, et al., 2010) to make the underlying knowledge networks more visible and insightful for the entire community. These researchers have developed a data-intensive cyberinfrastructure to allow engineering education scholars to visually explore over 130,000 peer-reviewed EER publications and grant proposals. The greater visibility of knowledge potentially improves diffusion of innovations and increases the possibility for EER practitioners to successfully identify academic collaborators.

Regardless of whether face-to-face interactions or virtual environments are preferred, a close review of the collaboration status among engineering education

scholars has potential to guide the development of academic activities. Future development of workshops, programs, and social networking platforms can better define who to serve, how to engage the target audience, and how to evaluate research outcomes.

### 2.3.3 Small-world network theory and field evolution theory

Network research often aims to study either social networks or semantic networks. A *social network* is a social structure composed of a set of actors and ties among them (Wasserman & Galaskiewicz, 1994). The term *actors* (also known as agents) often refers to individuals, groups, and organizations. A *semantic network* is a set of concepts and their semantic relations (Cohen & Kjeldsen, 1987). The semantic interaction makes those mechanisms and patterns specific to social networks inapplicable in the analysis of semantic networks. Therefore, these two types of networks are often studied separately (Roth & Cointet, 2010). This separation may cause problems when analyzing certain kinds of networks, such as in scientific collaboration networks that have both social and semantic characteristics. For example, a scholar is an expert in a domain (agent-concept and between-concept links) and collaborates with some other scholars (between-agent links), which requires analysis of both social and semantic networks. The integration of social and semantic features gives rise to the *epistemic network*, which has also been named the *socio-semantic network* (Roth & Cointet, 2010). An epistemic network can be defined as "a group of agents sharing a common set of subjects, concepts, issues, and a common goal of knowledge creation." (Roth, 2007). In the context of scholarly collaboration, an epistemic network is a network where the authors are the agents and the topics used in papers are recognized as the concepts (Roth & Cointet, 2010).

The notion of a *small-world (SW) network* was first coined in 1998 (Watts & Strogatz, 1998) in order to describe a network topology that has the mixed characteristics of *regular networks* and *random networks* (Harary, 1994). Compared to regular networks and random networks, SW networks have been recognized as a model that mimics real-world social and biological networks, such as the collaboration network among film actors (Watts & Strogatz, 1998) and the topology of the World Wide Web (Albert, Jeong, & Barabasi, 1999). Since the coinage of the term, a number of follow-up studies have extended the original SW network model with the application of new characteristics such as scaling properties (Newman & Watts, 1999), classes of networks (Amaral, Scala, Barthélémy, & Stanley, 2000), and efficiency (Latora & Marchiori, 2001). The fundamental belief of this model is that, within a network, most nodes are involved in a highly clustered local community but can also reach nodes in other communities by a small number of hops. The typical separation between any two random nodes grows only proportionally to the logarithm of the number of nodes in the network (Watts & Strogatz, 1998).

Given the above discussion, when networks deviate from an ideal small world network model, this essentially means that either there are aspects of local community formation that could be problematic. Further, it could also indicate that the pathways for the locally clustered communities to reach other parts of the network are non-existent or blocked. Therefore, this essentially becomes a problem for rapid diffusion of innovations. This is precisely why this paper studies whether the collaboration network existent among engineering education scholars fits the SW network model. In addition,

interpretation of measures in the model is further discussed in the context of the EER community based on the SW network model.

Network theories focus primarily on individual-level interactions, whereas field evolution research studies the structure of the collective actions. One major distinction between the two theories is that network research tends to provide snapshots at any given time, whereas field evolution research places more emphasis on the timely or longitudinal change (McPherson, Smith-Lovin, & Cook, 2001). As Powell et al. (2005) suggested, these two separate research areas should be tightly coupled in order to examine how fields have evolved because the network research topology has both guided the choice of partners and shaped the trajectory of the field.

Another factor that influences field evolution is the notion of *attachment bias*, an element which is rarely considered with the SW model. The concept of attachment bias (Powell, et al., 2005) refers to the fact that individuals within a community demonstrate preferences when making their connections rather than following the equal probability function of the SW model. This is commonly referred to as 'the rich get richer' phenomenon within networks. The present study explores how different sources of attachment bias contribute and shape to the formation of networks.

### 2.3.4 Bibliographic and network analysis of EER publications

As qualitative methods are inappropriate for studying large-scale datasets, the present study uses a big data quantitative solution. One common methodology in characterizing scientific collaboration quantitatively is bibliometrics, which is defined as a set of methods designed to quantitatively evaluate publications, scholars, journals, institutions, and larger population steps based on large-scale publication metadata

(Borgman & Furner, 2002). Recent studies in EER have started to analyze bibliographic data for revealing time-based trends and overall status. Jesiek et al. (2009; 2008) have drawn upon articles in international journals and conference proceedings to characterize the international difference in the state of EER in terms of primary research areas, institutional infrastructures, research strategies, funding sources, and publication outlets. Beddoes et al. (2009) chose a similar approach to analyzing academic publications and studying international patterns but had a particular focus on gender/women-related topics. Other than these studies, a line of research aims to analyze specific publication venues by reviewing archives from these venues. Wankat (2004) examined the JEE articles over 1993-2002 and identified the main research areas, topical trends, and sources of financial support. Borrego (2007) analyzed publications on four engineering education coalition websites: Foundation, SUCCEED, ECSEL, and Gateway.    Based on the analysis, Borrego (2007) presented the status of the population studied, major methodologies, and the type of contributions. The above studies may not have the same research purpose as the present study but share a similar approach of analyzing a set of academic publications. As shown in Table 2.1, these studies review papers on a small scale as compared to the big data analysis of this present study.

Table 2.1 Comparison of the present study with prior studies w.r.t. publication data scale.

| Prior studies | Num. of sources | Num. of years | Num. of papers |
| --- | --- | --- | --- |
| (Jesiek et al., 2008) | 3 | 3 | 833 |
| (Jesiek et al., 2009) | 7 | 4 | 815 |
| (Beddoes et al., 2009) | 7 | 4 | 63 |
| (Wankat, 2004) | 1 | 10 | 597 |
| (Borrego, 2007) | 4 | 16 | 700 |
| **The present study** | **8** | **12** | **24,172** |

In contrast to studying specific journals and conferences, some scholars aim to characterize the overall picture of the whole EER area. Osorio (2005) summarized the current state of EER literature by providing an overview of overall scholar profiles, sources of support, types of documents, main topics, and major publication venues. Madhavan et al. (2010) provided an intuitive data gateway called Interactive Knowledge Networks for Engineering Education Research (iKNEER) for engineering education scholars to explore publications using large-scale data. iKNEER provides users with insights in the form of statistics and visualizations. Xian et al. (2012) studied the collaboration pattern among engineering education scholars who received funding from the National Science Foundation (NSF) and identified how the breadth of collaboration varied by research areas. These studies all share a similar approach of relying on bibliographic data analysis or meta-analysis of engineering education publications, with the last two studies focusing on ultra large-scale data or what is commonly referred to as 'big data'. Bibliometrics is a reliable, objective, scalable, and efficient method to measure research output (Archambault & Côté, 2008). The present study therefore applies this technique in investigating academic collaborations within the EER community.

### 2.4    Methodology

#### 2.4.1    Overview

This section outlines the major steps in the large-scale bibliographic study. As illustrated in Figure 2.1, the bibliographic data are downloaded (step 1) from an indexing engine and only those relevant to engineering education are included. Then name disambiguation and topic extraction are performed (step 2) to assure the quality of data for the later analysis. A social network analysis is conducted to reveal the statistics and

patterns of the overall scholarly collaboration status (step 3). Based on scholars'

affiliation information and publication (step 4), they are grouped first by their

disciplinary backgrounds (step 5), then research areas (step 6), and geographical locations

(step 7). For each of these three factors, similar analyses are performed to characterize the

network topology among the scholars.
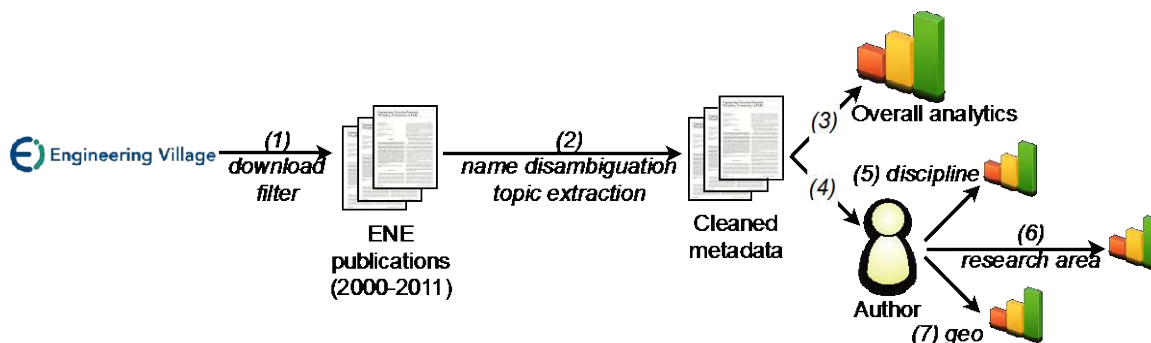


Figure 2.1 A framework overview of the bibliographic study.

### 2.4.2      Sampling bibliographic data

Engineering education journal and conference papers gathered over the period of

2000-2011 are selected for this study. Due to the unavailability of some publications in

2012 at the time the present study is conducted, papers published in 2012 have been

excluded. Table 2.2 lists publication venues and their numbers of papers.

Table 2.2 Publication venues and number of papers reviewed in the present study.

| Publication venue | Number of papers | Years covered |
| --- | --- | --- |
| Advances in Engineering Education (AEE) | 53 | 2009-2011 |
| IEEE Transactions on Education (IEEE) | 830 | 2000-2011 |
| International Journal of Engineering Education (IJEE) | 1,431 | 2000-2011 |
| Journal of Engineering Education (JEE) | 541 | 2000-2011 |
| Journal of Professional Issues in Engineering Education and Practice (JPIEEP) | 495 | 2000-2011 |
| European Journal of Engineering Education (EJEE) | 544 | 2000-2011 |
| Frontiers in Education (FIE) | 4,770 | 2000-2011 |
| ASEE Annual Conference Proceedings (ASEE) | 16,439 | 2000-2011 |

The above publication venues have been chosen based on the following criteria (using Compendex on Engineering Village) for the years 2000 to 2011:

(1) The publication venue must have "engineering education" in the name or contain over 200 papers related to engineering education. Over half of all its papers should be related to engineering education. This is to ensure its relevance to EER;

(2) It should minimize any disciplinary orientation so as to avoid introducing significant bias into the analysis of intra- and inter-disciplinary collaborations; and

(3) It must be a journal or conference proceeding that has existed for over two years during 2000-2011 so that the publication venue's popularity and reputation are guaranteed to some extent.

The above criteria are designed to ensure comprehensive data coverage and consistency of research work and scholars in EER while maintaining a low level of noise (documents and scholars not in the EER community) in this research. It is commonly believed that 2004-2005 was a critical timeframe in engineering education research (Streveler & Smith, 2006), where milestone publications (Felder, Sheppard, & Smith, 2005; Lohmann, 2005) emerged. These publications marked the transition of EER into a more rigorous discipline and engineering education departments started to form. Therefore, the year range of 2000-2011 has been selected to more fully cover research efforts happening at such historic crossroads.

A total of 24,172 papers and 29,116 scholars are included in the present study. Publication metadata are downloaded from *Engineering Village* and include the

following attributes: *title*, *abstract*, *author*, *affiliation*, *publication date*, *publication venue*, and *controlled/uncontrolled terms*. Other attributes such as language, DOI, and ISBN are also available but are not utilized for analysis in the present study because they are irrelevant to the research questions. The attributes for each publication are extracted from the downloaded metadata and inserted into a MySQL database. Engineering Village provides a Compendex database that has over 15 million engineering publications as of February 2013. This database has been recognized as the most comprehensive index for EER publications (Osorio, 2005).

### 2.4.3   Scholar and affiliation ambiguity resolution

The metadata acquired often suffers from inconsistency and incompleteness problems. For instance, scholar names may be represented in various forms because of first name abbreviation, middle name omission, spelling errors, and so on. Meanwhile, two individual scholars may share the same names. Failure to recognize these problems may significantly reduce the quality and threaten the validity of the analysis. To solve the name ambiguity problem, a token-based (Levenshtein, 1966) name disambiguation algorithm (implemented as a computer program) has been developed to automatically compute the between-name similarity and group similar names as one entity. Two scholars' names are to be considered as identical if all of the following conditions are met: (1) the last names are identical or at one-character distance from each other; (2) if one first name is abbreviated, the first characters of both first names are the same; and (3) the publications written by the two names share at least one common topic. Like any unsupervised name disambiguation algorithm, there is no guarantee of 100% accuracy. For example, if there are three author names, M. Smith, Michelle Smith, and Michael

Smith and all of them have very similar research interests, this algorithm cannot determine how to disambiguate M. Smith. However, such cases are rare and therefore the name disambiguation algorithm mentioned above still obtains a high accuracy.

A similar technique can be applied to disambiguating institution names. However, scholars often include department/school names and addresses within their affiliations and the order of these elements may vary to a great extent. Unlike scholars' names, affiliations tend to vary more frequently and these variations may be too different from each other to be recognized as similar by the algorithm above. For example, "School of A, College of B, C University" has a Levenshtein Distance (Levenshtein, 1966) of 27 from "C University" (the first affiliation name must have the first 27 characters removed to be identical to the second name). Such a large distance implies a low similarity between the two although they semantically represent the same institution. Therefore, if an affiliation name is part of another name, they are considered identical with the shorter name representing the group of variations, regardless of their length difference. However, different campuses of a university are considered as different institutions. Also, scholars and their affiliations were bound to that date when the article was published so as to take into consideration the movement of scholars across affiliations.

### 2.4.4    Geographical location and disciplinary background

A scholar's geographical location is looked up based on his/her affiliation. When provided with an institutional name, that organization's zip code, congressional district, and state are determined based on a lookup database used by the National Science Foundation (NSF). This database includes institutions and companies that have applied for an NSF grant during 1976-2012 at least once and therefore should provide a relatively

comprehensive list for looking up all engineering education scholars' affiliations. The present study uses the designated state (i.e. Indiana, Michigan, etc.) to represent a scholar's geographical location. However, there are still companies, institutions, and even personal addresses that are not included in this dataset and in such cases, the affiliations are parsed to check if any state name appears. For example, "Abcd LLC, MI 12345" is recognized as a company located within Michigan. Also, due to the movement of some scholars across institutions, they may be initially affiliated with an institution in state A and then move to state B later. These scholars are grouped as "cross-state" (XS) and are separated from either state A or state B so that group A, group B, and group XS are mutually exclusive.

Using the NSF database and U.S. states implies that the geographical analysis is U.S.-centric. Scholars who have no affiliation information or are affiliated with unrecognizable or non-U.S. organizations are not to be considered within the geographical analysis. The reason why non-U.S. authors are excluded in the geographical analysis is because including these authors introduces a significant amount of noise in the data that threaten the validity of the results. In the publication database used in the present study, affiliations are often presented on papers with no country information. Also, the same international institution tends to vary in their English names more often than U.S. institutions. As a result, inferring an author's nationality using affiliation is inaccurate and may yield misleading results.

A scholar's disciplinary background can also be derived from the school, department, and college in one's affiliation. However, grouping engineering education scholars based on their detailed affiliation information is a problem that is actually more

complex than scholar name and institution name disambiguation. First, not all scholars include their school/department/college names within their affiliation. For some journals and conference proceedings, only institution names are mandated, which leads to missing disciplinary information for a large number of scholars. When the same scholar has published a paper with a detailed program name in a different publication venue, the detailed record is used to complement his/her missing data in another paper. Second, even when an academic program name is provided, universities do not share the same organizational structure. For example, some universities have Computer Engineering as a separate department, whereas other universities categorize it as part of the Electrical and Computer Engineering department. In the present study, disciplines are defined based on the available Classification of Instructional Programs (CIP)'s list (CIP, 2000). To resolve issues regarding disagreement with program names, the same techniques for disambiguating institutional names is applied in order to compare the scholars' affiliations with the CIP program list. It is possible that a scholar has been affiliated with more than one program and, in such cases, the scholar is recognized as interdisciplinary. Also, affiliations that cannot be matched to any program are labeled as "Uncategorized".

### 2.4.5   Research topics

In bibliographic data analysis, author-supplied key terms are widely used to define the research topic of a given study. However, key terms are sometimes unavailable in publications. Assigning key terms to those documents manually by domain experts (Wankat, 1999, 2004) is so costly that it becomes unfeasible when analyzing big data. Therefore, instead of simply relying on the experts' annotations, there are also reliable machine-generated solutions that assist in extracting key terms from documents.

Word frequency counts are based on the simple criterion that the more frequently used words are more important for describing the content of a text. Typically, high frequency stop words (e.g., this, that, is, he, she, etc.) are eliminated according to a fixed stop words list. Because of its simple nature and the fact that it is even superior to some more sophisticated automatic indexing methods (Carroll & Roeloffs, 2007), simple word frequency count is widely used for determining the core content of texts including the indexing of scientific literature (Luhn, 1957). Despite its simplicity and usefulness for automatically indexing documents, one drawback of the simple word frequency count is with regards to the manner employed for eliminating stop words. Stop words are usually eliminated according to a set of fixed stop words. This illustrates a lack of flexibility. For documents within a specific domain, such as engineering education research, the words "engineering" and "education" will occur with a very high frequency, but they do not provide much insight into detailed theories, backgrounds, and methodologies of this domain. The inverse document frequency (idf) method has been introduced to solve this problem by taking into consideration the context of the words used.

Within the idf scheme, a measurement often known as the Term Frequency-Inverse Document Frequency (tf-idf) (Salton & McGill, 1983) exists, where the frequency of occurrence of a term $t_i$ in one document is called "term frequency" (*tf*), and the "inverse document frequency" (*idf)* is a weight to be applied to this term. Therefore, the product of *tf* and another *idf* is used to determine the relative importance of $t_i$. As a result of this weighting process, if a term has a high frequency within one document, it only becomes important when the term has a relatively low frequency among all of the documents researched. Follow-up studies (HaCohen-Kerner, Gross, & Masa, 2005; Medelyan, Frank,

& Witten, 2009; Turney, 1999) extend the measurement of tf-idf to support the extraction of keyphrases instead of single words. The tf-idf method recognizes important terms based on their context rather than on a fixed list. However, it does consider terms as a list of entities and lacks the capability of grouping terms hierarchically according to their conceptual meanings.

Topic modeling builds a folksonomy based on probability models of word co-occurrence (Johri, et al., 2011). Folksonomy refers to creation and management of collaborative human-powered annotations of content, which is different from authoritative hierarchical taxonomy (Peters, 2009). Researchers studying topic models have proposed multiple approaches to modeling textual corpora. Latent dirichlet allocation (LDA) (Blei, Ng, & Jordan, 2003) and its variations (Blei & Lafferty, 2006, 2007; Mei, Shen, & Zhai, 2007; Ramage, Hall, Nallapati, & Manning, 2009; Wei & Croft, 2006) annotate each document with a probability distribution over a mixture of topics and each topic includes a cluster of words. For example, in the first step, an LDA algorithm is trained with a set of publications known as being relevant to "engineering education". Then the use of this algorithm produces a list of words (e.g., design, assessment, retention) and their occurrence probability. This pattern for the topic "engineering education" can be used to categorize publications and annotate them with a mixture of topics. While the topic modeling technique works effectively in categorizing documents automatically given a pre-defined classification scheme and training data, it still does not create a taxonomy based on the conceptual meanings of topics.

The present study mixes the human-curated method with machine-assigned method by annotating topics to publications automatically based on a human-generated taxonomy.

The human-generated taxonomy is based on the results of analyzing educational publications in Education Resources Information Center (ERIC) (2013). Each topic in this taxonomy has a list of sub-topics and, again, each sub-topic continues to have its own sub-topic until the topic is narrow and specific enough. For instance, the topic *curriculum* includes sub-topics such as *course design,* and a college curriculum itself further includes areas such as: freshman composition, college science, and so on. Abstracts of each publication to be analyzed run through all of the topics in the taxonomy, and the topics that occur are used to annotate the publication. The result is that each publication is tagged with no, one, or more concepts. The taxonomy has a total of 5,020 education-related topics. The present study chooses to explore the research community of "learning" in engineering education because it has the greatest number of publications. There are also other important topics in engineering education, such as design and faculty professional development. All of these topics can be analyzed by using a similar approach to the one proposed in the present study.

### 2.4.6 Scholar collaboration and network analysis

In this study, engineering education scholars are defined as authors in the selected papers. In the language of network analysis, engineering education scholars are nodes and their co-authorships on papers are edges in a collaboration network. Due to the broad coverage of EER literature, a significant majority of engineering education scholars have been included in the analysis and only minor bias from the population is introduced. Collaboration between scholars may arise in various situations, such as serving in the same committee and organizing a workshop together. However, such activities are not formally documented and cannot be easily acquired. Based on well-documented materials,

there are also other ways of tracking scholarly communication and collaboration, such as the study of acknowledgements (Cronin & Overfelt, 1994; Laudel, 2002), citations (Garfield, 1972; Sims & McGhee, 2003; L. C. Smith, 1981), and co-citations (Acedo & Casillas, 2005; Gmür, 2003; He & Hui, 2002; Small, 1999) in papers. This kind of collaboration is known as `invisible` (Laudel, 2002), whereas coauthorship is the most tangible, widely used, and best-documented form of collaboration (Glänzel & Schubert, 2005; M. Smith, 1958). Therefore, the present study defines collaboration as coauthorship within at least one paper selected in this study, and the other forms of collaboration are not viewed as factors to consider.

In social network analysis, there are several possible metrics by which to measure network cohesion and to characterize community structure. Modularity is measured by "the number of edges falling within groups minus the expected number in an equivalent network with edges placed at random" (Newman, 2006). The intended use of modularity is to find or evaluate a way of dividing a large network into modules, and this is, hence, not applicable for sparse networks. Network density is defined as the total number of edges divided by the total possible number of edges (Scott, 2000). Density depends on the total number of nodes. Therefore, comparing density across networks of differing sizes often yields misleading results (Niemeijer, 1973).

As a size-independent alternative to density, the average clustering coefficient (ACC) is calculated by establishing the number of triangles over the number of connected triplets (Luce & Perry, 1949). ACC measures the extent to which nodes tend to cluster together and has the range of 0 to 1. A low ACC value indicates that the connections in the network exist more in the form of weak ties. In sparse networks, a large number of

nodes are single, which cannot be measured by ACC. To take this into consideration, the

number of isolated nodes (i.e. nodes with zero degree) is also measured in the analysis. A

high percentage of isolated nodes indicate that a large number of scholars are publishing

without collaborating with other scholars. In contrast to isolated nodes, the size of the

largest network is an indicator of how many scholars can potentially reach one another.
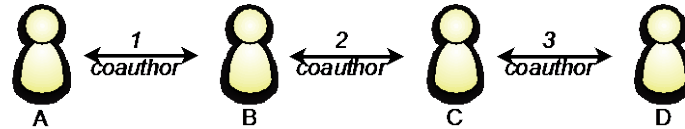


Figure 2.2 An illustration of a path length of 3 between scholars A and D.

To further elaborate how likely it is that one scholar can reach any other scholar

within the largest network, diameter and average path length are also measured in the

network analysis. Path length is the distance between two nodes in the network. As

illustrated in Figure 2.2, if scholar A collaborates with B, and B with C, and C with D

(assuming that A has not collaborated with C or D), then the path length between A and

D is 3. The average path length is the average of all path lengths between any two nodes.

The diameter is the longest path length within a network. If a network has a high average

of both path length and diameter, then scholars within said network are less likely to

connect with other scholars than are those scholars operating within a network with a low

path length and diameter. In addition, both the average degree (AD) and average

weighted degree (AWD) are measured to establish the number of collaborators per

scholar and the likelihood of working with the same set of collaborators. The bigger the

gap between these two values, the higher the tendency is for an engineering education

scholar to frequently collaborate with the same scholars without reaching out for

additional collaboration opportunities available with other communities. Table 2.3 and

Table 2.4 summarize terms and measures in social network analysis that will be

frequently mentioned in the results section. These terms and measures are introduced in

the context of the present study and their mathematical definitions can be found in

Aggarwal's (2011) book.

Table 2.3 A summary of social network analysis terms used in this study.

| Term | Definition and interpretation |
| --- | --- |
| Node | Engineering education scholars included in this study |
| Edge | Coauthorship between scholars in papers |
| Cluster/Component | Any two scholars in the same cluster are connected via at least a path of edges. Any two clusters have no edges in between. |

Table 2.4 A summary of measures used in this study, their definitions, and

interpretations.

| Measure | Definition and interpretation |
| --- | --- |
| Average degree (AD) | The mean of scholars' numbers of unique coauthors in papers. A high AD value means that scholars in the group tend to collaborate widely with many different scholars. |
| Average weighted degree (AWD) | The mean of scholars' numbers of collaborations in papers. A high AWD value indicates that scholars in the group frequently collaborate with other scholars. |
| Average clustering coefficient (ACC) | The mean of possibilities of any two scholars (A and B) coauthoring in a paper if these two scholars coauthor with the same scholar C. A low ACC value means that a large number of weak ties exist in the group. |
| Percentage of isolated scholars (% iso) | The percentage of scholars whose papers are all single-authored papers. |
| Average path length | The mean of lengths between any two scholars in a cluster. A long average path means that scholars are less likely to connect to others in the same cluster and it takes longer to disseminate research innovations. |
| Size of the largest cluster | The number of scholars in the largest cluster. A high value indicates that a large number of scholars have potential to reach each other via the connections in between. |

2.5     Results

2.5.1    Overview

Based on 24,172 conference proceedings and journal papers, 29,116 unique

scholars are identified. Figure 2.3 presents the full coauthor network of all scholars in the

EER community. This figure presents the full picture. It is not customary to identify

individual scholars in studying network topologies in a bibliometrics study.
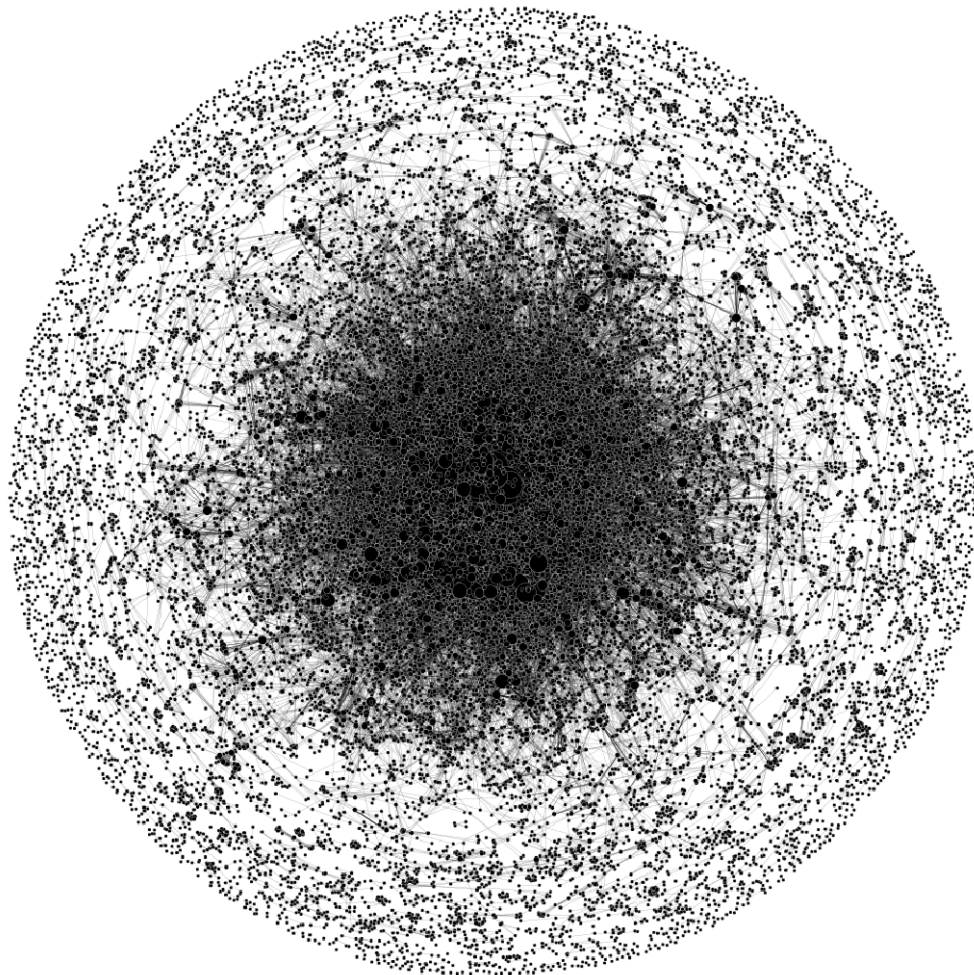


Figure 2.3 The coauthor network of all 29,116 engineering education scholars (Node -

scholar; Edge - coauthorship in papers).

Understanding this large network requires both scientific measures of the network and a deep dive into different aspects of this community topology. On average, each scholar has 4.73 collaborators and 6.13 collaborations. When compared to other scientific collaboration networks, as those listed in Table 2.5, the average number of collaborators in the EER community is relatively low second only in comparison with computer science. However, the results are based on different disciplines, different time frames, and different sample size, which may all introduce bias into a direct comparison of numbers.

Table 2.5 The average number of collaborators in EER as compared to other disciplines.

| Discipline/Population | Average degree | Citation |
|---|---|---|
| Condensed matter physics | 6.28 | (Barrat, Barthelemy, Pastor-Satorras, & Vespignani, 2004) |
| MEDLINE | 18.00 | (Newman, 2001) |
| Computer science | 3.93 | (Elmacioglu & Lee, 2005) |
| PhD scientists | 13.76 | (Bozeman & Corley, 2004) |
| **Engineering education** | **4.73** | **The present study** |

One characteristic of a small-world network is that the degree of distribution follows the power-law function. As is shown in Figure 2.4, the number of scholars versus both the number of collaborations (weighted degree) and the number of collaborators (degree) approximately follow a power-law form except when degree is low (less than 4). These low-degree scholars may represent those new to the community, working in isolation, or opting out after their early EER publications. A possible explanation is that there are fewer engineering education scholars who have one or two collaborators than the predicted value of a small world network. The fact that the degree distribution follows a power law also indicates that the scholarly collaboration network in engineering

education has a degree-biased graph topology (White, Owen-Smith, Moody, & Powell, 2004). A degree-bias is also known as an attachment bias (aka 'rich get richer'), in which when the nodes are linked, they favor the highly connected nodes (Barabási, 2005). This is a common phenomenon arising in both small world networks and those scholarly collaboration networks where scholars prefer to collaborate with those key actors in the field who have already owned a large professional network.



(a)                                    (b)
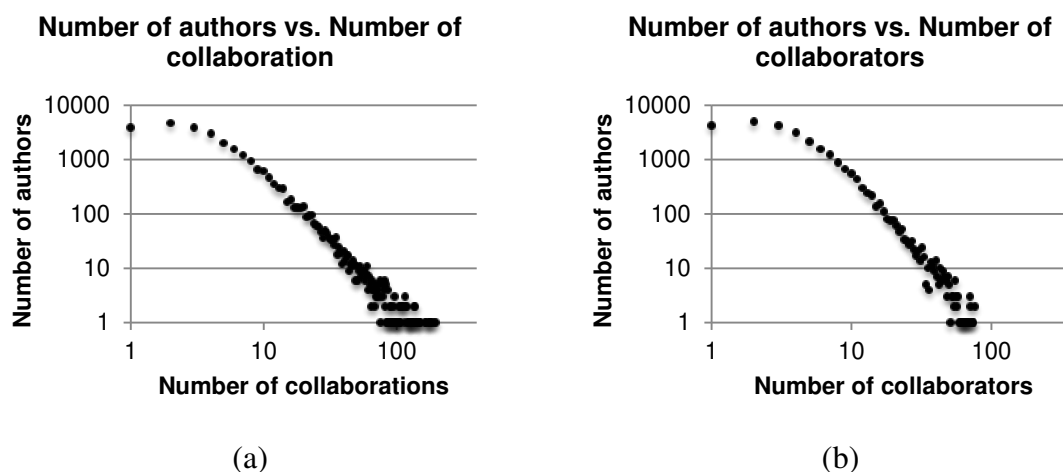
Figure 2.4 (a) Number of scholars vs. number of collaboration and (b) Number of scholars vs. number of collaborators follows a power-law function.

Table 2.6 Isolated clusters in the coauthor network of the entire EER community.

| Cluster ID (sorted by size) | % of all authors |
| --- | --- |
| 1 (largest) | 66 |
| 2 | 0.13 |
| 3 | 0.12 |
| … | < 0.1 |

There are 3,611 isolated clusters existing within the network, with the largest cluster composed of 66% of all the scholars. This means that, among those scholars within the largest cluster, any two scholars could either collaborate directly with each other or can be connected via networks existent between them. Table 2.6 shows the top

three clusters in terms of size. Within each of these clusters scholars are connected but do not collaborate with those in a different cluster. As Table 2.6 illustrates, the second and third largest networks are significantly smaller in size (both at about 0.1% of all of the scholars) when compared to the largest one, and each of the additional clusters is then composed of less than 0.1% of all of the scholars. This indicates that the EER community has achieved a significant coverage by the largest cluster (a process known as site percolation within the small world network theory (Newman & Watts, 1999)). In the future, the largest cluster is unlikely to suddenly expand by a large degree. On the other end, approximately 4.9% of all of the scholars have no collaborator. The diameter of the largest network is 25, and a scholar within the largest network is 7.1 hops away from another scholar on average. The 7.1 average path length (in the language of graph theory) is significantly higher than 5.0, as computed based on the random scale-free networks with the small world property (Fronczak, Fronczak, & Hołyst, 2004). This fact, again, illustrates less collaboration and connectivity existent within the EER community as compared to the typical small world network model itself. The collaboration network within the EER community has an average clustering coefficient of 0.833. This amount indicates that when scholar A collaborates with scholars B and C, there is an 83.3% chance that scholars B and C collaborate with each other too. In all, it demonstrates that over the years of 2000-2011, scholars within the EER community have started to form a small world network and a large connected network has indeed formed. However, the insufficiency in collaboration inhibits the EER community from gaining those critical characteristics that in turn inhibit the advantages of a typical small world network, such as short distances between any two scholars.

2.5.2    Role of key players

This section measures the influence produced by key players in bringing the engineering education community together. Key players are those scholars who frequently bridge local networks and are often located in the center of the network (measured by a "betweenness" centrality). They are essential in helping to form new collaborations among scholars. However, according to the small world network theory, the network topology itself should remain quite similar when these key players are removed from the network. Therefore, this section measures changes within the network topology given the removal of the top 1%, 2%, 3%, 4%, and 5% of the predominantly central scholars.

As illustrated in Figure 2.5, when compared to the original network (as indicated by 0%), the removal of the central scholars leads to radical fragmentation. The size of the largest network falls from 66% of all scholars to 6% when the top 5% of the central players have been removed, as is illustrated in Figure 2.5(a). The number of isolated networks increases from 3,611 to 6,412, which indicates that more of the groups are working in isolation without the central actors, as is shown in Figure 2.5(b). The average numbers of both collaborators (5.1) and collaborations (6.9) drop, most radically when the top 1% (4.5 collaborators and 5.7 collaborations) and 2% (4.1 collaborators and 5.1 collaborations) are eliminated, as is presented in Figure 2.5(c). Scholars that were, on average, originally 7 hops away from each other now need to travel through 21 scholars, and the maximum distance (diameter) increases from 25 to 70, as is indicated in Figure 2.5(d). Finally, fewer bridging scholars are observed, as implied by the slight increase in the average clustering coefficient, rising from 0% to 5%.

**Size of the largest network vs. % of central scholars removed**



(a)

**Number of isolated components vs. % of central scholars removed**



(b)

**Number of collaborators/collaborations vs. % of central scholars removed**



(c)

**Path length vs. % of central scholars removed**
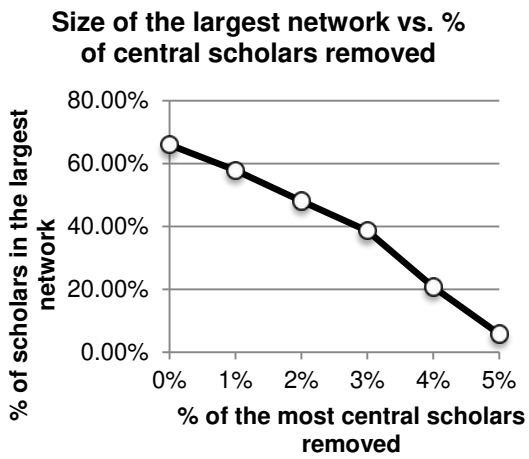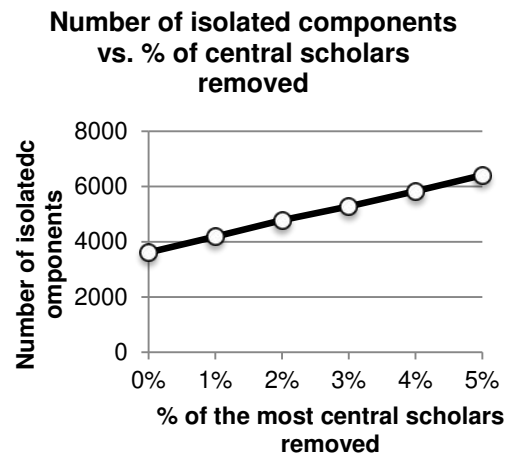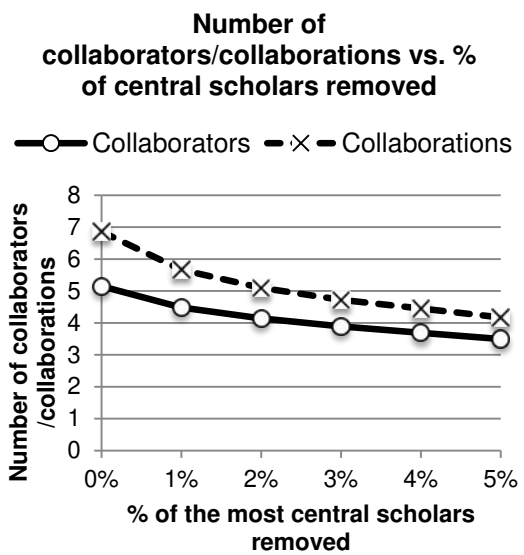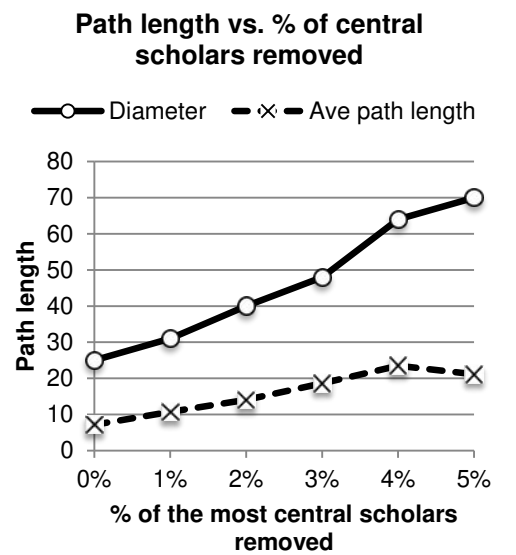


(d)
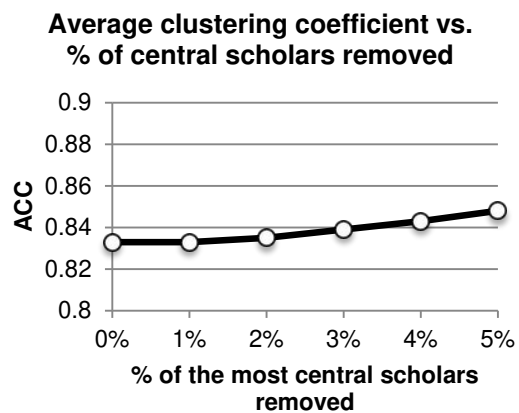
(e)

Figure 2.5 Significant changes of network topology as key scholars are removed from the

collaboration network.
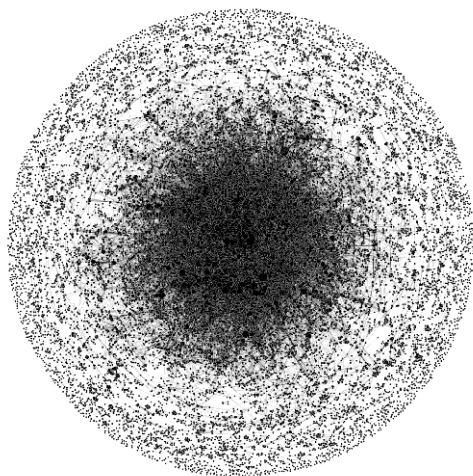


(a)
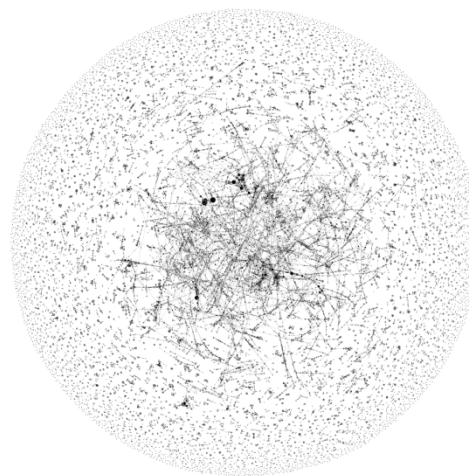


(b)

Figure 2.6 A network illustration of significant changes in the network topology as key

scholars are removed from the collaboration network. (a) The original coauthor network,

and (b) The same network with top 5% central players removed resulting in significant

fractures in the community network structure.

This indicates that the EER community relies on a small number of key players in order to bind the space. The network layout places key players in the center, with the isolated scholars and teams closer to the edge. An absence in key players results in a significant change in the collaboration network topology, as shown in Figure 2.6. Therefore, a need for increased capacity exists in order to avoid overly relying on a few central scholars.

### 2.5.3 Discipline

This section shows the disciplinary difference in the topology of collaboration networks within the EER community. As illustrated in Figure 2.7, scholars are first analyzed based on their general disciplinary backgrounds, such as Engineering, Mathematics, and Technology. Second, scholars in engineering are further divided into different engineering disciplines, such as Electrical and Computer Engineering and Mechanical Engineering. In both cases, scholarly collaboration is measured within each group (by discipline or engineering discipline) and across groups.
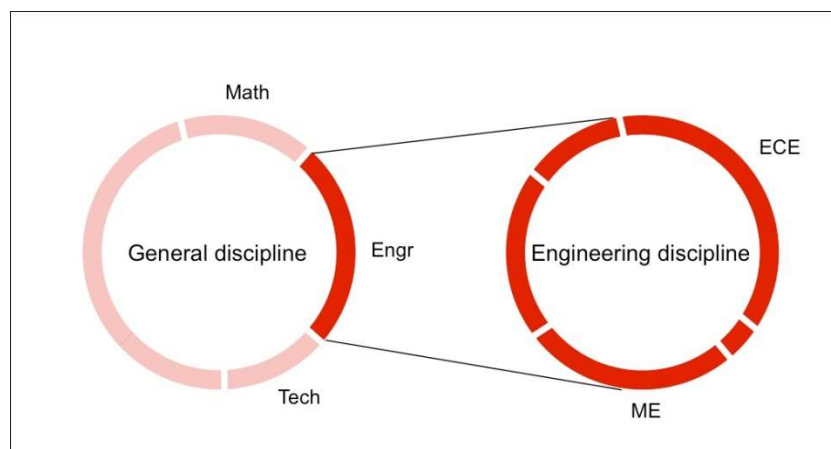


Figure 2.7 A deep dive by a general discipline, such as Engineering, and then a further deep dive by an engineering discipline, such as Electrical and Computer Engineering.

1. General disciplines

Figure 2.8 illustrates that about half of scholars are affiliated with only one engineering school/department/college. This confirms a prior study by Wankat (2004) that revealed the significant role of engineering scholars in EER. However, the present study shows that one third of scholars do have an Interdisciplinary background. As discussed earlier, these two groups are mutually exclusive, which means that if a scholar has both an Engineering and Computer Science background, that scholar is considered to be "Interdisciplinary" and is not evaluated within the Engineering discipline itself. Together, these two groups constitute about 82% of all engineering education scholars. About 6.9% of scholars have affiliations that cannot be mapped as part of any discipline. Scholars within Computer Science, Education, and Physical Sciences take the fourth through sixth places respectively in terms of the calculated number of scholars.

**Number of authors in each discipline**

| Disc.[*] | AD/AWD | ACC | % iso |
|---|---|---|---|
| Engr | 2.6/3.4 | .79 | 17% |
| Interd | 4.2/7.7 | .73 | 9% |
| CIS | 1.5/2.1 | .86 | 29% |
| Edu | 0.7/1.0 | .87 | 53% |
| PhySci | 1.2/1.9 | .91 | 41% |
| BMM | 0.7/0.7 | .85 | 50% |
| Math | 0.5/0.6 | 1 | 55% |
| Psy | 0.8/1.0 | 1 | 54% |

[*] Engr - Engineering, Interd - Interdiscipline, CIS - Computer and Information Sciences, Edu - Education, PhySci - Physical Sciences, BMM - Business/Management/Marketing, Math - Mathematics, Psy - Psychology

Interd 32.5%
Uncat 6.9%
CIS 4.3%
Edu 1.9%
Others 1.8%
PhySci 0.9%
BMM 0.8%
Math 0.6%
Psy 0.4%
Engr 49.9%

Figure 2.8 Number of engineering education scholars and their cohesion within each discipline.

Among scholars affiliated with more than one discipline, Engineering dominates. The top seven most common combinations of disciplines are all engineering-related, as shown in Figure 2.9. These interdisciplinary areas are Engineering with Computer and Information Science, with Technology, with Education, with Business/Management/Marketing, with Physical Sciences, with Arts, and with Mathematics. When comparing this interdisciplinary distribution with the single-disciplinary profile of Figure 2.8, it becomes clear that scholars with a background in either Technology or Business/Management/Marketing join the EER community more often when they have an interest in engineering. This does not hold true for other disciplines as Computer and Information Science, Education, and Physical Sciences where scholars without an engineering background can still contribute and publish EER work.

**Number of interdisciplinary authors**
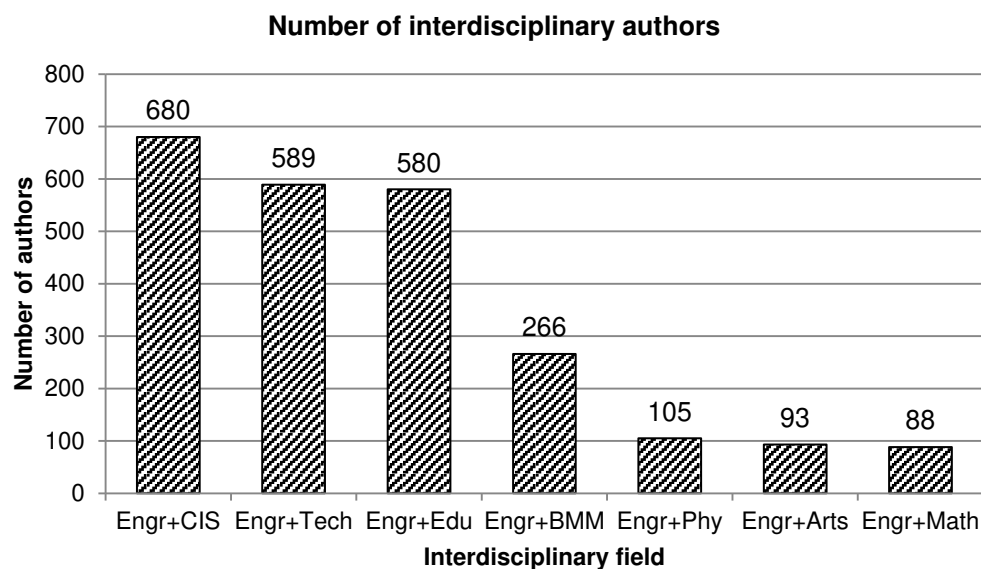


Figure 2.9 Number of engineering education scholars in different interdisciplinary combinations.

Regarding the network topology within each community, as introduced earlier, a higher average degree (AD) means that scholars have more collaborators. A large difference between average degree and average weighted degree (AWD) implies that scholars tend to collaborate with the same colleagues more frequently rather than working evenly with a broad range of research partners. First, as presented in Figure 8, engineering education scholars with an Interdisciplinary background have the greatest number of collaborators with other Interdisciplinary scholars but are still more inclined to work with the same research partners. The Engineering community comes in second in terms of within-disciplinary collaboration. For all of the other disciplines, collaborations within the same discipline rarely happen. Second, a low ACC and a small number of isolated scholars indicate that scholars in general are well connected with a relatively large number of 'bridging' players. This demonstrates exactly what occurs in Engineering and Interdisciplinary communities. Scholars in Computer and Information Science form numerous strongly connected sub-communities but lack connections among them. All other disciplines show yet another different picture, where most scholars are working in isolation and almost no bridging exists. Such differences in network characteristics may imply that scholars with Engineering or Interdisciplinary backgrounds play a critical role in converging the EER community. These scholars connect to members of the local and well-connected groups, without whom the scholars of other disciplines would suffer from an insufficient connectivity. This hypothesis will be validated by the between-discipline statistics illustrated below.

The collaboration between every two disciplines is shown in Figure 2.10. It clearly shows that Interdisciplinary and Engineering scholars have frequent collaborations within

their communities and also act as hubs that link to all other disciplines. Besides collaborating with intra-disciplinary scholars, those scholars in Education and Business/Management/Marketing primarily work with the two hubs when publishing academic work, whereas Mathematics and Computer and Information Science collaborate with a broader range of disciplines. This result validates our earlier hypothesis that scholars with Interdisciplinary and Engineering backgrounds form weak ties in the collaboration network that brings multiple communities together. Weak ties have been known as important in disseminating information as they often serve as bridges between otherwise disconnected groups (Granovetter, 1973).
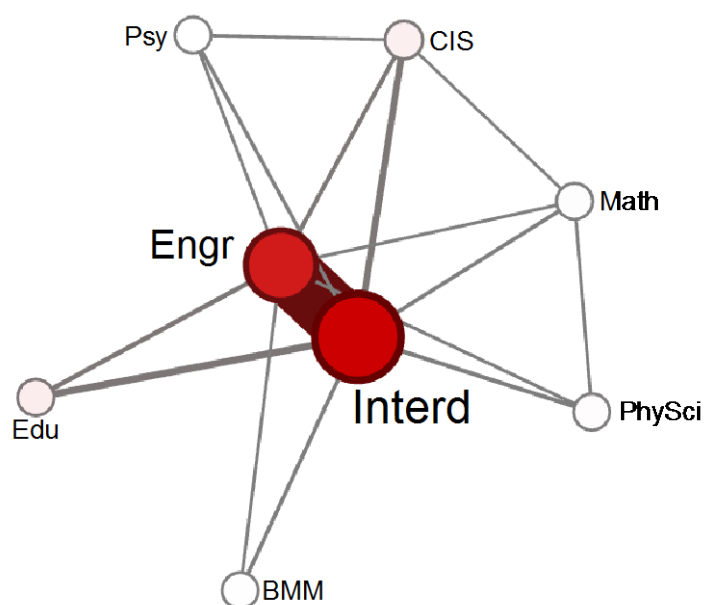
Figure 2.10 Number of coauthorships between engineering education scholars in the same discipline and between those in different disciplines. Node size - number of coauthorships within a discipline; Node color darkness - total number of coauthorships with other disciplines; and Edge weight - number of coauthorships between two linked disciplines.

2. Engineering disciplines

With regards to engineering, specifically, scholars generally have more collaborators within the same domain and are less likely to work in isolation when compared to broader disciplinary categories such as Education and Psychology. Interdisciplinary engineering, Electrical and Computer Engineering, and Mechanical Engineering have the largest number of engineering education scholars, as indicated in Figure 2.11. This confirms the results of a prior analysis conducted about a decade ago (Wankat, 2004) in which it was stated that no single engineering discipline dominated the EER community. However, the results of the present study further show the uneven distribution across differing engineering disciplines. In particular, there are a large number of scholars with interdisciplinary backgrounds. Within engineering disciplines, Mechanical Engineering, Civil Engineering, Industrial Engineering, and Aeronautics and Astronautics Engineering share similar characteristics of community topology. These scholars have a very small number of collaborators and collaborations with other scholars working within the same community. This does not imply a level of insufficient collaboration, because the scholars from these disciplines may be more likely to collaborate with scholars from other engineering disciplines. Interdisciplinary Engineering, Electrical and Computer Engineering, and Biomedical Engineering, on the other hand, have frequent intra-discipline collaborations and fewer isolated scholars.

**Number of authors in each engineering discipline**



| Disc.[*] | AD/AWD | ACC | % iso |
|---|---|---|---|
| InterdE | 2.2/3.2 | .79 | 21% |
| ECE | 2.3/3.0 | .85 | 24% |
| ME | 1.6/2.1 | .82 | 29% |
| Chem | 1.9/2.4 | .90 | 28% |
| Civil | 1.3/1.5 | .89 | 35% |
| IE | 1.1/1.5 | .80 | 40% |
| Bio | 2.4/2.9 | .89 | 23% |
| AAE | 1.6/2.1 | .90 | 29% |

[*] InterdE - Interdisciplinary Engineering, ECE - Electrical and Computer Engineering, ME - Mechanical Engineering, Chem - Chemical Engineering, Civil - Civil Engineering, IE - Industrial Engineering, Bio - Biomedical Engineering, AAE - Aeronautics and Astronautics Engineering

Figure 2.11 Number of engineering education scholars and their cohesion within each engineering discipline.

Mechanical Engineering, Civil Engineering, Industrial Engineering, Aeronautics and Astronautics Engineering, and Biomedical Engineering have almost an equal number of collaborations between intra-disciplinary and inter-disciplinary collaborations. This does not hold true for all of the other disciplines. As shown in Figure 2.12, scholars in the Interdisciplinary Engineering group play a significant role in connecting other disciplines together. Further, Figure 2.12 highlights that there is no link between any two individual disciplines, which means scholars from these disciplines rarely collaborate with those in a different discipline. The Mechanical Engineering group is the second best in bridging the disciplinary gap, and it connects almost evenly with all of the other disciplines. The link between Mechanical Engineering and other disciplines is not visible in Figure 2.12 because the number of coauthorships is very low compared to the collaboration within

Mechanical Engineering. Electrical and Computer Engineering, on the other hand, does not stand out with regards to this role, although it is given that that this field has an even higher number of scholars than Mechanical Engineering.
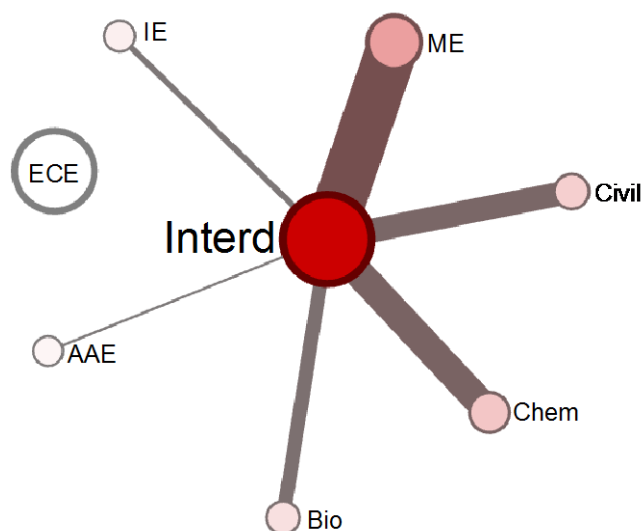


Figure 2.12 Number of coauthorships between engineering disciplines. Node size - number of coauthorships within an engineering discipline; Node color darkness - total number of coauthorships with other engineering disciplines; and Edge weight - number of coauthorships between two linked disciplines.

### 2.5.4   Research area

Papers related to learning are analyzed and categorized into: active learning, problem-based learning, experiential learning, cooperative learning, lifelong learning, discovery learning, electronic learning, visual learning, and others. There are also other sub-areas of learning but they are not included in this analysis because the number of scholars publishing in those areas is too small (less than 20) to produce any valuable insights for this research domain. Regarding the most popular sub-areas of learning listed above, the top five learning sub-areas in terms of number of scholars are active learning,

problem-based learning, cooperative learning, experiential learning, and lifelong learning, as shown in Figure 2.13. For each of these areas, a strongly connected community has been established with scholars collaborating sufficiently and clustering together.

The number of scholars who specialize in multiple learning-related areas is very low as compared to those who are publishing in only one area of study. Problem-based learning, cooperative learning, and lifelong learning make up approximately half of the scholars charted within the community as collaborators with scholars in other sub-areas of learning. A similar extent of collaboration is not observed within the other areas.

**Number of authors in each learning-related research domain**

| Area[*] | AD/AWD | ACC | % iso |
|---|---|---|---|
| Act | 4.1/8.1 | .83 | 6% |
| PBL | 3.8/6.9 | .89 | 7% |
| Coop | 3.9/8.4 | .88 | 9% |
| Exp | 4.1/8.1 | .88 | 7% |
| LL | 3.1/10.0 | .88 | 9% |
| Disc | 4.5/9.0 | 1 | 10% |
| Elec | 4.6/5.7 | 1 | 3% |
| Vis | 2.1/4.7 | .91 | 4% |

[*]Act - Active learning, PBL - Problem-based learning, Coop - Cooperative learning, Exp - Experiential learning, LL - Lifelong learning, Disc - Discovery learning, Elec - Electronic learning, Vis - Visual learning

Active 37.5%

Others 1.2%

Visual 0.9%

Electronic 1.0%

Discovery 1.3%

Lifelong 9.6%

Problem Based 20.6%

Experiential 13.6%

Cooperative 14.2%

Figure 2.13 Number of engineering education scholars and their cohesion within each learning-related area.

### 2.5.5   Geographical location

Engineering education scholars are widely distributed across the U.S., with no single state dominating the community. As is shown in Figure 2.14, the states that have

the most engineering education scholars are Indiana, Pennsylvania, Texas, Michigan, and California. XS represents that grouping of scholars which has affiliated with more than one institution, where the institutions are located in different states. Each state in Figure 2.14 shares characteristics that are similar between a large number of collaborations and with a small number of isolated scholars. This clearly indicates that the engineering education scholars within a state are forming a tightly linked cluster. There is an exception, namely XS, which has a significantly lower average clustering coefficient and more isolated nodes. This is not a surprise because those scholars who are staying in multiple states do not necessarily collaborate with each other. Rather, they may become the active links between scholars in other differing states. The next section explores whether the XS group, like the interdisciplinary community described above, helps to establish connections across states.

Top eight states and their number of ENE scholars

| State[*] | AD/AWD | ACC | % iso |
|---|---|---|---|
| XS | 2.9/6.8 | .50 | 24% |
| IN | 3.6/4.9 | .77 | 13% |
| PA | 3.2/4.4 | .81 | 15% |
| TX | 3.2/4.5 | .81 | 13% |
| MI | 3.7/5.1 | .80 | 10% |
| CA | 2.6/3.3 | .85 | 19% |
| VA | 3.5/5.1 | .82 | 13% |
| MA | 3.5/4.6 | .82 | 12% |

XS - Cross-state, IN - Indiana, PA - Pennsylvania, TX - Texas, MI - Michigan, CA - California, VA - Virginia, MA - Massachusetts
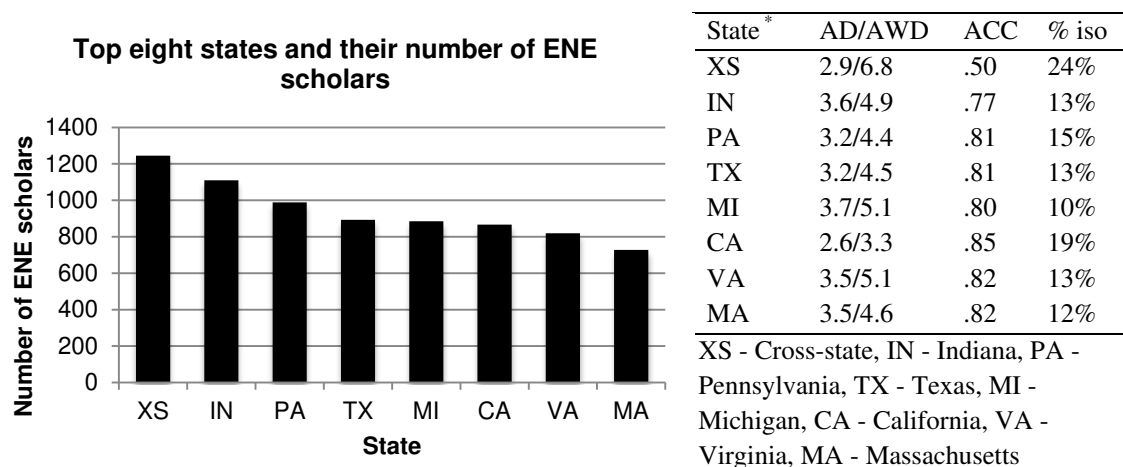
Figure 2.14 Number of engineering education scholars and their cohesion within each state in the U.S. (XS - Cross-state).
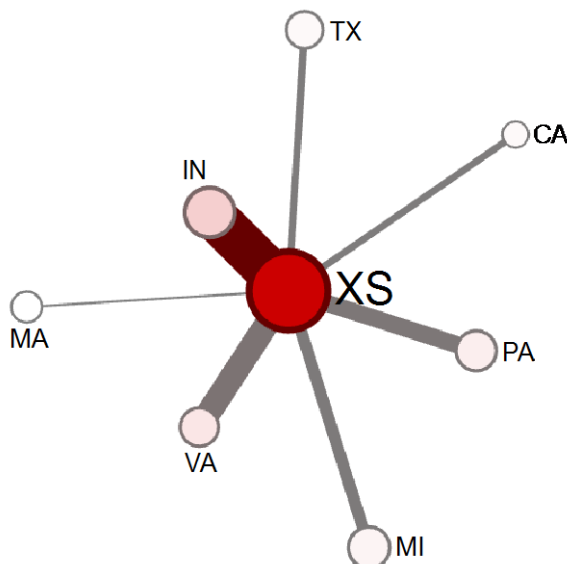
Figure 2.15 Number of collaborations (as measured by coauthorship) between states in

the US. (Node size - number of coauthorships between authors within the same state;

Node color darkness - total number of coauthorships with other states; and Edge weight -

number of coauthorships between authors in two states).

As has been predicted, the XS group has a significantly higher number of

coauthorships with other states than does any single state (Figure 2.15). This indicates,

with the between-state collaboration, that scholars who have professional networks in

multiple states both maintain their academic collaboration with past and current

colleagues and assist in bridging with the local communities. However, this study has

also found that for each state, intra-state collaborations outnumber any inter-state

collaborations, even with the XS group. As illustrated in Figure 2.15, there is no link

between any two individual states, which means scholars in these states rarely collaborate

with those in a different state. Given the effort of the XS group in bringing together

scholars from different states, the geographical location remains an influential factor in scholarly collaboration.

## 2.6    Discussion

The results presented in the previous section demonstrate that the EER community is at its early stage of forming a small world network. The notion of small-world networks is particularly critical in studying community structure within EER. The author has argued throughout this chapter that significant deviations from the small world network model indicate gaps in pathways for research innovations to diffuse to a wider audience. While the EER community is poised to attain some critical characteristics of a small work network model – which in the future is of importance to disseminate knowledge, at the present time such formation is still in its infancy. Our study does not claim that the EER network will eventually resemble a stable small network model. However, it seems from the results that such small world network characteristics are forthcoming. Furthermore, due to the general insufficient degree of collaboration, the scholarly collaboration network in EER is still experiencing significantly longer distance (7.1 on average) between the involved scholars than is a small world network (5.0), which can inhibit the diffusion of innovations.

The current EER collaboration network also tends to rely on a few key players, without whom the entire network will fall apart. Ideally, the network topology should not be radically affected because of the removal of a few key players. However, at present, the EER community may suffer greatly in the dissemination of knowledge if some key players decide to change their career paths. This result indicates a need not only for an increase in scholarly collaboration, but also for a sharing the loads of current key players

and allowing more peripheral scholars to start to play central roles in the community. Traditionally, we have always emphasized the need for experience in selecting scholars to leadership positions at major community organized events. Perhaps, teaming upcoming researchers or purposely seeking out researchers from outside the EER community helps to bring in more people to the core of the network. Allowing newcomers to the community to take on more responsibilities in the community may allow breaking the "rich get richer" problem observed in our analyses. This allows for more robust network characteristics also. On a separate note, the realization that the problem of insufficient collaboration is critical. However, efforts to solve this problem are not trivial and require a deeper understanding of the differing factors that influence the network topology.

Discipline is the first factor explored in the present study. It is not a surprise that the majority of the engineering education scholars have an engineering background. However, it has never been revealed that scholars who have interdisciplinary backgrounds are the second largest population within the community. Along with the percentage of computer science, education, and other disciplines illustrated, these results not only depict the current status of disciplinary distribution, but also guide our efforts for drawing new scholars into the EER community. Another interesting finding is that since there are a lesser number of interdisciplinary scholars than those who focus on a single engineering discipline, the former play a far more significant role in bridging with other disciplines. Therefore, the group of scholars falling under the interdisciplinary category is critical in identifying those scholars who may have the potential to become key players. This factor continues to hold true within the engineering field, where scholars who have multiple engineering backgrounds tend to collaborate more with all other engineering

disciplines. Scholars who are interdisciplinary are perhaps better hires in schools and organizations attempting to diffuse engineering education innovations as our data suggest that such people are the ones forming new links (and therefore capacity to diffuse innovations).

When studying how a research area affects the collaboration network with a particular focus on learning-related work, this study has demonstrated that active learning, problem-based learning, and a few other sub-domains have gained the most attention from scholars working on learning-related topics. Also, scholars within each sub-domain are well connected and collaborate more than the average of the entire network. This is a positive signal that illustrates that people working on similar topics form connections with each other. However, the results also clearly show a very limited degree of collaboration across topics. This does not necessarily denote a negative phenomenon because, conceptually speaking, some topics may share very little common information or concepts with another topic. Therefore, instead of blindly promoting collaboration between two topics, it is more important to recognize the agenda and plan drafted by varied research institutions (such as the National Science Foundation, National Academy of Engineering, or American Society for Engineering Education) and see how the documented plan can be mapped to the existing research innovations. For instance, how did the research agenda (2006) affect the subsequent research studies in engineering education? Is there a discrepancy between what have been frequently studied and what is recognized as important by the community?

Geographical location also strongly determines how scholars can collaborate. The large gap existing between in-state collaboration and between-state collaboration

becomes the most obvious element when compared to the other factors above. This has been demonstrated within a different context (Jesiek, et al., 2008). On the one hand, this means that traditional brick and mortar organizations have significant value, as geographical proximity significantly affects the collaboration network topology. Therefore, providing organizational structure that invests in bringing people closer geographically has significant impact on how research innovations are diffused. Perhaps even establishing regional centers of excellence – tied in with national organizations such as ASEE or IEEE – provides a framework for better collaboration. On the other hand, the fact that between-state collaboration is less common suggests a great need for a transformative change in the way scholars communicate. Although in-person meeting is still strongly preferred (Borrego, et al., 2010), emerging technologies – such as social media and online collaborative tools – can help eliminate the barrier caused by physical distance.

The fragmentation of knowledge, if not treated promptly and properly, could hinder the development of engineering education. Educators, researchers, and other stakeholders in the community hold discrepant views of fundamental concepts, definitions, and statuses of specific research areas. For example, definitions of problem-based learning (PBL) vary by domain, and different scholars hold incompatible beliefs about what should be counted as a PBL approach and how to correctly implement PBL into our educational practices (Barrows, 1996). Similarly, the concepts of multidisciplinarity, crossdisciplinarity, interdisciplinarity, and transdisciplinarity (Max-Neef, 2005) have been widely used but literatures rarely agree on the same definition and taxonomy regarding these terms. In an early stage of a discipline evolution, the imprecision and

inconsistency in understanding subject matters is a common phenomenon. However, such a lack of consensus presents challenges in scholarly communication/collaboration and community capacity building.

## 2.7    Conclusions

This paper is the first attempt to characterize the scholarly collaboration network in the EER community and explore how different factors influence the network topology based on an unprecedentedly large set of bibliographic data (big data). The author uses the small-world network model as a comparative base. One of the greatest advantages of using small world networks as a way of studying the topology of collaboration within the engineering education research community is that small world networks are inherently stable. They are also found extensively in nature. The present study argues that when the community structure deviates significantly from the small world network model, this is usually an indication that there are structural blocks in the way information and new innovations diffuse. The purpose of this paper is simply to provide such a comparison and characterize the state of the community. The authors acknowledge that there are significant implications of such a characterization for the community both in terms of structural transformations and policies to enable such transformations. However, a discussion of the policy implications or the epistemic forces that led to the current structure are simply not the focus of this study. However, where appropriate the author has identified launching points for potential policy discussions and identified need for future work.

The results show that the EER community has started to form a small world network. If as a community, EER were to continue along the current trajectory, it is not

clear that it would reach its full potential under the small world network model. While our study reveals that the community is still in its infancy with respect to forming a small world network, it does not guarantee that the structure and topology would indeed evolve naturally to a small world network without serious discussions regarding hiring, inclusion of others outside the community, and policies. At the current time, however, due to insufficient collaboration, the scholars involved are less likely to connect to each other through their academic network at its current state. Also, the entire scholarly network overly relies on a small number of key players, without whom the network will radically fall apart. This study has also presented how scholars' disciplines, research areas, and geographical location influence the network topology. While engineering scholars are the largest population within this community, those who have an interdisciplinary background play a more active role in bringing scholars from differing disciplines together. Scholars studying the same topic are working closely with each other, and this same pattern has been observed for scholars who remain within the same geographical state. The quantitative findings of this present study explicitly characterize the current status of scholarly collaboration in the EER community. Therefore, the study raises a community-wide awareness of how we collaborate in the past and at present. More importantly, the present study identifies the causes of problems and suggests possible remedies for improving scholarly collaboration.

There are other factors that may influence scholarly collaboration in the EER community. Differences in culture and language are recognized by other research communities as barriers in scholarly communication and collaboration. Given that the present study focuses on the EER community based on publications written in English,

publication venues in non-English-speaking countries could be analyzed to compare collaborative patterns across nations using the same methodology as developed in this present study. Age and diverse nature of EER may also affect analysis of scholarly collaboration. As a new and diverse community, EER may show characteristics that are not commonly seen in well-developed disciplines. Comparing EER with other new and interdisciplinary communities such as nanotechnology, cancer research, and human-computer interaction may help further understand the status of EER in terms of scholarly collaboration. However, due to the lack of similar bibliometrics studies performed in those research communities, the present study is not able to compare EER with them.

Also, by including publications written before 2000, one may draw a historic picture of how EER has emerged and evolved and further confirm the findings of this study. The present study examines the research community that work on learning-related topics. However, the same technique can be applied to analyze other problem spaces, and our future study will continue to explore these areas.

CHAPTER 3.    A REVIEW OF COMMUNICATION AND COLLABORATION
FEATURES IN SOCIAL RESEARCH NETWORK SITES

### 3.1    Introduction

Internet has facilitated human communication and collaboration and flattened the

world we live in (Freidman, 2005). In the Web 1.0 era, communication happened

primarily in unidirectional channels. The majority of users acted merely as content

consumers (Cormode & Krishnamurthy, 2008). Since the inception of Web 2.0, social

media sites have provided us with bidirectional communication channels and

collaboration platforms. Web 2.0 brings the vast majority of web users closer to each

other than before. A project studying the topological characteristics of Twitter has

revealed that we are now on average 4.8 hops from each other on Twitter (Kwak, et al.,

2010), which is shorter than the well-known six degrees of separation (Milgram, 1967).

As Internet contributes to flattening the world (Freidman, 2005), Web 2.0 facilitates

inter-person connections even further.

In academia, such an improvement of inter-person connections is also highly

appreciated. The present status of science shows a fragmented map with large

interdisciplinary gaps between clusters of specialties (Campbell, 1969). Researchers have

worked in isolation and showed a limited degree of communication and collaboration

with researchers in other domains. If Web 2.0 can bring researchers closer, as it has for

the general public, it seems to pave the way for a paradigm shift that can solve the fragmentation problem in science.

There are tremendous efforts that incorporate Web 2.0 into construction of a more dynamic and interactive research community. Myhill et al. (2009) attempted to highlight fundamental Web 2.0 features that might improve research environments. Peña-López (2007) described how individual scholars could adopt Web 2.0 to enhance diffusion of innovations. As scientists started to develop awareness of using Web 2.0 in research, industry has developed different types of services to target the researcher market. Social research network (SRN) sites such as ResearchGate[1] and Academia.edu[2] have emerged and already attracted a large population of scholars. According to the interview with ResearchGate's founder (Watters, 2011), ResearchGate had 500,000 registered users in 2010 and about 2,000 new users were joining every day. Online citation management services such as Zotero have offered scholars a platform for bookmarking and sharing references. Blogging services such as PloSBLOG aim to build a blog network to engage scientists in addressing and sharing diverse issues in science. All these efforts fall into the area of e-Research, which is defined as "the use of networked, distributed and shared digital tools and data for the production of knowledge" (Schroeder, 2008). With more emphasis on collaboration, e-Research is sometimes used interchangeably with e-Science (Hall, De Roure, & Shadbolt, 2009; Jirotka, Procter, Rodden, & Bowker, 2006). With the Web 2.0 label and more social emphasis, it is often called Research 2.0 or Science 2.0 (Codina, 2009). Science 2.0 refers to "new practices of scientists who post raw

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[1] ResearchGate: https://www.researchgate.net
[2] Academia.edu: http://www.academia.edu/

experimental results, nascent theories, claims of discovery and draft papers on the Web

for others to see and comment on." (Waldrop, 2008) Science 2.0 tools are technologies

that facilitate these online practices.

Although we acknowledge the potential of SRN sites in connecting scientists, the

rapid growth of SRN sites does not necessarily lead to more collaboration in science

(David, Besten, & Schroeder, 2006). We do not fully understand how these sites enable

scholars to communicate and collaborate. There are no formal studies that show what

exact features are provided by these sites and how these features enhance communication

and collaboration among scholars. Some features may intrinsically support tightly

coupled work (Neale, Carroll, & Rosson, 2004), whereas other features may focus on

knowledge sharing. For example, some sites allow users to set online schedules for the

research team, whereas some other sites only allow sharing of citation information.

### 3.2    Research questions

This paper reviews popular SRN sites with a particular focus on what

communication and collaboration features are available and how they support different

level of work coupling. This study will answer the following research questions:

(1) What are the main communication and collaboration features provided by

prominent SRN sites?

(2) What is the level of work coupling each feature supports?

(3) What are some good/bad practices in supporting different work coupling levels?

To answer these questions, the present study first selects 12 SRN sites by sampling

from more than 100 Web 2.0 tools used for research purposes. The sampling criteria will

be discussed in Section 3.4.1. Neale's collaboration model (2004) is used to guide the

recognition of features relevant to communication and collaboration on each site (RQ1).

These features are categorized according to the level of work coupling (Neale, et al.,

2004) they support (RQ2). Next, the design issues of some popular communication and

collaboration features (RQ3) and the current status of SRN are further discussed. The five

work-coupling levels in communication and collaboration are defined as (Neale, et al.,

2004):

(1) *Lightweight interactions*, where contextual information such as personal life and

work situations are shared without concerns of specific work;

(2) *Information sharing*, which establishes the fundamental background related to the

work. This can happen in a unidirectional or a bidirectional manner;

(3) *Coordination*, which refers to members scheduling their work according to the

team status;

(4) *Collaboration*, where users work together within a shared workspace and

individual outcomes can be integrated; and

(5) *Cooperation*, where users share goals, plans, and tasks and usually work

synchronously towards a goal.

### 3.3    Theoretical framework and related work

#### 3.3.1    Computer-supported collaborative work (CSCW)

Pioneering attempts in Computer-Supported Collaborative Work (CSCW) has

highlighted the importance of reconciling computer-based technologies with the nature

and requirements of cooperative work (Schmidt & Bannon, 1992). This argument echoes

Bannon et al. (1989)'s belief that CSCW should not be viewed as the techniques per se.

But it must factor in the support requirements of cooperative work. Overlooking what

cooperative work requires can lead to a complete failure of any CSCW system. For example, Grudin (1988) explained how CSCW systems failed because they did not consider the reward disparity for different user groups or because they failed to recognize the diverse needs from users with different background. The present study holds the same belief that the existence of Web 2.0 technologies does not guarantee effectiveness in supporting communication and collaboration among scholars.

The tight coupling of CS and CW suggests that any information technology has its applicable scope to best serve a certain type of cooperative work. Some technologies are more appropriate to be used for face-to-face interaction, asynchronous interaction, synchronous distributed interaction, or asynchronous distributed interaction - the four scenarios of cooperative work known as the time-space matrix (Ellis, Gibbs, & Rein, 1991). These four types of cooperative work ask for significantly different groupware systems to support. Another model, called the 3C model (Borghoff & Schlichter, 2000), describes how different types of groupware systems should be selected for supporting various degrees of communication, coordination, and cooperation. Neale et al. (2004) built upon the time-space matrix and the 3C model to propose a five-level collaboration model: lightweight interaction, information sharing, coordination, collaboration, and cooperation. The social networking nature of SRN sites implies that users primarily participate in asynchronous and distributed interactions. Therefore, analyzing features based on the time-space matrix does not provide much insight. The 3C model was proposed to classify groupware, which implies closer and more frequent interactions between users. Again, the social networking aspect of SRN makes the 3C model inapplicable. Neale et al.'s model covers a broader range of work-coupling levels: from

the most lightweight interactions to the tightly-coupled cooperation and is appropriate for analyzing SRN sites. Therefore, the present study uses Neale et al.'s (2004) model to classify features provided by SRN sites into five work-coupling levels. This classification turns the question of whether into how a feature supports communication and collaboration.

### 3.3.2    Existing reviews of Science 2.0

A line of research focuses on defining Science 2.0 and examining the adoption and use of its services. Codina (2009) referred to Science 2.0 as the marriage of Web 2.0 and science and presented the major characteristics of ResearchGate as well as other similar sites. A more formal definition of Science 2.0 has been given by Waldrop (2008) as "new practices of scientists who post raw experimental results, nascent theories, claims of discovery and draft papers on the Web for others to see and comment on." Regarding adoption of Science 2.0 tools, a Nature report by Gewin (2010) introduced ResearchGate, Mendeley, and VIVO and concluded that no single existing site can meet all of scientists' needs. MacDonald et al. (2008) discussed social networking and data sharing services in research and the corresponding Web 2.0 applications. Again, MacDonald et al. (2008) believed that encouragement to embrace this new paradigm would be needed for better knowledge transfer. Nentwich (2010) summarized researchers' typical use of Web 2.0 services for scholarly communication: social networks, wikis, (micro-)blogs, and tagging platforms. Priem et al. (2010) developed a partial list of popular Web 2.0 sites for scholars and suggested the use of network metrics based on these tools for measuring scholarship. A recent report has collected and introduced 99 Web 2.0 sites used for sharing science and categorized them into sharing research, sharing resources, and

sharing results (Rebiun, 2011). These studies investigate the adoption and use of Web 2.0

tools in science in general without comparing services or products in achieving a

particular goal.

Rather than briefly introducing a list of tools, some researchers review and compare

prominent Science 2.0 tools in greater depth. Procter et al. (2010) studied disciplinary and

gender differences in researchers' adoption of generic publication resources such as

Google Scholar as opposed to more specific resources such as PubMed. Instead of

investigating users' discipline and gender, Jung et al. (2011) analyzed the visual design

on four Science 2.0 sites and proposed evaluation criteria for network visualization and

graphic charts. Kubalik et al. (2011) compared various aspects across four social

networking portals for science and extracted common features that were to guide the

development of their own portal. Studies by Jung et al. (2011) and Kubalik et al. (2011)

shared a common goal with the present study in terms of comparing and evaluating

features of Science 2.0 sites and creating guidelines for future development. The above

studies have demonstrated the need to analyze and compare certain aspects across

Science 2.0 services in detail. These studies also show great potential of using the

research findings to evaluate and guide the development of Science 2.0 sites. However,

none of them focuses specifically on SRN or communication and collaboration features.

Comparative studies of SRN sites have recently gained great attention. Moeslein et

al. (2009) reviewed 24 SRN sites and compared characteristics such as identity and

network, interaction and communication, information and content, topical focus, and

degree of openness. Built upon Moeslein et al.'s (2009) findings, Bullinger et al. (2010)

interviewed the founders of SRN sites regarding their opinions about the 24 case studies.

Based on the interview data, Bullinger et al. (2010) proposed a taxonomy of SRN sites and summarized four fundamental characteristics of SRN sites: identity management, network management, information sharing, and scholarly collaboration. However, the present study has a specific focus on communication and collaboration rather than the general assessment of the whole website.

Among all the above studies, the REBIUN report (Rebiun, 2011) and Moeslein et al.'s (2009) review have provided a list of Science 2.0 sites that not only encompass all sites mentioned in the other studies but also cover many others that have never been analyzed in academia. Therefore, the scope of the present study is based on over 100 sites reviewed by these two articles (Moeslein, et al., 2009; Rebiun, 2011).

### 3.3.3 Design principles and usability issues

The success of a CSCW system depends not only on how a feature conceptually satisfies the requirement of cooperative work, but also on whether it is implemented in an intuitive manner to follow users' mental models, which can be evaluated by design principles and usability evaluation.

There are two ways to evaluate website usability: heuristic evaluation and usability testing. Heuristic evaluation refers to the process of relying on design experts to judge whether a UI element conforms to established design principles (Nielsen, 1994). Usability testing is a systematic way of observing actual users trying out a product and collecting information to measure the level of difficulty users encounter during interacting with the product (Dumas & Redish, 1999).

Both methods rely on a set of design principles. Cooper (2007) introduced a comprehensive list of practical design principles for general software interface design.

Nielsen (1999) proposed his design principles for designing usable web pages that continues to be widely used for guiding and evaluating Web 2.0 design (Sellitto, Burgess, Cox, & Buultjens, 2009). Bernard (2002) developed criteria to evaluate positions, text presentation, and arrangement of the UI elements on a web page. MIT (2011) offered an evaluation form as usability guidelines for assessing websites.

As Web 2.0 sites, SRN applications should be evaluated using heuristics for generic web page interfaces and design principles that are specific in Web 2.0 applications. In developing Web 2.0 sites, while most of the above design principles for Web 1.0 remain applicable, the increased functionality brought by Web 2.0 (O'Reilly, 2007) has posed additional design complexity and usability issues to implementation (Sellitto, et al., 2009). Lin (2007) highlighted three factors that designers must consider in implementing Web 2.0 sites: simplicity, scalability, and interactivity especially when designing user feedback, recommendation systems, search engines, and mashups.

### 3.4    Evaluation of existing SRN sites

This section describes how SRN sites are selected for review and how to classify communication and collaboration features based on Neale's (2004) model. Twelve SRN sites are selected using a criterion sampling method. The five levels of work coupling in Neale's model (2004) are also introduced briefly.

### 3.4.1    Selecting SRN sites

The present study aims to analyze and compare across all popular SRN sites. The candidate list comes from the REBIUN report (2011) and Moeslein et al.'s (2009) review. These two articles have provided a list of Science 2.0 sites that not only encompass all sites mentioned in the other studies but also cover many sites that have not been analyzed

in academia. Therefore, the scope of the proposed study is based on over 100 sites reviewed by these two articles. Among these sites, however, some are generic Web 2.0 sites such as SlideShare and Del.icio.us but are not intended for scholars like SRN sites. Some SRNs are no longer available or may not be English-friendly. Out of over 100 candidates from these two articles, purposeful sampling, more exactly criterion sampling (Patton, 2001) is used to further restrict the scope. A site selected must meet all of the following criteria:

On 04/10/2013,

(1) The site must be publicly accessible;

(2) The site must be intended for scholarly communication and collaboration and therefore this study excludes sites intended for the general public such as Facebook and Twitter, even when they can be potentially used as communication platforms for scholars;

(3) The site must provide free and open registration;

(4) The site must offer a mechanism to allow one user to connect to another. This is to ensure the possibility of social networking between users;

(5) The site must have at least 10,000 registered users;

(6) The site must offer the majority of features on the web pages rather than relying on standalone software or widgets; and

(7) The site must support English language.

Based on these criteria, 12 SRN sites are selected: Nature Network, Academia.edu, Mendeley, ResearchGate, Epernicus, MyNetResearch, ScienceStage, CiteULike,

Biomedexperts, Researcher ID, nanoHUB, and SciVee. A list of excluded sites and the reasons for exclusion can be found in Appendix A.

### 3.4.2  Identifying and categorizing communication and collaboration features

An SRN site may contain (1) features that are irrelevant to communication and collaboration such as news and (2) features that allow users to identify, communicate, and collaborate with collaborators such as discussion boards and academic publication sharing. This study only focuses on the second category. The author attempted to exhaust communication and collaboration features in all SRN sites that are reviewed. It took the author on average 64.3 minutes to explore each selected site. For the first time, the author ran through all these sites to compile all communication and collaboration features into a list. In the second run, every feature in the list was labeled as either available or unavailable for each site. The author ran through all selected sites for another iteration to ensure the correctness of his labels.

All features related to communication and collaboration are then categorized into different work-coupling levels. Higher work-coupling levels, according to Neale et al.'s model (2004), mean greater demand for coordinated behaviors and communication. For example, co-writing a paper requires more frequent communication and better coordination between two scholars than sharing academic articles. A communication and collaboration feature can be associated with more than one work-coupling level. A one-to-one mapping between features and work coupling levels is not enforced because a feature may be capable of supporting multiple contexts.

3.5    Results

3.5.1    Communication and collaboration features recognized in the selected sites

This section describes communication and collaboration features recognized in the selected sites. A feature is selected even when it is available on only one site. For each feature, there are descriptions of what the feature is about and what users can accomplish with this feature. Based on how the feature facilitates users' communicative and collaborative activities, the feature is categorized into one or more work coupling levels in Neale et al. (2004)'s model. Also, a summary of the feature's availability across all selected SRN sites is presented.

(1) **Live feeds and comments (LC)**: This category of features allows users to post updates, questions, and answers usually in the form of text visible to all registered users. It functions almost the same as Facebook feeds with the purpose of informing other users of one's updates or inviting others to join a conversation. In particular, there are two features in this category: writing live feeds and commenting on others' live feeds. Live feed is recognized as associated with communication and collaboration because users can share their personal lives, status updates, and work progress with others. Both writing and commenting fall into the lightweight interactions level, as indicated in Table 3.1.

Table 3.1 The corresponding work coupling level of each LC feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** **Info. Sharing** **Coordination** **Collaboration** **Cooperation** | Writing live feeds; commenting on live feeds |

Table 3.2 Availability of the live feeds feature across all selected SRN sites.

| Sites | Write live feeds | Comment on live feeds |
|---|---|---|
| Nature Network | √ | √ |
| Academia.edu | √ | |
| Mendeley | | |
| ResearchGate | √ | √ |
| Epernicus | √ | √ |
| MyNetResearch | | |
| ScienceStage | | |
| CiteULike | √ | |
| Biomedexperts | | |
| Researcher ID | | |
| nanoHUB | √ | √ |
| SciVee | | |

(2) **Blog (BG)**: It refers to the blogging function provided for each user. Users can publish articles and share them with other users. Like other blogging services such as Blogger and Wordpress, blogging in SRN sites usually offers a full-fledged editor and allows embedding hyperlinks and even multimedia content within blog posts. This category includes two features: writing blog posts and commenting on blog posts. Blog posts are in general more informative and work-related than live feeds. Therefore, writing and commenting on blog posts promotes information sharing, as described in Table 3.3.

Table 3.3 The corresponding work coupling level of each BG feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** | |
| **Info. Sharing** | Writing and commenting on blog posts |
| **Coordination** | |
| **Collaboration** | |
| **Cooperation** | |

Table 3.4 Availability of the blog feature across all selected SRN sites.

| Sites | Write blog posts | Comment on blog posts |
| --- | --- | --- |
| Nature Network | √ | √ |
| Academia.edu | | |
| Mendeley | | |
| ResearchGate | | |
| Epernicus | | |
| MyNetResearch | √ | √ |
| ScienceStage | | |
| CiteULike | √ | √ |
| Biomedexperts | | |
| Researcher ID | | |
| nanoHUB | √ | √ |
| SciVee | | |

(3) **Direct messaging (DM)**: This refers to the capability of sending private messages
between users. Note that this feature is not implemented as instant messaging like
Skype. Instead, it resembles email services where users manage contacts and
messages. Unlike live feeds, direct messages are only visible to senders and
receivers. Features included in this category are sending messages, reading
messages, and replying to messages. Direct messaging can be potentially used for
casual chatting and information sharing. When it is used by users in the same
team, it can also promote coordination and collaboration. Understanding how
users prefer to use it in different contexts is beyond the scope of this study. As a
result, direct messaging is considered as applicable in these four levels.

Table 3.5 The corresponding work coupling level of each DM feature.

| Work coupling level | Features |
|---|---|
| LW interactions | Sending, reading, and replying messages |
| Info. Sharing | Sending, reading, and replying messages |
| Coordination | Sending, reading, and replying messages |
| Collaboration | Sending, reading, and replying messages |
| Cooperation | |

Table 3.6 Availability of the direct messaging feature across all selected SRN sites

| Sites | Direct messaging |
|---|---|
| Nature Network | √ |
| Academia.edu | √ |
| Mendeley | √ |
| ResearchGate | √ |
| Epernicus | √ |
| MyNetResearch | √ |
| ScienceStage | √ |
| CiteULike | |
| Biomedexperts | √ |
| Researcher ID | |
| nanoHUB | √ |
| SciVee | √ |

(4) **Artifact annotation (AA)**: The artifact annotation functions encourage user to

annotate an article, video clip, or any other artifact contributed by other users.

Such annotations include tags, comments, and ratings. In some cases, users'

collective efforts produce a valuable supplement to the original artifact. This

category involves the following features: tagging, bookmarking, rating, and

commenting on academic publications and multimedia resources. All these

features support information sharing that revolves around artifacts.

Table 3.7 The corresponding work coupling level of each AA feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** **Info. Sharing** | Tagging, bookmarking, rating, and commenting on academic publications and multimedia resources |
| **Coordination** **Collaboration** **Cooperation** | |

Table 3.8 Availability of the artifact annotation feature across all selected SRN sites.

| Sites | Publication | | | | Multimedia (mm.) resources | | | |
|---|---|---|---|---|---|---|---|---|
| | tag | bookmark | comment | rate | tag | bookmark | comment | rate |
| Nature Network | | | | | | | | |
| Academia.edu | √ | | | | | | | |
| Mendeley | √ | √ | | | | | | |
| ResearchGate | | √ | | | | | | |
| Epernicus | | | | | | | | |
| MyNetResearch | | | | | | | | |
| ScienceStage | | √ | √ | | | √ | √ | |
| CiteULike | | | | | | | | |
| Biomedexperts | | √ | | | | | | |
| Researcher ID | | | | | | | | |
| nanoHUB | √ | √ | √ | √ | √ | √ | √ | √ |
| SciVee | √ | √ | √ | √ | √ | √ | √ | √ |

(5) **Resource sharing (RS)**: Resources are defined as user-generated content that are formally documented. Resources shared are intended to reach a broader scope of audience than within a team. This includes sharing of publications, awards, citation libraries, research data, research tools, and multimedia resources. Research tools are user-contributed artifacts that can serve as parts of a larger scientific workflow and hence are classified as supporting collaboration. Sharing research data helps scholars identify potential research areas and integrate individual research findings to address grand challenges (Clubb, Austin, Geda, &

Traugott, 1985). Therefore, it contributes to coordination and collaboration levels

in the model, as shown in Table 3.9.

Table 3.9 The corresponding work coupling level of each RS feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** | |
| **Info. Sharing** | Sharing publications, awards, citation libraries, and multimedia resources |
| **Coordination** | Sharing research data |
| **Collaboration** | Sharing research tools; sharing research data |
| **Cooperation** | |

Table 3.10 Availability of the resource sharing feature across all selected SRN sites.

| Sites | Publications | Awards | Citation libraries | Research data | Research tools | Mm. resources |
|---|---|---|---|---|---|---|
| Nature Network | | | | | | |
| Academia.edu | √ | | | | | |
| Mendeley | √ | √ | √ | | | |
| ResearchGate | √ | | | | | |
| Epernicus | √ | | | | | |
| MyNetResearch | √ | √ | | √ | | √ |
| ScienceStage | √ | √ | | | | √ |
| CiteULike | √ | | √ | | | |
| Biomedexperts | √ | | | | | |
| Researcher ID | √ | | | | | |
| nanoHUB | √ | | | | √ | √ |
| SciVee | √ | | | | | √ |

(6) **Team activities (TA)**: This category includes activities performed within a team

of users. Instead of naming it *team*, some sites call it *group* or *projects*.

Sometimes teams are not created by users but instead, they represent communities

that share the same research interest. For example, some SRN sites define a

taxonomy for all research topics and these topics become groups. Users who are

interested in certain topics are welcome to join the corresponding groups.

Regardless of what a team is called, this category of features aims to create a local shared space for only a limited number of users. It may include features such as discussion boards, activity scheduling, project artifact sharing, poll, workflow management, wikis, and programming environments. Their corresponding levels can be seen in Table 3.11.

Table 3.11 The corresponding work coupling level of each TA feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** | |
| **Info. Sharing** | Discussion board, project artifact sharing, wiki |
| **Coordination** | Activity scheduling, poll |
| **Collaboration** | Project artifact sharing, workflow management, programming environment |
| **Cooperation** | |

Table 3.12 Availability of the team activities feature across all selected SRN sites.

| Sites | Discussion board | Artifact sharing | Activity scheduling | Poll | Workflow | Wiki | Prog. env. |
|---|---|---|---|---|---|---|---|
| Nature Network | √ | | | | √ | | |
| Academia.edu | | | | | | | |
| Mendeley | | | | | | | |
| ResearchGate | √ | √ | | √ | | | |
| Epernicus | √ | √ | | | | | |
| MyNetResearch | | √ | √ | | | | |
| ScienceStage | √ | √ | | | | | |
| CiteULike | √ | | | | | | |
| Biomedexperts | | | | | | | |
| Researcher ID | | | | | | | |
| nanoHUB | √ | √ | √ | | | √ | √ |
| SciVee | | | | | | | |

(7) **Off-site extensions (OE)**: This category presents users an option to share or bookmark an article, comment, link, or other artifacts via external social

networking or bookmarking sites such as Twitter, Facebook, and del.icio.us.

Features in this category may also inform users of offline activities such as

workshop, conferences, and job/funding opportunities. Therefore, it includes two

features: sharing via SNS and offline events. The former extends information

sharing to reach other user groups while the latter may also influence users'

schedules, as presented in Table 3.13.

Table 3.13 The corresponding work coupling level of each RS feature.

| Work coupling level | Features |
|---|---|
| **LW interactions** | |
| **Info. Sharing** | Sharing via SNS, offline events |
| **Coordination** | Offline events |
| **Collaboration** | |
| **Cooperation** | |

Table 3.14 Availability of the off-site extensions feature across all selected SRN sites.

| Sites | Sharing via SNS | Offline events |
|---|---|---|
| Nature Network | | √ |
| Academia.edu | √ | |
| Mendeley | √ | |
| ResearchGate | | √ |
| Epernicus | √ | |
| MyNetResearch | | |
| ScienceStage | √ | |
| CiteULike | √ | |
| Biomedexperts | √ | √ |
| Researcher ID | | |
| nanoHUB | √ | √ |
| SciVee | | √ |

### 3.5.2  A summary of communication and collaboration features

**The most popular features across the seleted sites**
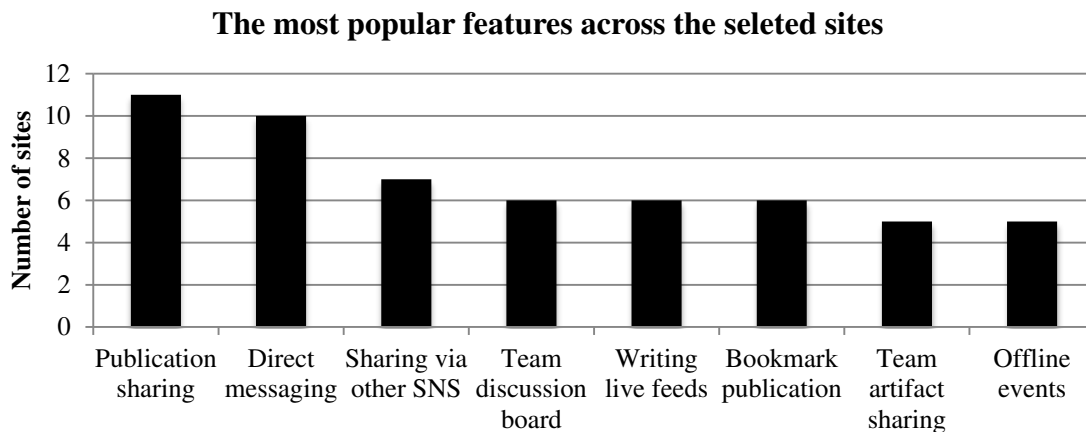


Figure 3.1 A summary of the most popular features across the selected sites.

**Collaboration levels and the total number of features over all the selected sites**
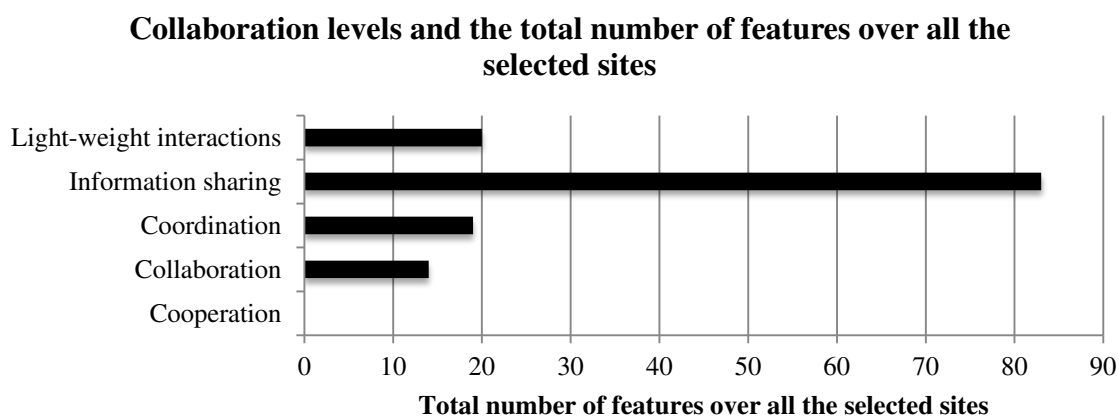


Figure 3.2 The total number of communication and collaboration features over all the

selected sites for each collaboration level.

Publication sharing, direct messaging, sharing via other SNS, team discussion

board, writing live feeds, team artifact sharing, and grant opportunity sharing are the most

popular features among all the selected sites, as summarized in Figure 3.1. In general,

existing SRN sites focus little on providing high-level collaboration support. No site that

was studied as a part of this project provided any feature to enable synchronous

communication. As illustrated in Figure 3.2, the majority of communication and collaboration features support information sharing, coordination, and lightweight interactions.

### 3.5.3　Comparison of UI design

According to the results in section 3.5.2, the majority of SRN sites provide a diversity of services to support low-level communication and collaboration but only limited support for high-level communication and collaboration. This section shows the analysis and comparison of the design of prominent features across the reviewed sites at each collaboration level. Such a comparison provides design implications for implementing specific features so as to guide future development of SRN sites. Because no reviewed site has offered any feature at the cooperation level, the following discussion will elaborate only the other four levels: lightweight interaction, information sharing, coordination, and collaboration.

　　(1) Lightweight interaction

The most prominent feature at the lightweight interaction level is live feeds. In designing live feeds, one common issue is the lack of content categorization. For example, Academia.edu mixes status updates, Q&A, and users' activities together, which poses an additional cognitive load to users, as illustrated in Figure 3.3(a). According to Cooper's (2007) principles of visual interface design, similar elements should be grouped to form a clear hierarchy. In contrast to the mixed view, Epernicus categorizes live feeds into BenchQs, links, profiles, status, and groups, and users can choose to view all updates, as shown in Figure 3.3(b).

<center>(a)                                        (b)</center>
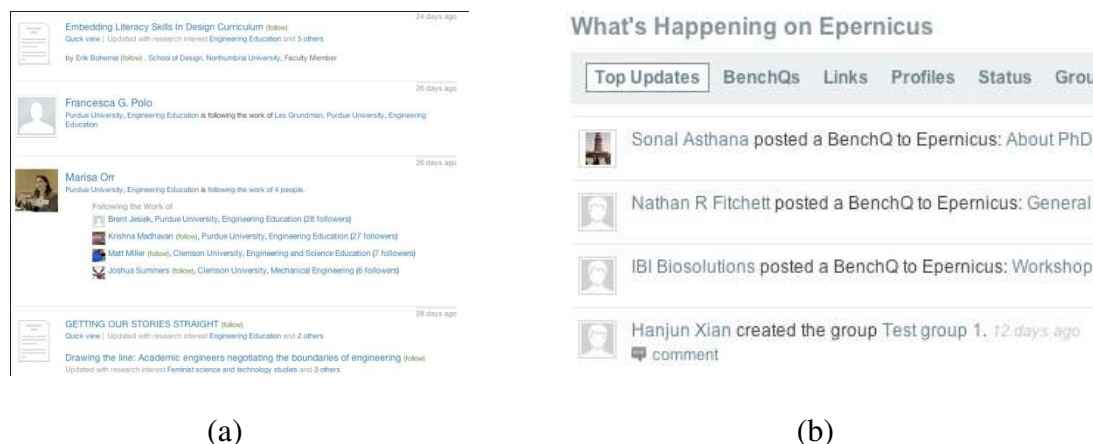
Figure 3.3 The live feeds design on (a) ResearchGate and (b) Epernicus.

Another popular feature at this level is direct messaging. All the reviewed sites follow the notion of mailbox and place a link in a fixed position next to the 'account' at the top right corner on every page, which is consistent with users' perceived position of the account management link (Bernard, 2002). In SciVee, the 'inbox' link remains the same even when new messages come (Figure 3.4(a)) and therefore users will not be notified of new messages unless they click the inbox to get to the message management page. nanoHUB displays the count of new messages to constantly monitor the status of the message box (Figure 3.4(b)). Better still, ResearchGate offers previews of new and past messages to eliminate unnecessary excise of switching to the mailbox (Cooper, et al., 2007), as shown in Figure 3.4(c).



<center>(a)                              (b)                              (c)</center>
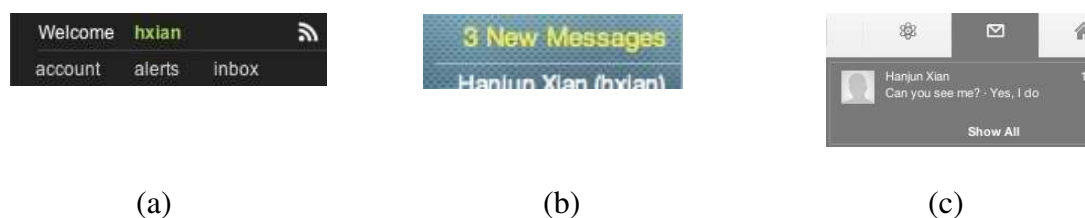
Figure 3.4 The design of direct messaging in (a) SciVee, (b) nanoHUB, and (c)

<center>ResearchGate.</center>

(2) Information sharing

The most prominent features at this collaboration level are publication sharing. Almost every reviewed site allows users to list and/or upload publications that later become visible to other users. Most reviewed sites make such user-uploaded publications available for all registered users by default. However, in many sites, publications often remain in contributors' own profiles and do not circulate around the online community. To create more values from user-contributed publications, some reviewed sites allow user annotations that not only supplement the original articles but also make them more searchable. For example, any article on nanoHUB can be tagged by its contributor and reviewed, bookmarked, and rated by other users, as illustrated in Figure 3.5(a). The search capability has always been essential for users to seek for information (Nielsen, 1999) and for Web 2.0 sites, the search scope should be extended to cover user-generated content. Besides annotation, SciVee integrates full texts with relevant slides, videos, audios, and demos to represent publications, as demonstrated in Figure 3.5(b).



(a)                                    (b)
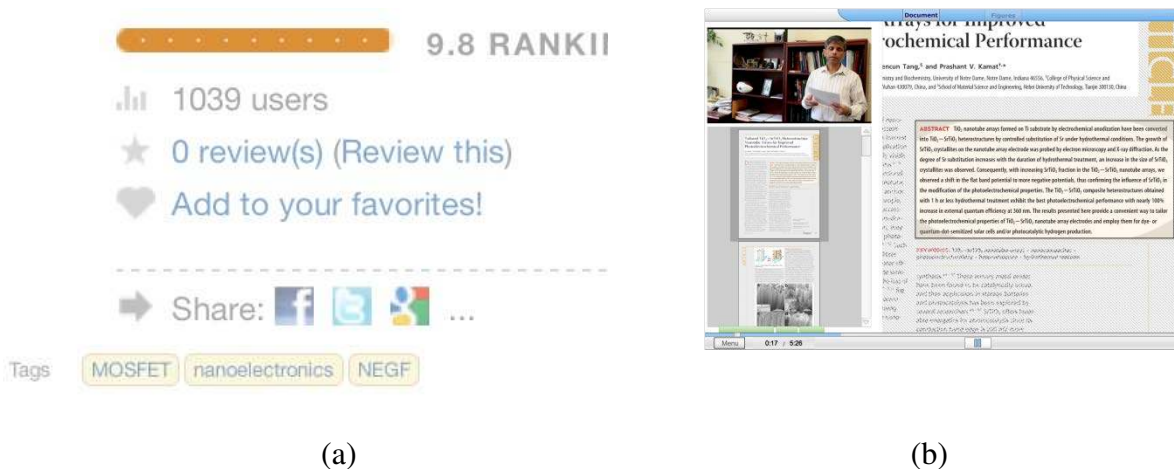
Figure 3.5 Publication sharing on (a) nanoHUB and (b) SciVee.

(3) Coordination

Coordination among users is achieved often via project management features for a team. For example, in MyNetResearch, users can schedule tasks within a group by describing the task, assigning it to a group member, and setting the start/end time. As a task progresses, the task status can be updated to open, delayed, or completed, as illustrated in Figure 3.6(a). Representing tasks as a list does not follow users' mental model and nanoHUB approaches this feature with a different design. It has a built-in calendar for each group and a scheduled activity is displayed on the calendar, as illustrated in Figure 3.6(b).
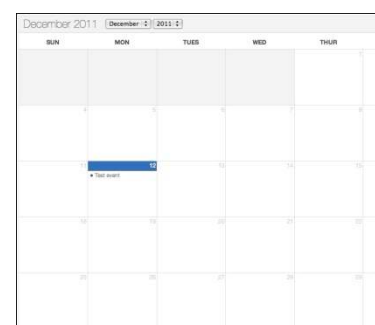


(a)                                        (b)

Figure 3.6 Activity scheduling on (a) MyNetResearch and (b) nanoHUB.

(4) Collaboration

Sites that contain collaboration features only offer basic functions such as file sharing without more advanced infrastructure to allow integration of individual work. For example, ScienceStage creates a local space for hosting videos and documents for each group. However, the shared resources are organized in a plain list. These shared resources can be downloaded and revised on users' local computers but cannot be manipulated online, as presented in Figure 3.7(a). nanoHUB offers an online development

environment where multiple users can share the same workspace to manipulate team artifacts together, as shown in Figure 3.7(b). However, a user must know the exact user name of another peer in order to share a session. This feature can be improved to give a user a visual hint so that a user does not have to remember another user's account name.



(a)                                                                                            (b)
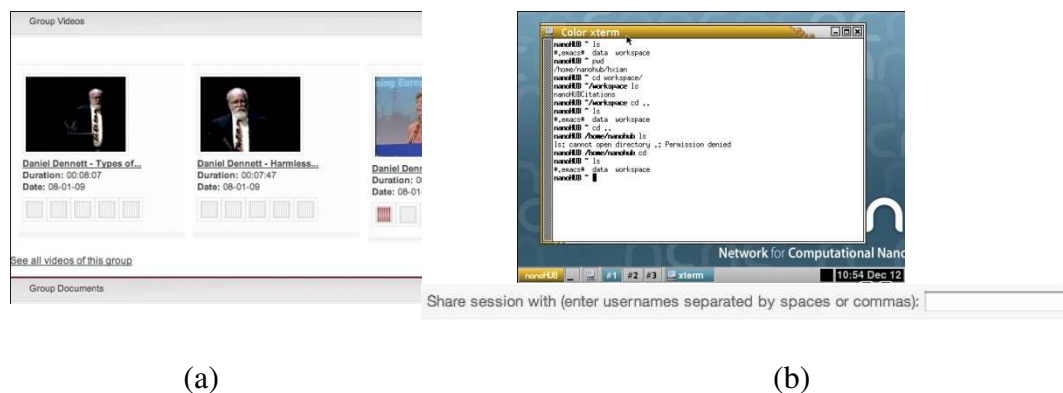
Figure 3.7 Sharing and manipulating team artifacts on (a) ScienceStage and (b) nanoHUB.

## 3.6    Implications

The increasing popularity of SRN sites demonstrates scholars' demand of sharing knowledge and connecting with each other. Current SRN sites tend to support communication and collaboration between scholars in many different aspects, most of which belong to the categories of information sharing, lightweight interaction, and coordination. This tendency echoes users' preferred activities on general social networking sites. A prior study (Parker, 2009) recognized the most frequent activities on social networking sites. These activities were messaging friends, uploading photos, finding old/new friends, and joining a group. In other words, SRN's emphasis on facilitating network management and information sharing meets users' perception of

what a social networking site is supposed to function. Some sites attempt to achieve high-level communication and collaboration but so far these features have not been widely adopted. Therefore, future evaluation of SRN sites should focus on how well they support network management, information sharing, and other low-level communication and collaboration features.

In supporting low-level communication and collaboration, SRN sites share many similar features such as publication sharing and direct messaging. These features constitute the fundamental infrastructure of an SRN site and should be prioritized in the development of a SRN site. However, implementations of these features vary significantly from site to site and design principles and usability test can guide the detailed design of each feature.

Last but not least, the user-contributed content has not been fully exploited and users' contributions are not rewarded properly. For example, many sites allow users to upload their own publications and keep them in the user profiles. However, the publications uploaded cannot be easily searched or read by other users. The only way to get to them is by visiting each user's individual publication list. If shared content continues to stay in contributors' own repository, users may lose motivations because they do not feel they help others, learn from others, and gain reputations (Ardichvili, Page, & Wentling, 2003; Nov, Naaman, & Ye, 2010; Oreg & Nov, 2008). Future SRN sites should balance between asking researchers to contribute and helping researchers achieve their goals.

## 3.7 Conclusion

This paper explores the communication and collaboration features in 12 prominent SRN sites and analyzes similar features across sites. Neale et al.'s (2004) 5-level

collaboration model is used to categorize communication and collaboration features. In all the reviewed sites, publication sharing and direct messaging are the most popular features. On contrary, features in collaboration and cooperation levels are rarely provided by existing SRN sites. The present study compares the implementations of popular features and proposes effective and optimal ways of designing each feature. Findings in this study can be used to evaluate existing SRN sites and guide the future development of SRN sites.

Based on the research findings, future studies can further explore the actual use of communication and collaboration features by examining how and in what context users adopt them. Also, the availability and categorization of features can be extended to create a model for classifying SRN sites by the level of work coupling they support. Finally, a future study may measure certain SRN sites' impact on converging the research community.

CHAPTER 4.    UNDERSTANDING ENGINEERING EDUCATION SCHOLARS'
RESEARCH COLLABORATION AND THEIR TECHNOLOGY USAGE: A
GROUNDED THEORY STUDY

## 4.1    Introduction

Prior studies have recognized a need for more collaboration in engineering

education. For instance, Wankat (2011) showed that engineering educators from different

disciplines seldom communicated and collaborated with each other. CHAPTER 2

analyzed scholarly collaboration in the entire engineering education research (EER)

community and revealed that engineering education scholars had fewer collaborators than

material engineering, biomedical research, physics, zoology, electrical engineering, life

sciences, civil engineering, industrial engineering, and Ph.D. scientists. There are many

more disciplines to consider and therefore engineering education may not be among the

least collaborative research communities. However, from a more theoretical and

mathematical perspective, again the EER community has far fewer collaborations than

the ideal small-world network model (Watts & Strogatz, 1998). The need to increase

collaboration becomes more critical to the EER community particularly considering that

the nature of EER work is often interdisciplinary.

Insufficient scholarly collaboration has many undesirable consequences. Research

findings are rarely represented using educator-friendly language and therefore have a

very limited influence on guiding educational practices and policy making

(Borrego, et al., 2010; Fincher, 2009). Likewise, educators' experiences are rarely documented and published as academic articles to validate pedagogical theories or help generate new research questions (Adams & Felder, 2008; Hutchens, 1998; Streveler & Smith, 2006). Scholars may duplicate research efforts in solving what has already been examined by other scholars in a different region (Jesiek, et al., 2008). Single-authored papers have a lower possibility of getting accepted and often get a smaller number of citations, which implies a lower research quality than collaborative ones (Smart & Bayer, 1986).

Given the need for more collaboration in the EER community, little is known about why engineering education scholars do not collaborate as frequently and widely as those in many other disciplines (Barrat, et al., 2004; Newman, 2001). Williams et al. (2012) revealed that time commitment, the interdisciplinary nature, and financial support were major issues that new engineering education scholars encountered early in their careers. However, it remains unclear whether these difficulties also inhibit scholars' development of collaboration and whether they affect senior scholars. Therefore, the first objective of the present study is to investigate engineering education scholars' collaborative behavior related to collaboration. On the one hand, recent social networking technologies such as ResearchGate claimed to be adopted by a large number of scholars (Watters, 2011). On the other hand, a recent study (Borrego, et al., 2010) showed that engineering education scholars still rely heavily on face-to-face interaction in communicating ideas. It remains unclear whether engineering education scholars frequently use social networking technologies for scholarly communication. Therefore, the present study aims to identify mainstream technologies used for scholarly communication and collaboration by

engineering education scholars. Success of this project helps guide development of technology to increase collaboration in EER.

<center>4.2   <u>Theoretical framework and related work</u></center>

The present study aims to investigate engineering education scholars' collaboration process and their technology usage. This implies two main foci: behavior related to research collaboration and behavior related to technology usage. Therefore, this section first reviews existing research efforts in studying scholars' behavior related to research collaboration. Then it presents multiple theories of technology acceptance, which include adoption theories. Finally it discusses computer-based technology adoption by faculty for teaching and research purposes.

<center>4.2.1   Scholarly collaboration</center>

Prior studies have described major tasks in collaboration and different types of collaborative relationships. Austin et al. (1991) defined four stages of an effective collaboration: choosing members, dividing the labor, establishing work guidelines, and ending collaboration. Hart (2000) recognized different research tasks that commonly involve collaborative work in psychology research: having the original idea, reviewing the literature, designing the study, collecting data, analyzing data, writing the paper, and revising the paper. Hart ranked these tasks by their perceived importance by collaborative scholars. Hart's findings (2000) showed that scholars considered writing papers and collecting data more important than having the original idea and designing the study. Besides major collaborative tasks, researchers also recognize different types of relationships between collaborators. Hagstrom (1975) proposed three types of collaborative arrangements: complementary (work closely on the same problem at the

same time), supplementary (contribute to different aspects of a project based on different knowledge specialization), and master-apprentice (between experienced researchers and novices). Similarly, Dickens et al. (1997) summarized four types of collaborative relationships: pedagogical (a more experienced individual with a less experienced one), instrumental (based on practical reasons), professional (shared agendas), and intimate (intellectual and emotional closeness).

Another strand of research focuses on challenges and barriers to scholarly collaboration. Austin et al. (1991) found that collaborative efforts often involve issues related to fairness among team members, the loss of professional identity, and integrity-related issues. Bohen et al. (1998) recognize emphasis on individualism by traditional western education, reward structure, and administrative structure as three major barriers to scholarly collaboration. Creamer (2004) studied closely how differences in opinion influence collaboration and how long-term collaborators interpret and resolve disagreements. Kochan et al. (2003) also found that miscommunication, different working styles, and credit being unfairly claimed are major disadvantages of collaboration perceived by women faculty. Hoekman et al. (2010) analyzed publication data in European countries and found that scholars still tend to collaborate with co-located colleagues and that physical distance remains a barrier in scholarly collaboration. The present study shares a common goal with the above studies – to recognize barriers to scholarly collaboration in the engineering education research community. Findings from the present study will be compared with results from the above studies to identify commonalities and differences in challenges in scholarly collaboration.

Besides recognizing barriers, some researchers attempted to understand what strategies scholars used in collaborations. Austin et al. (1991) emphasized the role of administrators in allocating resources, policy support, rewarding team members, and removing inhibiting factors. Bohen et al. (1998) further identified factors that lead to successful faculty collaboration: a clear research vision, leadership, institutional commitment, financial resources, and rewards.

Instead of focusing on behavior in scholarly collaboration, some researchers studied motivations and benefits of scholarly collaboration. Bohen et al. (1998) believed that hunger for learning new knowledge, collecting feedback about new ideas, and broadening impact were main motivations for scholarly collaboration. Hart (2000) identified scholars' perceived benefits of scholarly collaboration. The two main benefits were improved quality of research work and diverse expertise. Creamer (2003) investigated case studies of collaborative pairs in research. Creamer (2003) found that collaborative research projects usually aimed to solve complex problem and were politically motivated. Kochan et al. (2003) also recognized mutual learning, emotional support, feeling valued, and the exchange of ideas as benefits for scholarly collaboration among women scholars. The present study targets a different research discipline than the above studies and focuses on engineering education scholars' behaviors related to collaboration. Results from the present study will be compared with the above findings in the implication section.

The above studies discussed different aspects of scholarly collaboration in various disciplines. However, no similar research has been done in the EER community. More importantly, the present study attempts not only to examine individual elements in

scholarly collaboration, but also to synthesize them to provide a bigger picture of how engineering education scholars collaborate. During scholars' development of collaboration, technology use demonstrates scholars' collaboration mode. It also implies different communicative strategies that scholars use. Choice of technology can even influence productivity of the entire research team. Therefore, the next section reviews theories of technology acceptance.

### 4.2.2    Theories of technology acceptance

The earliest model of technology acceptance is commonly believed to be derived from the theory of reasoned action (TRA) (Ajzen & Fishbein, 1980). The core assumption of TRA is that individuals are rational and can utilize information available to them effectively to guide their actions. The decision to adopt technology depends on one's evaluation of the usefulness and possible outcomes and the social norms (Ajzen & Fishbein, 1980). However, there are often cases where human behavior may not be rational and is only a result of habits. To overcome this limitation, Ajzen et al. (1991) added a perceived behavioral control (PBC) component to TRA and proposed the theory of planned behavior (TPB). The PBC component factors in individuals' intentions to perform a certain behavior. TPB, however, cannot explain scenarios where individuals are not motivated to act deliberately (Taylor & Todd, 1995).

Investigation of acceptance of information systems mainly uses the technology acceptance model (TAM) and diffusion of innovations (DOI) (Al-Qeisi, 2009). These two theories originated in different disciplines but share a lot of commonalities. TAM is contextualized in information systems (Venkatesh, Morris, Davis, & Davis, 2003). It uses *perceived usefulness* and *perceived ease of use* as two main external variables in

determining attitude of adopting a technology (Davis, 1989), which echo DOI's five factors (Rogers, 2003) that influence innovation adoption. The first main external variable in TAM, perceived usefulness, is a more concrete construct and corresponds to part of attitude toward behavior in TRA. The second main external variable in TAM, perceived ease of use, corresponds to PBC in the TPB model. Diffusion of innovations has also included in the model the adoption process and adopters' categories (Rogers, 2003). The present study uses these different models to explain engineering education scholars' adoption and usage of various technologies.

### 4.2.3   Faculty's technology adoption

Prior studies have revealed faculty members' technology preferences for teaching. On the one hand, Groves et al. (2000) found that word processing, Internet, presentation software, and email are the most popular technologies used by faculty in teaching. On the other hand, Roblyer et al. (2010) showed that social networking sites were unlikely to be adopted for pedagogical purposes. Also, users' perceived benefits of adopting technologies and infrastructure readiness largely determined technology adoption and long-term use for teaching (Mazman & Usluel, 2010; Nicolle & Lou, 2008; Teo, 2009).

Besides adopting technology for teaching, scholars also studied faculty members' technology adoption in research. Weller et al. (2010) analyzed researchers' usage of social software in academic settings. Their survey results demonstrate that most participants are passive users of the social software and the majority of Web 2.0 achievements, except Wikis, only played a minor role in users' academic work. As opposed to the not-so-optimistic future of using social software intended for the general public in academia, social research network sites have gained increasing attention from

scholars. According to an interview with the co-founder of *ResearchGate* (Hofmayer & Wieselberg, 2009), an SRN site that has more than 1.4 million registered users by February 2012, 37% of users found academic information such as publications and 34% expanded professional networks using *ResearchGate*. Scientists started to adopt social networking sites such as Twitter and ResearchGate and used them for academic purposes (Codina, 2009; Nentwich, 2010) and the EER community is no exception. In using social networking technologies, existing studies imply scholars' preference of SRN sites intended for scholars to generic social networking software intended for the general population. Forkosh-Baruch et al. (2012) showed high dropout rates of generic social networking sites (SNS) such as Facebook and Twitter utilized for scholarly purposes and that SNS in general has not been widely adopted. In fact, Borrego et al. (2010) reported that engineering department heads still primarily rely on colleagues and word of mouth to find out about relevant innovations. Traditional face-to-face communication, such as workshops, continues to play a key role in promoting academic collaboration and innovation diffusion (Felder & Brent, 2010; Simpson, et al., 2010; Streveler & Smith, 2006).

Contrary to the large volume of literature that characterizes the adoption of technologies in higher education, only a few research studies explored technology adoption for research purposes. Based on existing studies about technology adoption for scholarly collaboration, there is no agreement regarding what technologies scholars prefer. Nor does any existing study explore in what context these technologies are used. Technology adoption shows scholars' collaboration mode, implies different

communicative strategies, and may affect work productivity. Therefore, the present study attempts to study technology adoption in the context of scholarly collaboration.

## 4.3    Research questions

Scholarly collaboration particularly the kind that leads to academic deliverables such as publication, is often an outcome of an intentional and long-term partnership. Therefore, instead of asking in general why engineering education scholars collaborate insufficiently, it is necessary to investigate scholarly collaboration in a systematic way. For instance, it is essential to understand what starts or inhibits collaboration and what scholars collaborate on. It is also important to learn what strategies collaborators use to collaborate and what influences their choices of strategies during collaboration. Finally, the present study investigates the final outcomes of collaboration. The present study also focuses on identifying technologies that aid collaboration and examines how engineering education scholars use these technologies. In sum, this study attempts to answer the following questions:

(1) How do engineering education scholars develop scholarly collaboration?

(2) What technology(-ies) do engineering education scholars use for communication and collaboration?

Understanding engineering education scholars' collaborative behavior and technology usage can uncover scholars' workflow, technology preference, and difficulties encountered in communicating and collaborating with their research partners.

## 4.4    Methodology

In this study, the definition of scholarly collaboration is derived from Bohen et al. (1998): scholars' collaborative activities in pursuit of academic publications and grant

proposals. In reality, however, collaboration between scholars may happen in various

forms such as co-teaching (Austin & Baldwin, 1991; Stevenson, Duran, Barrett, &

Colarulli, 2005). However, the present study focuses only on collaboration in research.

Because the purpose is to understand how scholars develop collaboration, the nature of

making sense of participants' collaborative experience and stories makes qualitative

research methods better applicable. The present study uses a semi-structured interview to

capture engineering education scholars' responses regarding their collaborative

experiences and technology usage. Twelve participants were interviewed, and the

audio-recorded content is transcribed. Finally, the data is analyzed using grounded theory

method.

### 4.4.1   Data collection

Data for this study was collected using a semi-structured interview (Patton, 2002).

Semi-structured interviewing enables exploration of engineering education scholars'

behavior and experiences in their past collaboration. Participants vary in their

collaborative experience and it is often necessary to probe and have more in-depth

discussions on certain aspects based on participants' stories. Such a degree of openness

makes semi-structured interview an appropriate data collection method. All interview

questions can be found in Appendix B. Participants were asked about their individual

collaboration experiences and also their opinions about how the community can increase

collaboration. As discussed earlier, scholars' technology use is an important factor that

determines their collaboration modes, strategies, and productivity and is another major

focus of this study. Therefore, the entire interview is composed of three parts: (1)

collaboration in the community, (2) individual collaborative experience, and (3) technology usage in scholarly communication and collaboration.

The first part of the interview asks participants at a macro level what the EER community can do to promote scholarly collaboration and how they benefit from it. This set of questions aims to capture input from participants who have experiences about organizing events and changing policy in the community. It also offers an opportunity for participants to review the overall culture and environment regarding collaboration in EER. These questions were asked because the community's effort is a critical factor that influences collaboration among individual scholars. To start the conversation, participants were first presented with an image depicting a co-author network among engineering education scholars that demonstrated the need for increasing scholarly collaboration.

The second part encourages participants to share their experience of collaborating with one or two of their collaborators in the past. Questions in this part were organized sequentially from meeting the collaborator for the first time to the end of collaboration (Austin & Baldwin, 1991; Hart, 2000). These questions capture how participants first met their collaborators, why they decided to collaborate, what their first collaboration experiences were, and what motivated them continue to collaborate. More importantly, the interviewer tried to find out what difficulties participants encountered in each stage and how they solved them; and in what tasks participants managed with ease in particular experiences.

The third part of the interview aims to understand participants' technology usage in scholarly communication and collaboration. Participants were asked what technologies

they preferred, under what circumstance they used these technologies, and why they favored them over other alternative technologies. This is different from asking what technologies are available. Internet and Web 2.0 have offered numerous innovative and efficient solutions in support of scholarly communication and collaboration. Nevertheless, the technologies per se do not guarantee success in enhancing communication and collaboration among researchers until they are widely adopted and used. Therefore, the interview asks what technologies are preferred among existing alternatives. Also, it is critical to understand why certain technologies are preferred, in what context they are mostly used, and what aspects of them satisfy scholars' needs.

### 4.4.2   Sampling criteria and recruitment of participants

Criterion sampling and extreme case sampling (Patton, 2001) were selected as the participant sampling methods in the present study. The rationale is discussed below. First, the purpose of this study is to understand engineering education scholars' collaborative behavior and experiences. This implies that, participants should be allowed enough time to seek out collaboration opportunities, although it is up to the participants themselves whether to collaborate eventually. For instance, it is not reasonable to claim that a senior faculty who has been working in EER for 20 years is more collaborative than a first-year PhD student based on their collaborative experience. Selected participants should both have a significant number of publications and a relatively long publication history in EER. So the first criterion is that, the selected engineering education scholars should have at least six EER publications. The second criterion is that, the selected participants should have a publication history of at least six years in EER. A scholar's number of EER publications and publication history is computed based on the bibliometric study in

CHAPTER 2 that reviews an extremely large number of publications in EER. The

selection of six years is to exclude scholars who change their career path as an

engineering education scholar due to PhD graduation or failure to earn tenure. Choosing

an even longer time tends to select senior scholars who spend many years in EER and

often have a lot of collaborators. This implies less diversity in participants. As a result,

the voice of less-collaborative scholars is less likely to be heard, which affects the

comparative analysis mentioned in the next paragraph.

Second, among engineering education scholars who meet the two criteria above,

some of them are extremely collaborative, which means they tend to collaborate

frequently and widely. Likewise, there are scholars who prefer to work in isolation, with

very few, if any, research partners. To understand the cause of insufficient collaboration

in the EER community, it is essential to compare these two extreme cases to recognize

differences in their collaborative experiences and behaviors. There may be issues that

both groups of scholars face. However, these differences may tell us why some are more

collaborative than others. Therefore, the present study uses extreme-case sampling to

choose participants in the top 5% (named the frequent collaborator group) and bottom 5%

(named the infrequent collaborator group) in terms of their number of collaborators.

Again, a scholar's number of collaborators is based on the same dataset used in

CHAPTER 2. The focus on comparing the two groups makes extreme case sampling an

appropriate strategy in this study.

The selected participants were recruited either through face-to-face invitation

during the American Society for Engineering Education Annual Conference 2013 or

through email. A total of six frequent collaborators and six infrequent collaborators

participated in the semi-structured interview. The six frequent collaborators have an average of 77.7 collaborators on various EER projects, whereas infrequent ones have only 2.5 collaborators. The twelve interviewees come from eleven different institutions. Four of them are full professors and the rest are associate professors. There were five female participants and seven male participants.

### 4.4.3   Data analysis

Twelve participants were interviewed for a total of 3.5 hours, an average of 18 minutes per participant. A PhD researcher transcribed audio content into text. Transcriptions have a total of 23,798 words, an average of 1,983 words per participant. The frequent collaborator group and the infrequent collaborator group have almost the same amount of interview time and word count in transcriptions. During the interview, nine participants share two different collaborative experiences, whereas the other three participants describe experience with only one collaborator.

Investigation of scholars' collaborative behaviors involves a researcher interviewing one participant at a time with a similar set of questions. The data analysis aims to reveal patterns from participants' input. The present study attempts to theorize scholarly collaboration in engineering education. Therefore, grounded theory (Glaser & Strauss, 2009) is selected as a data analysis method in the present study.

Based on grounded theory, the analysis of 12 interviews started with open coding, where the audio-recorded content was transcribed, segmented, and recognized into categories and subcategories. The researcher did not make any assumptions and was not given any input about what to look for in the data. The researcher ran through all the transcriptions eight times to recognize all categories relevant to scholarly collaboration.

Then in the axial coding step, the researcher selected scholarly collaboration as a central phenomenon based on how categories were inter-related. The central phenomenon was then surrounded by four categories of themes. The first category was what preceded and led to scholarly collaboration, also known as causal conditions in grounded theory. The second category of themes described what actions scholars took in the collaboration process, corresponding to strategies in grounded theory. The third category was what influenced scholars' choices of strategies (intervening conditions). The fourth category included themes related to outcomes from scholarly collaboration (consequences). There was no limitation on how many categories should be assigned to each type. The researcher also did not revise the themes or categories recognized earlier to fit them into a model. Finally in selective coding, the researcher examined the model and created a story line to describe the interrelationships between categories.

## 4.5    Results

This section presents themes and sub-themes recognized from the interviews of 12 engineering education scholars regarding their behavior and technology usage related to scholarly collaboration. It first discusses what scholars collaborate on and their collaborative relationships. Then it elaborates factors that inhibits or triggers collaboration. Next, it shows conditions that influence scholars' strategies in developing collaboration. Then it demonstrates the main strategies engineering education scholars take to develop collaboration. Finally, it presents what scholars perceived as outcomes of collaboration. A model that summarized all these themes is given at the end of this section.

### 4.5.1    Central phenomenon: scholarly collaboration

The themes and sub-themes in this section are related to participants' definition of collaboration and kinds of collaboration. Scholarly collaboration was referred to as collaborative efforts that lead to finishing papers and grants. During this process, collaborative relationships between team members varied given different teams.

(1) Participants defined scholarly collaboration as a common goal to contribute together to papers and grants.

When participants mentioned scholarly collaboration, they actually referred to collaboration on papers and grant proposals. On the contrary, activities between two scholars without a common goal were not considered as part of scholarly collaboration. For instance, engineering education scholars might talk to their colleagues casually and ask for feedback regarding their preliminary ideas and work. Participants did not perceive such an activity as scholarly collaboration and instead, thought of it as just learning from each other, as the following quote shows.

> *… The cool thing is, I can collaborate with her from the standpoint of helping me understand my stuff. … The collaboration is not so much. It's more like learning partnership kind of thing than collaboration.*

(2) Collaborative relationships varied in different research teams.

Participants further described various types of collaborative relationships. For example, a participant shared her experiences of working in a team where each team member contributed almost equally to the project. Instead of contributing equally, some participants described their teams as a centralized organization – i.e. one or two team leaders who contributed the most and the rest who provided feedback. Another type of

collaboration participants shared was between resource provider and resource consumer. This relationship was common between researchers and educators where educators provided researchers with access to students and classrooms while researchers conducted research studies and wrote papers. Participants believed that these different types of collaborative relationships had implications for authorship order on papers or proposals. Authorship order was often obvious when one member contributed significantly more than another. When members contributed almost equally, a participant stated that each team member took turns in serving as the first author, and they did not care too much about authorship order.

### 4.5.2 Causal conditions for scholarly collaboration

Several themes related to conditions that influence the decision to collaborate emerged from the interviews. Scholars' disciplinary backgrounds and research areas determined their tendency to seek collaboration. Scholars sustained awareness of others' work and made new connections mainly by attending conferences and workshops. Common interests, similar background, and complementary expertise were prerequisites to scholarly collaboration. However, these factors did not start collaboration; top-down appeals such as funds for collaborative work often triggered the start of collaboration. Meanwhile, proper evaluation of collaborative work also encouraged collaborative research.

(1) Disciplinary background and research areas were perceived as determining scholars' collaborative tendency.

Because engineering education is a new discipline, participants came from various disciplines before they joined EER. Participants from disciplines where collaboration was

rare did not feel the need to collaborate and were surprised by engineering education papers with many co-authors. Some examples of such disciplines were literature, communication, education, and mathematics. None of the interviewed participants with background in these disciplines became accustomed to the collaborative culture in EER even after they had been working on EER projects for many years. In fact, they were comfortable in their current situation and rarely acted actively in seeking collaborators. On the contrary, some other participants who focused on projects with interdisciplinary nature considered collaboration as the only way to deal with the challenging and complex problems. Here is an example of one participant's surprise by the degree of collaboration in EER:

> … It's curious that most engineering (technology education) papers are co-authored. It is very rare that you actually see a single author, whereas in my field, my degree is **** actually. It's very rare to see a lot of collaboration. They tend to be more, more solo events. One of my challenges in this organization is wrapping my brain about the whole idea of seven people writing one paper, which is not common.

(2) Conferences increased awareness of others' work and initiated inter-person connections.

Most participants agreed that academic conferences were the most important venues for establishing new connections prior to collaboration. However, as two participants pointed out, having a large group of scholars gather together might not result in effective professional networking, let alone collaboration. Participants suggested that when organizing conference sessions, it was essential to define clearly the intended audience so as to draw scholars with similar research interests. Participants also

mentioned workshop as another alternative because they usually had a clear topical scope and target audience and attendees spent an extensive period of time communicating with each other. For interdisciplinary communication, networking through general-purpose meals or networking sessions was perceived as more effective. However, conferences, workshops, and other sessions only helped initiate conversation and increase awareness of others' work but rarely led to collaboration immediately. All these can be demonstrated by a participant's opinion of conferences below:

> *… the ASEE conference, the networking session that happens in conferences, the NSF awardee conferences … TUES awardee conference, which gives folks working on that sort of proposals an opportunity to learn from each other and work together. But again, I don't think those necessarily create collaboration. They provide an opportunity for people to talk.*

(3) A common research interest, complementary expertise, and similar career stages were critical to collaboration.

All participants agree that a common research interest is a prerequisite for collaboration. Many participants also think that this explains why they did not collaborate with some other colleagues even when they know them very well. Besides common interests, similar knowledge background and complementary expertise are also fundamental factors in considering who to collaborate with, as demonstrated by the quote below.

> *She's actually a chemical engineer. So am I. We both have background in drug delivery. So it's kind of interesting though because we complement each other very well because my background was more on the modeling and mechanism side. Hers is more lab-focused ... So we realize that we were a good team in doing educational work because we can put these two aspects together.*

In addition, when seeking collaborators, participants tended to look for scholars who were close in career path and hierarchy. For example, both parties are graduate students, assistant professors, or department heads, as the quote below shows. While conferences contributed to building initial connections, these different types of commonalities had greater influences in getting scholars seriously consider collaboration. However, many participants felt that this was insufficient and they needed a reason to collaborate.

> *… I was a graduate student and she was just graduating … we would talk about these things that we are dealing with, these ideas, these new frameworks, these new methodologies, and find out that the other doing the exact same thing … It was somebody that I felt safe talking about ideas. We were hierarchically not that far apart …*

(4) Rewards for collaborative work triggered collaboration.

Participants all recognized institutional or community-wide appeals for collaborative work as what started their collaboration. The most common example that participants mentioned was National Science Foundation (NSF) requests for proposal (RFP) that explicitly required cross-institutional collaboration. Such messages motivated engineering education scholars to form a team to work together. Another similar example was a special issue/volume of a top-tier journal, which called for interdisciplinary and collaborative work.

> *... There are certain funding opportunities in a certain area that I think, you know, making it more of a collaborative funding opportunity. You need to give an incentive for researchers to work together …*

Meanwhile, a participant was worried that collaborative research was often underweighted by universities and sometimes not considered as original contributions. Such faculty evaluation criteria tended to favor individual work and single-author papers and therefore discouraged scholarly collaboration. Considerations of institutional reward structure are presented below:

*I think one of the biggest issues was probably inherent in research universities where they don't really know how to judge collaborative work. For example, when I was considered for promotion … from research assistant professor to research associate professor, the pushback I heard from a lot of colleagues who were trying to evaluate my engineering education research initiative was that, all my work was collaborative with other people. What was my original contribution? … So it's a lot harder for those of us in the engineering education research world to justify working collaboratively.*

### 4.5.3   Intervening conditions for scholarly collaboration

Participants discussed intervening conditions that influenced engineering education scholars' collaborative behavior. Among those conditions, issues related to time and location were reported as the most influential factors. Misalignment between individuals and the team also affect strategies chosen in collaboration.

(5) The biggest challenges in collaboration were time-related issues.

When talking about major challenges in collaboration, most of the participants shared their issues related to time. One common time-related issue was scheduling events during a conference so as to make new connections, learn new knowledge, and start new collaboration at the same time. The most common issue with time was schedule conflict and priority discrepancies among collaborators. One participant mentioned a case where the research projects involved interacting with students. Dedicating a large chunk of time

regularly to these interactions was very difficult. Such differences in schedule and priority may sometimes reflect the difference in work habit where some team members preferred to do things at the last minute while others preferred the opposite.   In fact, a participant decided not to collaborate with her close friend because of the difference in scheduling work. Participants believed that such time issues often had significant influence on the project progress if not dealt with properly. Here are three examples where participants describe their difficulties related to time:

> *… The hard part is always putting together, finding the time, getting everybody to meet …*

> *… those conferences are packed with other stuff. And carving out times to sit down and randomly talk with colleagues about ways we might expand our collaboration means something else has to give. Meaning I may miss conference sessions or something …*

> *She has a very different work habit than I do. She's like a last-minute person and I am an early bird. … She's still a very good friend of mine but I just realize that I could not work that way.*

(6) Collaboration with members from multiple locations was difficult.

As most participants pointed out explicitly, when collaboration happened across multiple institutions, such differences in location presented other kinds of challenges. Scheduling meetings among scholars at different institutions was a frequently mentioned challenge, particularly when there was a time difference between collaborators' locations. Cross-institutional collaboration may also imply culture differences among team members. A participant recalled a past experience with international collaborators. When team members did not share similar culture, ice breaking could be very challenging. This

rarely happened in domestic collaboration. Also, international collaborators tended to present the same idea in different ways and used different terminologies. As a result, it was time-consuming to understand and convince each other. A participant described the challenge of collaborating with scholars in a different country below:

> *… We have the idea but different ways to express and represent it. The idea is the same but different in how to present them …*

In contrast to remote collaboration, many participants expressed positive feeling about collaboration with co-located scholars. The quote below shows how a participant preferred local collaborators:

> *… And since we were co-located, we did a lot more work in person, whereas with [A] in [X University] and me at [Y University], most of the work was done at a distance. So I think in many ways collaborating with [B] was easier because we can just come together and sort things out …*

In collaboration with local colleagues, participants believed that it was primarily the size of the local scholar population that caused differences in scholars' collaborative behavior. In small institutions, scholars could meet colleagues in the same department or other departments much more easily than those in large institutions. However, there were fewer potential collaborators in small institutions than in large ones.

(7) Collaboration involves misalignment between individuals and the team.

In some collaborative research projects, team members' individual goals may have to be compromised to help the project progress as planned. On the contrary, a few members who persist in their own interests may hinder overall project progress. In such

cases, staying focused on one's own work while keeping individual contributions aligned with the whole project can be very challenging:

> *… when you have multiple collaborators, getting everybody do their work in timely manner and stay aligned with the overall project, not deviate too far from what we agree on… The same focus is probably the biggest challenge.*

Similar to the misalignment in goals, participants also pointed out that their preference of technologies may not be the same as their collaborators' choices. For example, the participant below described how the team was using a new technology that the participant was not familiar and comfortable with:

> *… So for me using the newer mode of technology is moving outside of my comfort zone. I've been pretty resistant to it. The collaboration, the newer collaboration that I use this kind of ideas has just evolved in the past few months …*

### 4.5.4   Strategies

Participants shared their strategies for working collaboratively. Being flexible and adaptable while clarifying individual contributions and goals was believed to be an effective approach in ensuring project success. Also, participants generally preferred local face-to-face interaction. Otherwise, email, phone calls, and videoconferencing were the most preferred technologies used for scholarly communication and collaboration within a team. New technologies such as social networking were rarely used and even resisted by almost all participants.

(8) Being flexible and adaptable was the first principle in collaboration.

Unlike individual projects that could be easily controlled, collaborative projects involved uncertainty about other team members' progress, discrepancy of schedule and

priority, and negotiations and compromises among team members. As mentioned in intervening conditions, setting up time for all team members to meet can be extremely difficult. Some team members may not contribute as much as others. Further, an individual may feel uncomfortable with technologies (such as document sharing software) used by other team members. The first strategy used by participants was that each team member should show respect to others' work habits. The second strategy was that team members should be more patient and adaptable. Every member should be willing to commit more, compromise, and adapt to the team. If the rest of the team used technologies that scholars strongly resist, participants stated that they would still be willing to learn these new technologies so as to conform to the team. This also means, being flexible and adaptable were expectations of both self and others, as shown in the two quotes below:

> *… There's one person there who just is very sad in her perspective. Keep trying to have that perspective to be the overarching thing. It's just, she doesn't listen. She often goes to the place feeling like nobody is listening to her. She's been the one who's talking the whole time. The commitment and the respect for others' perspectives, willingness to give up a little bit of turf to allow collaboration to turn into something neat.*

> *… For the research, you just have to be more flexible and adaptable and persistent. And then sometimes you make changes.*

(9) Team management was critical to collaborative projects

Being flexible and adaptable does not imply tolerating chaos in team management. Participants believed that dividing work clearly, creating detailed agendas, and having project managers were all effective strategies. These strategies could keep the project

going on track and progressing as planned. They could avoid misalignment between individual goals and project goals. They could even increase team members' productivity, as the example below shows.

> *… There's a higher possibility that you can get off-track. It's hard to get people into the conversation. It's more difficult to get myself organized … I try to establish some level of formalism such that we manage our activity by having a clear agenda, what we try to accomplish, and spend appropriate amount of time on things. Somebody monitor our process whether we go too fast. All these things are healthy for a productive meeting. When that happens, I love that …*

Besides, many participants thought that having a rigid deadline was the most effective way to ensure project progress. When certain members' efforts failed to meet the expectation, participants suffered and sometimes might have to eventually terminate the collaborative relationship with them, as described in the second example below.

> *… It is easy for a proposal because there's a rigid deadline. You just have to come together. For the research, you just have to be more flexible and adaptable and persistent. And then sometimes you make changes. Stop working with people and find other people if they don't come through ...*

(10) Local collaboration was preferred.

During the entire collaboration process, nearly all participants preferred local face-to-face interactions as a way to communicate with other team members. The initial contact happened through institutional or departmental events such as faculty lunches and seminars. Some participants connected with their collaborators because they happened to work with the same person or under the same grant. For participants who had experience of collaborating with both local and remote peers, they all thought local collaborations

were often easier. Even when collaborating with remote partners, participants tried to create opportunities to gather the entire team together in one location from time to time, at the cost of a large amount of travel grant, as one participant said below.

> *… If we have a group of such diversity from all across the country, if we need to get together, we create our own conference. But to do that, you have to either have one institute that says, okay, eat the cost, or you have to have a grant from NSF, which that one did, to pay for the cost of doing travel and having the conference. If you don't have some big grant doing something, that kind of collaboration doesn't get done.*

If having all remote collaborators physically join together was infeasible, another solution proposed by a participant was to agree on choosing one institution as a lead where team members in that institution met face-to-face to first establish fundamental frameworks and structures. Then remote team members contributed by commenting and revising based on these initial basic components, as described in the case below.

> *… Since we were on the same campus and we could meet almost daily. That's extremely powerful for us to get our things done. What we did then, because we had partners in other institutions, is we could use that as a conversation point to explain how we were accomplishing things and try to get buy-in from others.*

(11) Emails, phone calls, and videoconferencing were preferred for communication in team.

When face-to-face interaction is impossible, the top three technologies for communication and collaboration preferred by participants were emails, phone calls, and videoconferencing with screen sharing. Software for document sharing and co-editing was also starting to be adopted but was still far behind the top three technologies listed above in terms of participants' preference.

The two main advantages of email mentioned by most participants were its asynchronous nature and attachment feature. Participants felt it was convenient and comfortable using email because they had better control of pace and can respond when they are available. Participants whose first language was not English also preferred email because they could have more time to formalize the content and worry less about their accents. The attachment feature eased document sharing and provided a revision history of documents. One participant also mentioned that emails could also be considered as legal documents and this was essential in some contexts. Some senior participants referred to email as one of the very few options available in the 90s. These advantages provided by email can be derived from the following:

> *… Phone is okay but email is asynchronous. So I can do it at my own time and other persons can respond in their own time. That makes it more convenient. I don't like synchronous communication. I prefer asynchronous communication where each person can think about it and respond at the right time …*

> *… Email, for example, if you want to set things down, it becomes a formal process even in life. We accept it as a record. You cannot deny. If it is the email, it is there …*

Phone calls and conference calls were also widely used by participants mainly for getting quick responses from other team members. Similar to email, phone also has a long history and has been long adopted. However, as participants stated, its synchronicity overcame the drawback of email where one had to wait to get replies. Participants also thought that using a phone involved fewer operations to reach the other party than using video conferencing software. Although it failed to offer the capability of seeing each other's faces like videoconferencing, participants generally considered voice as sufficient

for most communication, as shown in the quote below. Compared to email, phone call approximated personal contact in reality and helped build trust between collaborators.

> *The phone, sometimes the lowest version of the technology is just more than enough. … I have a button on my phone for [A]. I click the button and call her. On Skype, I need to open it up and dial, di di da da ... It sounds more steps and more efforts than what it gives. I don't necessarily need to see her face because I know her so well … It's a super media and it's in your pocket and you don't have to think about it.*

Many participants used videoconferencing software but they held very different attitudes towards it. Some liked it because it approximated the face-to-face real-time interaction and cost less than a phone call. As participants suggested, video conferencing with screen sharing was appropriate for discussing complex topics with shared artifacts. Some disliked it because the sound quality was rarely as good as phone/conference call. Some perceived video as unnecessary and even an overhead. Here are reasons that participants liked or disliked videoconferencing:

> *Well I think from my experience, the best work, the most exciting ideas, building on one another's ideas, coming from synthesis, happens in face-to-face, real-time interaction. The video conference, especially when it is good quality, approximates that.*

> *I don't know if I need the visual face-to-face. Skype, so what is Skype, it is just adding the picture, video. So I don't see that is necessarily an ingredient in having a personal connection with somebody. You know, I am from the time of phone …*

(12) New communication and collaboration technologies were resisted but had potential for being adopted.

Participants generally admitted their resistance to new communication and collaboration technologies but might adopt them given time and motivations. New

technology here is a relative term. Some participants considered video conferencing and document sharing software as new technologies whereas others did not. Regardless of how one defined new technologies, many participants explicitly expressed their resistance towards using them. Two participants had experience with social networking sites, but none of the participants used any social networking feature in these applications. For instance, a participant used Google Hangout only as a backup plan for Skype video calls. In fact, some of them were strongly against using social networking applications for academic purposes. Some were afraid of the side effects of using social networking. For example, one participant thought using social network software would consume too much time. Nor did any participant use collaborative management tools such as *Asana*[3] and *Trello*[4]. Some thought these new technologies were not making the communication and collaboration process easier or that the technologies required more efforts than the benefit they offered. Some felt difficulty in managing multiple accounts on different software. Given all these barriers, participants expressed their willingness to slowly accept these new technologies if other collaborators preferred to use them. Here is an example of a participant who resisted but was willing to adopt Dropbox:

> *… I've been pretty resistant to it. The collaboration, the newer collaboration that I use this kind of ideas has just evolved in the past few months. So I've been getting up to speed. For me, it hasn't made things easier and it's a little bit out of my comfort zone. But I completely envision that as I get more comfortable with it, within a year from now, I am sure it will become my second nature …*

---

[3] Asana: https://asana.com/
[4] Trello: https://trello.com

### 4.5.5 Consequences

The outcomes of scholarly collaboration included access to resource and expertise provided by other scholars and continuation of collaboration in the future. None of these outcomes were unexpected by the participants. If the collaboration happened between department heads or deans, it had a more profound impact on the partnership of the two institutions.

(13) One benefit of collaboration was to gain access to resources and expertise that are otherwise not available or feasible just through individual effort.

This outcome corresponds to some participants' collaborator-seeking strategies, which is finding a matched person who is able to provide certain resource and expertise that can complement a project. A participant shared how he sought out potential collaborators with a biomedical-related background - who could provide different aspects of expertise. Another participant described how she was able to collect student data from a community college by collaborating with the department head of that institution:

> *… I think he may be the head of the math and engineering department … He's got an authority on his campus to really work with us. He just started the engineering program. It isn't like at a community college there are 27 for you to choose from. It's usually one or two that's in that position who can do something about it.*

(14) Continuation of collaboration depended on a project success and future opportunities.

According to participants' experiences, success of a collaborative project often led to continuation of collaboration in subsequent projects. In the long run, such a scholarly collaborative relationship might turn into a long-term personal relationship. All

participants agreed that completion of a paper or an award marked the end of that particular collaboration unless there were follow-up studies to pursue:

> *… If the project ends, it just stops. You got the paper written, that's all we want to do on them. Well, that sort of ends it.*

> *… we ended up finding new and different opportunities to work together. Again, under the umbrella of this grant to get the work done. And sure we were still motivated because of the fact that we were being funded by this.*

(15) Collaboration between department heads or deans was different in many aspects.

When collaborators were department heads or deans, scholarly collaboration had a more profound impact on various forms of collaboration between the two institutions. In return, this institutional partnership promoted more scholarly collaboration between individuals. In such cases, a head's initial selection of collaborators often factored in more than what was recognized in the causal conditions. The collaboration involved more considerations and paperwork and was often slower than ordinary collaboration in research:

> *... The only problem at this level is, if it is a research, it would have been a lot faster. But here we are talking about much bigger issues like ABET, which is at a much higher level. And that involves a lot of bureaucracy. It is not easy. Even for her and for me as well. I had to go to my dean and she has to go to the provost. It is at that level, at the accreditation level. So it kind of slows down a little bit … I had to write a formal report, proposal. She has to do the same thing there.*

4.5.6 Model
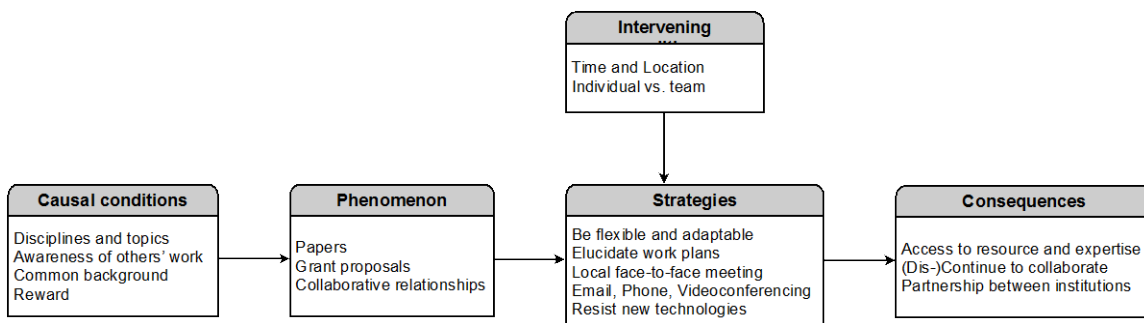


Figure 4.1 A model for scholarly collaboration in engineering education research.

In sum, there are five categories of themes among all themes recognized from the interviews, as illustrated in Figure 4.1. The first category, collaboration, refers to the nature of collaborative activities. The findings present that collaboration on academic papers and grant proposals are the venues for scholarly collaboration in engineering education. Also, various collaborative relationships exist among collaborators. The second category, causal conditions, refers to themes related to factors that trigger or inhibit scholarly collaboration. Based on the interview data, scholars' disciplinary background, research areas, awareness of other scholars' work, career development stages, and reward for collaborative work are important factors that drive the start of collaboration. The third category, intervening conditions, includes themes that influence interview participants' collaborative behaviors. These conditions include discrepancy in time schedule among team members, physical distance between team members, misalignment between individual and team goals, and differences in technologies preferred by an individual and the rest of the team. The fourth category, strategies, is participants' behaviors in collaborative research projects. Participants believed that being

flexible and elucidating work plans helped keep the collaborative project on track and all

team member informed of the present progress. Participants preferred local face-to-face

interactions but when that was infeasible, they primarily used email, phone call, and

video conferencing to communicate with other team members. The last category,

consequences, means the results from a scholarly collaboration. These five categories of

themes form a model in Figure 4.1 that demonstrates scholars' behavior related to

scholarly collaboration.

### 4.6    Implications

Based on the themes and the proposed model in Section 4.5, the present study

summarizes six important implications. Given the importance of collaborative grant

opportunities to collaboration, there are policy implications to increasing scholarly

collaboration in engineering education. There are also technical implications. For

instance, collaboration can be increased by creating new technologies and redesigning

current technologies to facilitate professional network building by face-to-face interaction.

Or technologies can overcome difficulties caused by cross-institutional collaboration.

Also, participants' perception of what counts as collaboration guides the measure of

scholarly collaboration in scientometrics studies. Finally, individual scholars may also

benefit from the comparison of the behaviors of frequent collaborators and infrequent

collaborators to become more collaborative in their academic careers.

First, the present study recognizes funding opportunities as the most direct and

influential factor in motivating scholarly collaboration. A prior study (Xian & Madhavan,

2012) also finds the strong correlation between engineering education scholars' number

of collaborators and number of NSF awards. Participants in the present study confirmed

this correlation and even identified it as a causal relationship. Bohen et al. (1998) also lists financial resources as one of the five factors that affect the success of a collaborative project but the present study emphasizes the role of financial support particularly in directly triggering collaboration. Therefore, one effective way to quickly increase collaboration in the EER community is for funding agencies to invest more on collaborative research work. Similarly, top journals may create special venues to encourage papers with interdisciplinary nature to be published.

Second, the present study finds that engineering education scholars still largely rely on face-to-face connection such as academic conferences, workshops, and on-campus events to develop collaboration. Therefore, the majority of collaborations still happen locally. This echoes a prior study by Frost et al. (2003) that also found that the majority of scholars credited seminars with influencing their interdisciplinary and cross-institutional collaboration. However, about 15 years ago, researchers were generally optimistic about technology in transforming scholarly collaboration because scholars were no longer restricted by geography due to the availability of email, voice mail, and online discussion group (Baldwin, 1998). Although geographical distance is still an important affordance, Baldwin's (1998) finding of email and phone calls being widely used is confirmed by the present study conducted several years later. The rationale for choosing these two media fits the TAM (Davis, 1989) and DOI (Rogers, 2003) models: perceived usefulness and perceived ease are the two main variables in determining attitude of adopting a technology. On the contrary, new technologies such as document sharing and social networking applications are still far from being widely adopted for academic purposes. Such technology preferences imply that email remains

the best media to disseminate information to engineering education scholars. Given the resistance to new technologies, engineering education scholars are still willing to learn them so as to conform to the rest of the team, which coincides with how educators adopt pedagogical technologies (Nicolle & Lou, 2008) and the subjective norm in the TRA model (Ajzen & Fishbein, 1980). Therefore, success of these new technologies depends mainly on how much these technologies can penetrate the population of frequent collaborators. Once frequent collaborators adopt these new technologies, their collaborators may also be affected and start to use the same technologies.

Third, the present study reveals that shared interests, complementary expertise, and similar career development stage are important ingredients in a collaborative team. The importance of common research interests has been recognized by a prior study (Creamer, 2003). The present study further identifies the importance of complementary expertise and similar career development stage. Also, to find perfect partners with common interests and complementary expertise, engineering education scholars primarily rely on attending conferences and reading papers. As participants admitted, attending conferences and reading papers had a level of randomness because selections of papers to read, sessions to go, and people to talk to were all limited by time invested by a scholar. A better mechanism is needed to help scholars read relevant papers and build connections with the right persons. Some of the interviewed participants ask the deans and department heads of specific institutions for the most matched faculty given the desired expertise. This strategy may work if one has a very specific requirement for the potential collaborator and has a short list of candidate institutions to look for collaborators. For other scenarios, a more generic solution is needed. Recently developed platforms such as

Interactive Knowledge Networks for Engineering Education Research (iKNEER)

(Madhavan, Xian, Johri, et al., 2010) aim to facilitate publication and collaborator finding

for engineering education scholars. Again, these new technologies have potential for

being adopted especially if they can attract frequent collaborators to be early adopters.

Fourth, low productivity and the lack of personal contacts make cross-institutional

collaboration difficult. All participants agree that collaboration requires more time

commitment than individual research. The complaint, however, is not about additional

time spent on communicating with their research partners. When all collaborators are

local, engineering education scholars are generally happy with working together weekly

or even daily, which echoes Hoekman et al. (2010)'s findings. The present study further

reveals that compared with remote collaboration, local is often more productive and

convenient, easier to schedule regular meetings, and provides more personal contact.

Although videoconferencing is believed to approximate real-world face-to-face

interaction, it only partially satisfies the need for personal contact. It is not even as

user-friendly and convenient as phone, let alone face-to-face conversations. There is

room for improving existing technologies to become more convenient to use, make it

easier to share calendars and set up meetings, and provide high-quality and stable

video/audio connections.

Fifth, the nature of individual contributions to the project does not qualify one as a

collaborative partner. Participants describe major tasks and various collaborative

relationships in collaboration similar to findings in prior studies (Austin & Baldwin, 1991;

Dickens & Sagaria, 1997; Hagstrom, 1975; Hart, 2000). However, participants'

perception of what counts as collaboration depends very little on the nature of

contribution. Providing feedback is one such example that happens both within a research team and between two non-collaborative individuals. Meanwhile, participants mentioned frequently their time commitment, role responsibility, and project deliverables in their collaborative experience. Therefore, collaborative efforts are distinguished from non-collaborative by how much job responsibility a party takes and whether a party is bound by an official contract. Using giving feedback as an example, it is the collaborator's responsibility to offer feedback, often based on a work division plan that every one agrees to at the beginning. Non-collaborators, on the other hand, are volunteering rather than mandated to do so. In some participants' collaborative experience, one of their collaborators contributes very little to the project and does not meet their expectations. Only occasionally are low-performance team members dismissed from team. This means - even the amount of contribution may not distinguish collaborative effort from non-collaborative. Collaboration, in such cases, is more based on the initial formal contract, such as both parties being listed as PI on an award. This means - measuring collaboration based on co-authorship on formal publications is not only because such a relationship is available and tangible (Glänzel & Schubert, 2005; M. Smith, 1958). But scholars also perceive such a contractual relationship as what distinguishes collaboration from non-collaborative relationships. This finding justifies the validity of studying scholarly collaboration using co-authorship data on publications.

Sixth, there are clear distinctions between frequent and infrequent collaborators in some aspects. First, frequent collaborators have more experience with and are more open to adopting new technologies. Although nearly all participants express their resistance towards new technologies, frequent collaborators tend to incorporate more technologies

into their collaborative activities than infrequent collaborators. For instance, frequent

collaborators more commonly use document sharing and videoconferencing. They are

also more willing to learn new technologies if necessary than their peers who collaborate

less often. This means, the frequency of collaboration has the potential to influence the

diffusion of new technologies used for scholarly communication and collaboration.

Second, frequent collaborators tend to worry about unfair judgment of their collaborative

work more than infrequent collaborators. This may be due to the fact that frequent

collaborators have most of their research work done collaboratively and therefore proper

evaluation of their collaborative work has a greater impact on them than infrequent

collaborators. Third, frequent collaborators have more experiences in dealing with issues

in collaboration. In fact, more strategies in Section 4.5.4 are drawn from participants in

the frequent collaborator group. Their approaches can guide new and infrequent

collaborators in their future collaboration. For instance, frequent collaborators recognize

that clarifying division of work, elaborating agendas, and monitoring project progress are

essential in ensuring individual and team productivity. Groupware should provide and

highlight corresponding features to facilitate scholars in performing these tasks and help

infrequent collaborators start to adopt these important strategies.

### 4.7   Validity and credibility

During the interview, participants might pick the most successful collaborative

experience to share. Although the interviewer did not encourage participants to share

only positive collaborative experiences, three participants explicitly said that the

collaboration they chose was the best among all their past experiences. Among the nine

participants who shared two different collaborative experiences, all of them referred to

one collaborative instance as good and enjoyable experience. Such a bias may hide many issues in ordinary collaboration and make scholarly collaboration sound easier. When this happened, the interviewer asked participants if they experienced any other collaboration that was different from the one they first talked about, without prompting to specifically seek negative examples. As a result, among the nine participants who talked about two collaborations, five of them used a somewhat negative collaboration as the second example, whereas three participants used a neutral example. This means that although participants tended to share their best examples, the fact that most participants also shared their less successful cases makes the interview data contain both positive and negative cases.

Preventative measures were taken to minimize the author's misinterpretation of the interview data. This means that when participants' input is ambiguous, the author who analyzes the data may misinterpret what participants talk about. During the interview process, the interviewer often paraphrases what the participants have just said and confirms with them if the interpretation is correct. In addition, after analyzing the data, the researcher used the member validation method (Shaffir & Stebbins, 1991) and sent an email to two of the participants asking if the findings made sense to them and if there was anything contradicting their opinions. Both participants validated the result and believed that it represented their input properly. This member validation step ensures a high accuracy of the researcher's interpretation. A researcher memo is attached in Appendix C to show the background, experience, and growth of the author who interviewed participants and analyzed the data.

Finally, data from only twelve participants may seem insufficient to draw conclusions. However, data saturation (Corbin & Strauss, 1990) is reached for all themes and categories proposed in Section 4.5. The sample size was determined based on the interviewer and researcher's judgment of whether all patterns had emerged and been confirmed by re-occurrences in the data.

## 4.8    Limitations

During the interview, some participants felt confused about what technologies referred to and asked for examples. Although the author provided a wide range of technologies as examples, such examples often served as options for participants to choose from. Therefore in such cases, the interview may fail to capture the actual technology preferences from the participants.

All interviews were conducted while participants attended an academic conference. This context might make participants recall more experiences about conferences. Meanwhile, the participants might overlook other communication and collaboration activities. As a result, the significance of attending conferences in initiating connections may be overly emphasized.

## 4.9    Conclusions

The present study aims to study how engineering education scholars develop their professional networks and their technology usage in communicating and collaborating with other scholars. To address this problem, a semi-structured interview was designed to capture engineering education scholars' input. Then a grounded theory study was conducted to build a model to describe scholars' behavior in developing research collaboration in engineering education. The analysis result demonstrates what precedes

and motivates collaboration and what scholars collaborate on. The result also shows what strategies they use to communicate and collaborate with their team members and what influences their choices of strategies. It also presents the outcomes that are produced at the end of collaboration. This study further highlights implications for scholarly collaboration in engineering education. It discusses the roles of funding opportunities, various technologies, academic conferences, and physical proximity in influencing scholarly collaboration. Findings from this study characterize the entire scholarly collaboration process as inter-related elements. It helps development of policies, technologies, and activities to increase collaboration in engineering education. It also offers individual scholars and teams an opportunity to reflect on their collaborative behavior and learn strategies to collaborate more efficiently and frequently.

Participants in the present study, especially frequent collaborators, are willing to change their behavior to conform to the rest of the team. However, it is unclear how a team decides how to communicate, what technologies to use, how to divide work, and how to resolve issues in a team environment. Such decisions have a great and long-lasting effect on technology adoption and team productivity and a future study is needed to reveal the underlying details. Also, the present study shows that some technologies such as videoconferencing and document sharing software start to be adopted by engineering education scholars. A longitudinal study of how these technologies are gradually adopted will help draw the path of diffusing new technologies into academia.

# CHAPTER 5.   CONFACT: A TOOL TO ENHANCE SCHOLARS' EXPERIENCES IN MAKING CONNECTIONS DURING ACADEMIC CONFERENCES

## 5.1   Purpose of this chapter

This chapter elaborates requirements specification and software design for a collaboration tool for researchers: *Confact*. Both requirements and design are based on the prior user study in CHAPTER 4 about engineering education scholars' collaborative behavior. They are also based on a review of existing social research networking (SRN) sites in CHAPTER 3. The user study captures scholars' past collaborative experience, workflow, preferred technologies, and difficulties encountered in collaboration. The review of SRN sites recognizes features related to communication and collaboration in research available in existing SRN sites. Details regarding how the user study and review are conducted can be found in CHAPTER 3 and CHAPTER 4.This chapter is intended for software engineers who would like to contribute to developing this tool and finally turning them into commercial products. Scholars are also welcomed to leave feedback on the software design and request additional features.

Section 5.2 introduces the process of user-centered design mainly based on Cooper's (2007) book. Sections that follow elaborate major steps in user-centered design such as requirements definitions, framework definition, and prototyping.

## 5.2    Introduction to user-centered design

There are three main design methods: user-centered design, activity-centered design, and goal-directed design (A. Williams, 2009). This chapter includes the first two fundamental phases in user-centered design, namely design research and design. The last phase, design evaluation that involves real users in evaluating the software prototype, is beyond the scope of this dissertation. Given the focus on early stages of user-centered design, the design process discussed in this chapter follows Cooper's (2007) design process.

There are five major steps in Cooper's (2007) design process: research, modeling, requirements definition, framework definition, and refinement. Research refers to a qualitative research study that aims to understand users by interviewing or observing them. An interview of potential users has been conducted and elaborated in CHAPTER 4. Modeling aims to create personas and recognize user goals based on user research conducted in the previous step. This chapter also identifies user goals but elaborating different personas is beyond the scope of this study. Requirements definition, in this chapter, includes user requirements and system requirements. These two requirement documents are fundamental components in requirement analysis of software system (Lightsey, 2001). User requirements describe key tasks that scholars frequently perform in collaboration, how they handle the tasks, what are the major challenges, and what they need. System requirements focus on the technical aspect and elaborate hardware and software prerequisites for the tool. In the framework definition and refinement stages, user requirements are translated into user interface design. In this chapter, an iOS mockup is presented to show the interface and interaction design of the proposed tool.

The tool design is essentially an elaboration of a model-view-controller software architecture (Krasner & Pope, 1988). In addition, a competitor analysis is provided to compare the proposed tool with its competitors.

### 5.3    Needs and opportunities from the user study

In CHAPTER 4, a user study was conducted to understand how engineering education scholars develop their professional network. Based on the user study, all participants agreed that common research interests and complementary expertise are critical to scholarly collaboration. Participants in general felt that they had good knowledge about who else was doing similar research by reading relevant papers in their fields. Participants also considered attending conferences as an alternative to help them learn the most recent efforts of others. Given scholars' good awareness of who work in the same field, it may seem trivial for scholars to find collaborators who have common research interests. However, as the user study revealed, when scholars looked for collaborators, they sometimes could not find the right person. That means, although scholars know most scholars who work on similar topics, they only perceive a very small number of them as potential collaborators.

Such a gap between who scholars know the effort of and whom they consider as potential collaborators can be explained by scholars' strategy of choosing collaborators. The user study indicates that scholars tended to find collaborators that they already knew in person. They rarely reached out of their own networks to collaborate with someone who they had never connected with. Therefore, although scholars knew most other scholars in the same domain by name, they only had connections with a few of them. Their professional network was so small that it was difficult to form a collaborative team.

Therefore, one major user need is how to facilitate scholars in networking with each other. The user study shows that academic conferences and networking sessions during these conferences are primary venues for making new connections and developing relationships with other scholars. As a result, this document proposes a solution to enhancing scholars' networking experience during conferences.

### 5.4    User requirements

### 5.4.1    Task description

A user is attending an academic conference and wants to connect to attendees he/she is interested in and to develop relationship with cohorts he/she already knows.

### 5.4.2    Workflow

Based on the interview data in CHAPTER 4, a user browses and searches the conference schedule to find presentation and poster sessions that interest him/her. The user also looks for networking sessions and judge whether these sessions are worth attending. The user tries to fit those into his/her current calendar. The user may spend time with peers he/she knows and changes the schedule accordingly.

### 5.4.3    Difficulties

The major difficulties are related to making initial connections to other attendees and scheduling of events during conferences, as recognized in CHAPTER 4. First, the conference schedule is not clearly written and organized and so looking for particular sessions can be difficult. Second, during conferences, there are multiple activities arranged to happen simultaneously and their selections of which one to attend are sometimes random. Third, even when scholars strategically choose which event to go, they inevitably miss some other events that may also provide great opportunities to make

new connections. Fourth, users are often uncertain of whether some of their peers also attend and it can be difficult to be strategic in balancing time between going to presentation sessions, meeting old friends, and meeting new people.

### 5.4.4   Requirements

Scholars need a more effective way to organize their schedules for better networking during conferences. More specifically, users need to easily look up sessions they are interested in and attendees they would like to connect to. They need to exchange ideas quickly and make smooth connections to other scholars to save time for other events. Users also need to take into consideration time spent on gathering with peers they know.

### 5.5   Marketing requirements

### 5.5.1   Main features

Given users' need for better networking experience during conferences, the user study in CHAPTER 4 shows that scholars prefer face-to-face interaction rather than communicating on any online platform. Therefore, *Confact* is designed to have four main features to help users establish connections and ease the initial conversation in reality: (1) *Session search,* (2) *Attendee search*, (3) *About me*, and (4) *Venue locator*.

*(1) Session search*

The session search feature addresses the user need of finding interesting conference events in a strategic way. Users open *Confact* on their mobile devices or laptops to find interesting sessions by research topics, institutions, and times. If users have papers or posters to present, they can find sessions that resemble their work. Details about a session are then displayed to users: time, location, agenda, and description. Users can choose to

add a future session to their calendar and download video replays and slides for past

sessions.

*(2) Attendee search*

Besides session search, *Confact* provides the feature of searching for conference

attendees. This feature corresponds to the user need of making new connections to other

scholars with similar research interests and planning for meetings with cohorts users

know before. Knowledge of who users have already connected comes from multiple

sources. It can be inferred by the coauthorship on past publications. It can also rely on

users' self-report list or their current address books. Again, users can search attendees by

discipline, research topic, and institution. Details about an attendee include name,

affiliation, email address, presentation schedule, publications, and connection paths.

Connection paths refer to the path between a user and the selected attendee where any

two linked persons in the path know each other. This is similar to the notion of *path* in

graph theory (Harary, 1994), where a path connects a sequence of nodes with a sequence

of links. Using this feature, a user can quickly look up attendees who share similar

interests, locate their presentations, and get an idea of their past research efforts. If users

specify scholars who they know, they can check whether they happen to attend the same

conference and send direct messages to them via *Confact*. Users can also send messages

to other attendees via SMS in *Confact* if the other party does not use *Confact*. This allows

users to better plan their meetings with cohorts they connected before.

*(3) About me*

The about me feature creates an academic profile for a user including the user's

presentation schedule in a conference, contact information, publications, and other

supplementary materials. This feature meets the user need of making initial connections and having conversations with other conference attendees easily. This user profile is essentially an advanced electronic business card for a user so that the user can introduce him/her-self better and exchange contact information more easily. This feature also allows two users to set up time for a meeting automatically based on the availability in both users' calendars.

*(4) Venue locator*

This feature satisfies the user need of scheduling conference events efficiently. *Confact* can guide users to the next event according to users' calendars. For instance, a user Mary just finishes attending the last presentation session in room 306 in the convention center. She can follow *Confact* to find the restaurant that holds the dinner session.

### 5.5.2   Competitors

The first group of competitors of *Confact* is event-scheduling tool. Examples of such tools are Doodle, Fasterplan, Pickate, SelectTheDate, Whenisgood, Dudle, Meetifyr, and Pleft. These tools all aim to facilitate event scheduling among a group of people by asking each invitee to specify their availability of time from a date range. Then based on all the responses, the event coordinator selects the best time. *Confact* also provides the feature that allows two conference attendees to find common times to meet during the conference. However, *Confact* skips the steps of asking users to specify availability and finally inserting the meeting manually on the calendar. Instead, when two attendees decide to meet, *Confact* reads both parties' calendars and automatically recognizes common available times. Upon users' confirmation, the new event gets automatically

inserted into both users' calendars. Therefore, *Confact* requires much fewer operations in

event scheduling than the existing tools, as illustrated in Table 5.1. Users can save time

on scheduling meetings with each other and focus more on other important activities.

Table 5.1 The workflow comparison of existing event-scheduling software and

*Co-Scheduler* (C - Coordinator, I - Invitee, CA1 - Conference attendee #1, CA2 -

Conference attendee #2).

|  | Existing software | *Confact* |
| --- | --- | --- |
| **Pre-scheduling (once)** | (1) Register an account | (1) Register an account<br>(2) Join a conference<br>(3) Connect calendar to *Confact* |
| **Scheduling (per event scheduling)** | (1) C opens their own calendar management software;<br>(2) C finds available time slots in his/her own calendar;<br>(3) C opens the event-scheduling site;<br>(4) C creates an event;<br>(5) C specifies time slots;<br>(6) C lists invitees' emails;<br>(7) C sends invitations to all invitees;<br>(8) C waits for responses;<br>(9) I indicates availabilities;<br>(10) C determines the best time slot;<br>(11) C sends the final decision via email;<br>(12) C and I mark the event in calendar; | (1) CA1/CA2 opens *Confact*;<br>(2) CA1 and CA2 choose to set up a meeting;<br>(3) CA1 and CA2 decides the best time;<br>(4) *Confact* marks the new event in CA1 and CA2's calendars |

Another group of competitors of *Confact* is social research networking (SRN) site.

Popular SRN sites include *ResearchGate*, *Academia.edu,* and other sites reviewed in

CHAPTER 3. These SRN sites provide features similar to generic social networking sites

such as Facebook and Twitter but only serve researchers specifically. They offer an

online community for users to share publications, ask and answer questions, connect to

other users, form a group, and even manage their research projects. However, these SRN

sites aim to help users network in an online research community and do not focus on

facilitating scholars' networking activities in the real world. None of the existing SRN

sites has features to improve scholars' networking ability during conferences. According

to the user study performed earlier, scholars still prefer face-to-face interaction when they connect, communicate, and collaborate with other scholars. Meanwhile, they strongly resist using social networking tools for scholarly communication and collaboration. Therefore, *Confact,* as a networking helper, is more likely to be adopted by scholars than SRN sites such as ResearchGate.

### 5.6    System requirements

#### 5.6.1    Software

Debian is selected because Debian is reported as the most popular Linux distribution on web servers (Gelbmann, 2012). Based on the same reason, Apache is chosen as the web server because it is used by about 65% of all the websites (W3Techs Web Technology Survey, 2013). Ruby on Rails is the most popular and appropriate for rapid prototyping and web development using Ruby on Rails is the most productive compared to other frameworks (Stärk, Prechelt, & Jolevski, 2012).

(1) Operating system: Debian 7

(2) Web server: Apache 2.4.6

(3) Web framework: Ruby on Rails 4

(4) Database: MySQL 5.5 and MongoDB 2.4.5

(5) Content management system: RefineryCMS

(6) Calendar implementation in Javascript: FullCalendar

(7) Version control: Git

(8) SDK for mobile development: Android SDK and iOS SDK

### 5.6.2    Hardware

Virtual private server is a cost-effective solution to running dedicated services. It offers virtual machines that share the same physical server. ChicagoVPS is chosen for its cost-effectiveness and reliability. It has the following hardware specification:

(1) Intel Xeon quad-core CPU E3-1270 V2 3.50GHz

(2) 3 GB RAM

(3) 120 GB disk space

(4) 3 TB monthly bandwidth

(5) 100Mbps network port

(6) Two IPv4 addresses

### 5.6.3    Services

(1) Reliability, performance, and security: CloudFlare Free

(2) Domain name: GoDaddy

(3) Site monitoring tool: Google Analytics

5.7    Software design

5.7.1    Framework
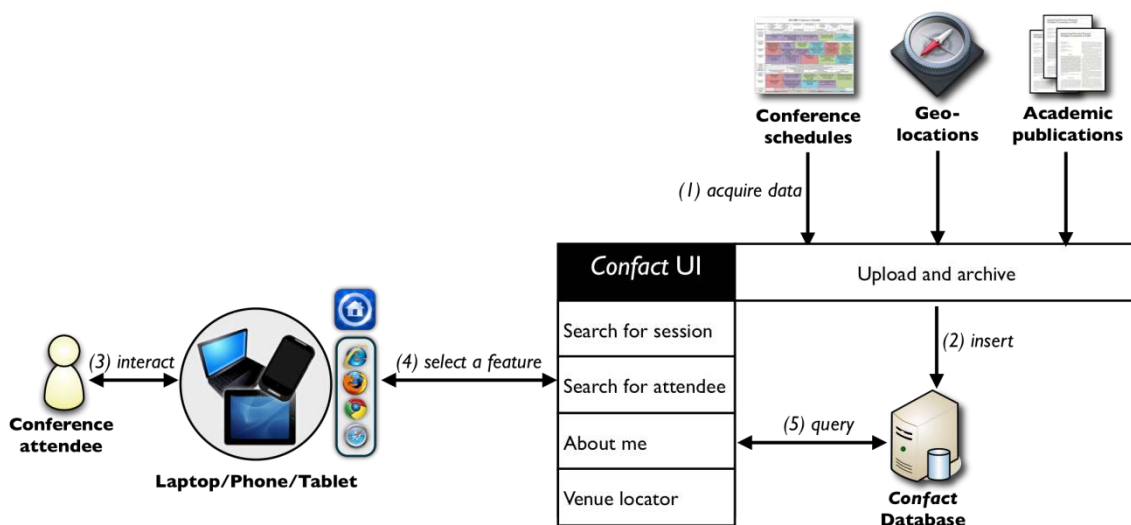


Figure 5.1 A software framework that shows how users interact with *Confact*.

Figure 5.1 shows the workflow of how users interact with *Confact*. First, *Confact* collects four types of data: conference schedules, geo-locations, academic publications, and user data. Conference schedules refer to the arrangement of times, locations, stakeholders, and other descriptions for conference events. If a conference makes detailed schedules available on the website, *Confact* reads and parses them automatically. Otherwise, as an alternative, conference organizers may upload the schedules via the *Confact* administration user interface. Geo-locations refer to the latitude and longitude of each location used by conferences. Precise positions of rooms in a building are rarely available in existing databases. When rooms are set up for a conference, organizers can save their current positions and name them properly using *Confact.* Academic publications are conference papers, journal papers, grants, and other academic documents that show the publication history and research interests of conference attendees. *Confact*

reads publication data from indexing engines such as Engineering Village, Web of Science, and Google Scholar. Users may edit their own publication with more details. *Confact* uses publication data to construct conference attendees' academic profiles and recognize scholars who have similar research interests. Finally, upon users' permissions, *Confact* also reads users' contact lists and calendars so as to better connect users to other conference attendees and fit events into users' schedule.

Second, the above data are inserted into the *Confact* database. Conference schedules, geo-locations, and academic publications are permanently stored in the database. However, users' contacts and calendars can be revoked at any time. *Confact* discontinues all connections to the user data at the end of a conference to perverse user privacy.

Third, conference attendees who are interested in using *Confact* can use their laptops, mobile phones, and tablets to open any web browser or the native application of *Confact*. The web-based user interface of *Confact* is adapted to different screen resolutions from a large display and a small one. The reason why a web interface is provided is because installing a native application on users' devices denotes users' decision to adopt the technology. However, based on the user study, scholars commonly resist new technologies and so native applications may not get installed in the first place. On the contrary, the hurdle of trying a website is much lower. However, native applications have the advantage of being able to integrate other services on users' devices such as communicating with users' calendar, sending text messages, reading users' contact lists, and so on. Therefore, both a native application and a web-based interface are available. However, the native application has extra features added on top of the

web-based version. An iPhone application is used as an example to show main features and the user interface of *Confact*.

Fourth, users select a feature from the list: search for sessions, search for attendees, about me, and venue locator. These four components correspond to the four main features discussed earlier in Section 5.5.1. Each feature contains a number of functions and Section 5.7.3 presents in greater details how users interact with each feature.

Finally, users' operations are translated into queries and sent to the database. Based on the data collected in the second step, the database returns appropriate responses to the user interface to display new information to users.

### 5.7.2    Backend design

1.  Database

Figure 5.2 is the entity-relationship diagram that shows the main tables and their associations. The table *User* refers to the registered user of *Confact*, whereas *Person* is the author of an academic document. *Event* represents both conference events and personal calendar items and an event is composed of a time slot, a location, and a description.
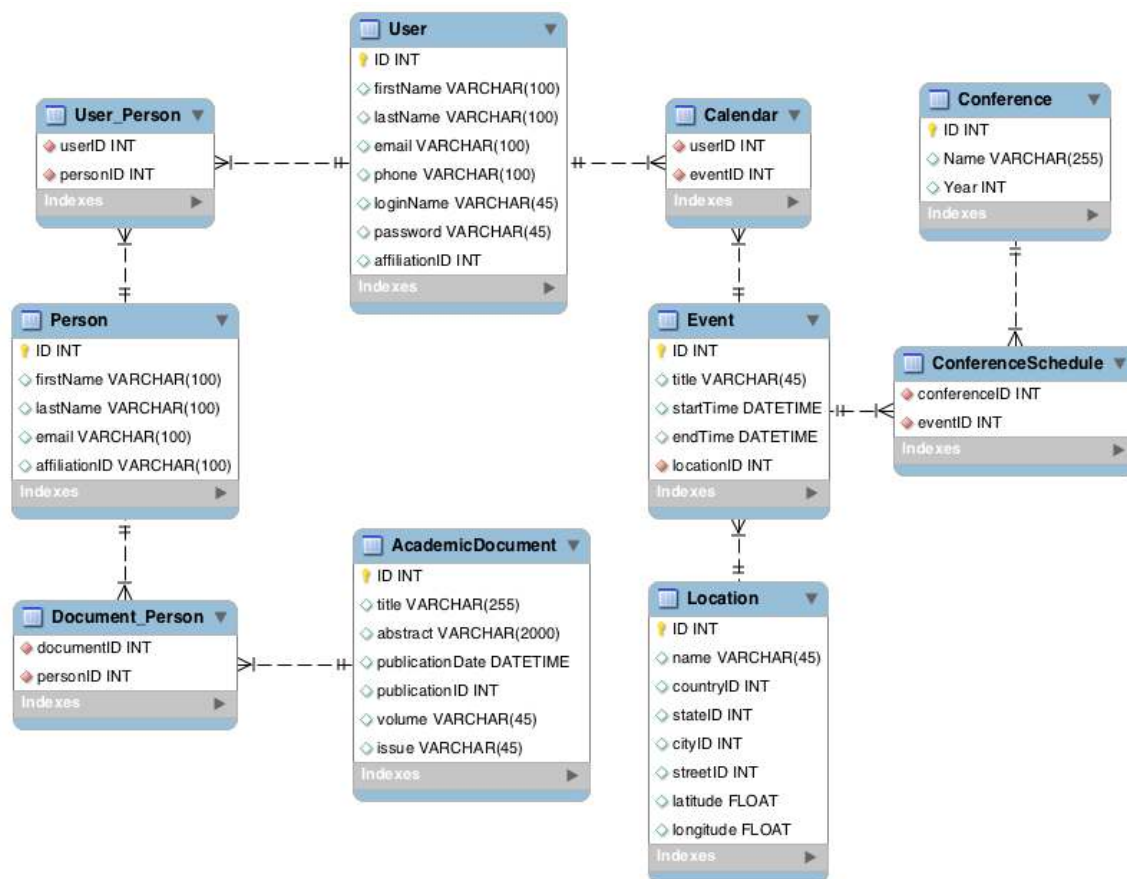
Figure 5.2 The entity-relationship diagram that describes the database design of *Confact.*

2. Web services

Table 5.2 Web services used in *Confact.*

| Web service | Description |
|---|---|
| searchSession | Given constraints such as time, presenter, and research topics, return sessions that meet all the requirements. |
| searchAttendee | Given constraints such as research interests and institutions, return conference attendees who meet all the requirements. |
| getSessionInfo | Return all information about a session: time, location, presenter, and description. |
| getAttendeeInfo | Return all information about a conference attendee. |
| updateCalendar | Update a user's calendar by adding, editing, or removing events |
| locateVenue | Return the latitude and longitude based on a location name |
| login | User login using a user name and password |

### 5.7.3    User interface

1. Check in



(a) Select a conference location                    (b) Select a conference

Figure 5.3 An iPhone interface for users to select a conference based on location.

When users first open *Confact*, they start by choosing a location where the

conference is hold. As shown in Figure 5.3, *Confact* detects users' current location and

uses it as the default option. However, users can also choose a different location if they

want to use *Confact* long before a conference starts. Given the selected location, users

then choose from a list of conferences that are hold now or will be hold in the future.

Users can also view past conferences to download past presentations.

2. Home page



Figure 5.4 The home screen where users choose the four main features in *Confact*.

Once users select a conference, they enter the home screen to choose the four main

features in *Confact*. Besides, users can quickly utilize their browsing histories for better

navigation by choosing from the recently viewed list. Once a conference is selected, the

home screen becomes the default landing interface until the conference is over or unless

users decide to go back to the location/conference selection interface.

3. Search for sessions



(a) Search for sessions         (b) Session details

Figure 5.5 (a) Users search for sessions by choosing from shortcuts or performing an

advanced search. (b) Users then view the session details.

There are four shortcuts in session search. First, users can let *Confact* find sessions

similar to users' own presentations. As mentioned earlier in Section 5.7.1, similarity

between users is computed based on research topics of their past publications. Or users can choose to attend presentations by conference attendees that they already know. Users can also quickly browse all the current sessions or the next available sessions based on current time. Finally, users can view sessions that have been added to the users' favorite folder. If users have a very specific need and none of the four functions help find the sessions, the users can specify values in the advanced search such as finding sessions about assessment or active learning.

4. Search for attendees

In attendee search, users may find other conference attendees who conduct similar research or check whether people they know also attend the conference, as shown in Figure 5.6(a). Users can also perform an advanced search to find attendees that meet certain criteria such as full professors from a certain discipline from university *A*. Once a conference attendee is selected, the attendee's basic information, presentations in the conference, and past publications are displayed. If users are interested in a specific attendee, they can send a direct message to the attendee, bookmark the attendee for future reference, or find other attendees from the same institution or with similar research interests, as demonstrated in Figure 5.6(b).

(a) Search for attendees       (b) Attendee details

Figure 5.6 (a) Users search for attendees by choosing from shortcuts or performing an

advanced search. (b) Users then view the attendee details.

5.   About me



Figure 5.7 A user's own profile page.

The "About me" feature allows users to create their own academic profiles, as shown in Figure 5.7. Two *Confact* users can choose to set up a meeting and the two devices will communicate with each other to find common available time based on both users' calendars. Users can also share their full profiles with another user to exchange contact information, research interests, publications, and projects.

6. Venue locator



Figure 5.8 Use venue locator to find directions to a location.

Venue locator incorporates the GPS feature on the device to help users get to the

location of a selected event, as presented in Figure 5.8. Wifi localization technology is

used to complement GPS when GPS is unavailable for indoor positioning.

### 5.8    Conclusions and implications

Given users' need to make connections during academic conferences, a new tool

called *Confact* is proposed. *Confact* is designed to facilitate communication between

conference attendees by providing four main features: session search, attendee search, about me, and venue locator. *Confact* is carefully designed based on a prior user study and a prior review of SRN sites. In the future when the tool is actually being implemented, user privacy, geographical positioning accuracy, and design evaluation are all fundamental considerations.

There are unique advantages that *Confact* offers to facilitate scholarly communication and collaboration in the EER community. First, it provides a low-cost solution for new EER scholars to easily find and connect to other scholars who share similar research interests. Second, it facilitates the initial contact between two conference attendees. Based on the network analysis in CHAPTER 2, the EER community needs more peripheral scholars to become central. Becoming central players can be achieved by either having peripheral scholars connected to central players (join existing core cliques) or helping peripheral scholars form and lead their own networks (form new core cliques). In both situations, it is critical to help scholars initiate connections with each other strategically. However, only knowing other conference attendees who share similar research interests may not be sufficient for building initial connections. *Confact* uses the collaboration networks studied in CHAPTER 2 to draw relationship paths between conference attendees. This helps both parties recognize common collaborators and makes the initial conversation smooth. The collaboration network in CHAPTER 2 also serves as a reference for conference attendees to decide who to connect to based on the other parties' relative positions in the network.

# CHAPTER 6.    IMPLICATIONS AND CONCLUSIONS

This section first links findings from the three studies to discuss important

implications for promoting scholarly collaboration in the EER community. Then it

summarizes the objectives, methods, and main findings from each study. Finally, future

work is proposed to suggest potential research topics that can be built upon this

dissertation.

## 6.1    Implications

### 6.1.1    Cross-institutional collaboration remains challenging

The first study has shown that engineering education scholars tend to collaborate

with scholars in the same geographical location. Cross-institutional collaborations happen

mostly with a scholar who plays a critical role in bridging between scholars from multiple

institutions. In essence, such cross-institutional collaborations are several local

collaborations linked by central players. Engineering education scholars' strong

preference towards local collaboration is confirmed by the third study. Nearly all scholars

interviewed agree that collaborating face-to-face with local research partners is much

easier than with remote ones, which confirms findings in a prior study (Hoekman, et al.,

2010) that examined the role of spatial distance in research collaboration.

While cross-institutional collaboration is not common or preferred, it offers many

advantages over local collaboration and its significance has been recognized. A prior

study by Jones et al. (2008) analyzed 4.2 million academic papers and revealed that

cross-institutional research efforts were more likely to produce high-impact work,

especially when collaborations include a top-tier university. In their study, top-tier

universities referred to those that produced highly cited papers. Also, according to the

award data from the National Science Foundation (NSF), the total number of

collaborative awards over the past five years are at least triple as many as those during

the years 2003 to 2007. This also holds for NSF collaborative awards related to

engineering education such as awards in Education and Human Resources (EHR) and

Engineering Education Center (EEC). Meanwhile, based on findings in the third study,

engineering education scholars think funding opportunities are the major trigger for

scholarly collaboration. This means that the EER community recognizes the importance

of cross-institutional collaboration, which is increasingly needed to attract funding.

One may also argue that immaturity in communication and collaboration

technologies may also present challenges for cross-institutional collaboration. However,

the second study has demonstrated that existing social research networking (SRN) sites,

along with generic social networking tools, have offered online platforms to facilitate

scholarly communication and collaboration at a low cost. Given the readiness of such

technologies, engineering education scholars commonly resist them and rely on email and

phone calls to stay in touch with their research team members. Then again, email and

phone calls are not preferred if it is possible for these scholars to interact face-to-face.

This explains why engineering education scholars perceive conferences and workshops as

the most important venues to connect to scholars from other institutions. Therefore, in

this dissertation, a new tool is proposed based on the need for enhancing networking during conference participation.

Based on CHAPTER 4, challenges in cross-institutional collaboration include incompatibilities in time schedules, differences in culture, ineffective project management, and a lack of personal contact. Heinze et al. (2008) also consider incompatible working routines as barriers to cross-institutional research collaboration. Challenges arising from cultural differences between collaborators, particularly those from different nations, have also been recognized by prior studies (Easterby-Smith & Malina, 1999; Freshwater, Sherwood, & Drury, 2006). Personal contact, both formal and informal, is critical in developing collaboration (Kraut, Egido, & Galegher, 1988). Also, physical distance between scholars reduces the frequency of such contact significantly (Kraut, et al., 1988). Given the technological advancements in recent years, physical proximity remains a critical factor in scholarly collaboration.

6.1.2   Disciplinary background is a double-edged sword in influencing collaboration

Collaboration within the same discipline is much more easily accomplished than is collaboration across multiple disciplines. The third study shows that engineering education scholars indicate that they are well aware of other scholars working in the same discipline, particularly those studying the same topic. But for scholars to find collaborators, the challenge becomes how to turn this awareness into actual connections. That is, how to move forward from merely having a knowledge of other scholars' research to knowing them in person. However, when one needs to find collaborators from a completely different discipline, neither awareness nor a connection is available. The challenge then becomes how to know who has the specific expertise in that discipline.

Even when collaborators are finally found, inter-disciplinary collaboration remains difficult because of the lack of common ground and differences in presenting ideas. Similar findings have been presented by Corley et al. (2006) to show that epistemic differences across disciplines present significant challenges in interdisciplinary collaboration. Findings from the first study (CHAPTER 2) may offer a solution to this problem. The first study finds that engineering education scholars with different disciplinary backgrounds rarely collaborate with each other directly. Instead, there is usually a scholar who has background from more than one discipline who coordinates collaborative projects. This means that although disciplinary background can both help collaboration (when collaborators share the same background) and hinder collaboration (when collaborators have different backgrounds), negative effects can be alleviated by having scholars with inter-disciplinary backgrounds as coordinators in a team.

Disciplinary background is also a strong indicator of engineering education scholars' collaboration tendency. The first study finds that scholars from certain engineering disciplines are inclined to collaborate more. The third study also shows that some engineering education scholars who come from a field where solo efforts are more common do not feel the need to collaborate on EER projects. Such differences in degree of collaboration in different disciplines are also presented by Babchuk et al. (1999). To increase collaboration, it is important to recognize the population of scholars who feel reluctant to collaborate as opposed to those who collaborate actively. Strategies for engaging these two different groups in collaboration also vary.

6.1.3    Increasing collaboration means turning peripheral players into central players

Proposing solutions for increasing collaboration is as important as knowing that there is insufficient collaboration in the EER community. There are many possible ways to increase collaboration. For example, we could consider inviting more scholars outside EER to join some research efforts. This may increase the possibility of scholars knowing each other and therefore leads to a more connected community. However, a prior study (Xian & Madhavan, 2013) has shown that a large number of new scholars join the EER community every year. However, this does not improve collaboration. We could also suggest that engineering education scholars should be encouraged to collaborate more with their research partners. However, the first study reveals that engineering education scholars tend to collaborate with the same team members repeatedly. Another way to increase collaboration is to assign more responsibility to central players to broaden their impacts to reach more scholars. This is again proved ineffective by the first study because the rich-get-richer effect has already been observed in the EER community leading to over-reliance on a few individuals to build capacity in this space. Scholars who have a large number of connections are so significant that if they were to leave the community, diffusion of innovations suffers radically. Therefore, none of the above approaches seems to work in promoting scholarly collaboration in EER.

Findings from the first and third studies provide solutions for increasing collaboration in the EER community. In essence, scholars should be encouraged to collaborate widely rather than with the same group of people frequently. The first study shows the gaps between the collaboration network in EER and the small-world network model (Watts & Strogatz, 1998). In a critical finding, the study shows that the community

currently overly relies on key players on building capacity within the community. Meanwhile, there are too few connections in the largest network to diffuse innovations quickly while about one third of scholars are working in isolation. All three of these gaps are the results of scholars having an insufficient number of collaborators.

To increase collaboration, the question then becomes how to transition peripheral scholars to the role of a more central player. First, funding agencies should continue to increase investments on funding interdisciplinary and cross-institutional projects. The third study presents that funding is the main trigger of collaboration. Prior studies (Bohen & Stiles, 1998; Xian & Madhavan, 2012) have also demonstrated the correlation between financial support and scholarly collaboration. Therefore, more investments in collaborative research open doors for more collaboration opportunities. As a result, scholars who used to rely on solo effort are motivated to seek out collaboration. Moreover, making such collaborative grant opportunities more visible to the target audience is as important as creating the opportunities. Given that scholars are aware of such funding opportunities, the same research team may get funded without the need to collaborate widely. So increasing investments on collaborative work cannot be the only solution to address insufficient collaboration in EER.

Second, more effective networking opportunities should be provided to scholars so as to help them develop connections with a wider range of scholars easily. Lunch sessions and seminars within an institution are common venues for making connections to other scholars within the same institution. Since most scholars being interviewed prefer local collaboration, organizing these networking events is essential in helping scholars develop connections. For connecting with peers at other institutions, scholars

often rely on attending conferences and workshops to initiate and develop their professional networks. Therefore, it is important to arrange conference sessions and workshops carefully so that scholars with similar research interests are drawn to communicate with each other. When scholars have larger professional networks, their selections of collaborators are wider. Therefore, it reduces the need to work with the same research partners every time. Borovoy et al. (1998) also envisioned conference attendance as critical to forming collaboration. In fact they proposed a wearable technology to help person-to-person transactions during conferences.

6.1.4 The collaborative research tool market has opportunities and challenges.

There is a real need to redesign existing collaboration tools. Also, there are many opportunities for developing new solutions. The first opportunity that this dissertation has identified is that engineering education scholars need a more effective way to make new connections to other scholars and maintain existing relationships. Attending conferences and workshops is a common approach for scholars to expand and maintain connections. However, scholars encounter a lot of difficulties in scheduling events at a conference. For example, they need to balance time spent on making new connections, attending presentation and poster sessions, and meeting old friends. The tool proposed in this work aims to address this problem by improving scholars' networking experiences at conferences.

The second opportunity is that engineering education scholars have difficulties in finding collaborators in another discipline because they are not familiar with the domain knowledge and major contributors in other disciplines. There is a great need to help scholars explore new disciplines quickly and easily even when they lack particular

expertise in these disciplines. Many existing social research networking (SRN) sites seem

to allow users to learn research innovations freely from other disciplines. SRN users can

also connect to users in other disciplines online. However, most SRN sites use a

pre-defined taxonomy to categorize disciplines, topics, and even users. Such a fixed

hierarchical structure implies that SRN users need a certain degree of domain knowledge

to explore a discipline. Compared to having a top-down taxonomy, some other more

effective SRN sites organize research topics based on folksonomy, which is based on

user-defined terms. Often these terms form a flat organization and there is a need to

group them based on their semantic and conceptual meanings.

The third opportunity is that scholars find it cumbersome to determine common

times for meetings among team members. When collaborators come from different

institutions, planning meetings among remote members is extremely difficult because of

the differences in time zones, university academic calendars, and class schedules. It is

even more difficult to arrange reoccurring events, events that require a long-term

continuous participation, and events that need to occur in the near future. Also, scholars'

schedules may change. So a perfect time that once satisfied every one suddenly fails and

the event has to be rescheduled. All of these factors complicate this seemingly simple

task: scheduling a collaborative event. None of the scholars that were interviewed in the

third study discussed finding a solution to this problem. Even when using existing

event-scheduling tools such as Doodle, scholars spend significant time receiving all

responses determining the best time to fit all team members. Existing event-scheduling

tools must be redesigned to expedite response collection and help resolve schedule

conflicts.

Given the above opportunities, tremendous effort is needed for new technologies to be adopted. Some mature technologies such as document sharing are still not as widely used, as some may think from a surface view of these technologies. Many scholars who were interviewed clearly indicated that they resisted social networking tools. On the one hand, reasons for resisting certain new technologies include: (1) technologies are difficult to use; (2) technologies provide no clear advantage; and (3) the rest of the team does not use such technologies. On the other hand, reasons for adopting new technologies include: (1) other team members use them, and (2) institutions and departments provide sufficient support for using the technologies. Therefore, success of new collaboration tools depends on the following factors. First, tools must be designed to be user-friendly. Second, new technologies must provide convincingly large advantages over users' existing solutions. Third, new technologies should be able to penetrate the population of scholars who collaborative frequently and widely. Key players recognized in the first study are potential users that new tools need to reach first. This is because they are often team leaders, and their technology adoption may influence their collaborators' adoption.

## 6.2    Conclusions

The purpose of this dissertation is to analyze scholarly collaboration in engineering education and to propose a user-centered design to address the need for more collaboration. The dissertation starts with a big-data scientometrics study that characterizes scholarly collaboration based on 12 years of publication data in engineering education. It measures how scholars' disciplinary background, research areas, and geographical locations affect the collaboration network topology. The results show that the engineering education research community is at its early stage of forming a

small-world network relying primarily on a small number of key scholars in the community. Scholars with interdisciplinary backgrounds play a critical role in bridging isolated research teams. Compared to other disciplines and the ideal small-world network model, the engineering education research community requires more collaboration among scholars.

The second study reviews the communication and collaboration features in popular SRN sites. It selects 12 SRN sites and categorizes their communication and collaboration features based on the level of work-coupling they support (Neale, et al., 2004). The results show that existing SRN sites tend to support lightweight communication but rarely facilitate collaborative and cooperative work among users such as project management.

The third study aims to study how engineering education scholars develop collaboration and their technology usage in communicating and collaborating with other scholars. To address this problem, a grounded theory study was conducted to describe scholars' behavior in developing research collaboration. The analysis result demonstrates (1) what hinders and motivates collaboration, (2) what scholars collaborate on, (3) what strategies they take in communicating and collaborating with their teammates, (4) what influences their choices of strategies, and (5) what outcomes are produced in the end. It further highlights the significance of funding opportunities in motivating collaboration, the important role of academic conferences, challenges caused by distance, the essence of collaborative relationships, and lessons learned from those who collaborate frequently.

Finally, based on engineering education scholars' needs in collaboration, a tool called *Confact* is designed. The tool aims to improve scholars' networking experience during conferences. *Confact* facilitates the search for sessions and attendees and also

helps users exchange ideas easily. It is carefully designed based on the user study and the review of SRN sites.

<div style="text-align:center">6.3   <u>Future work</u></div>

The tool proposed is based on user needs recognized by the interview data about how scholars collaborate and their technology usage. The specifications for the tool are elaborated scientifically with requirement documents and software design. Although the tool is fully grounded in user-centered design, it has to be actually implemented and validated with users. Therefore, it is necessary to involve potential users in the prototype design to constantly collect their feedback and to improve the software design. Eventually, users' adoption of the tool is an indicator of how much it increases collaboration in the EER community.

The grounded theory study results in a model that describes scholarly collaboration in engineering education. This model identifies attributes that influence scholars' tendency to initiate collaboration and their strategies taken in collaboration. For instance, funding opportunities and physical distance are two major factors that affect scholars' collaborative behavior. A quantitative study is needed to predict scholars' degree of collaboration using these attributes. This new prediction model may use scholars' number of collaborators and number of collaborations as indicators of their degree of collaboration. Results from this quantitative study can validate and complement the proposed model in this dissertation.

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APPENDICES

Appendix A <u>Sites excluded from the SRN review and reasons for exclusion</u>

1. Sites excluded because they are not accessible

   Feelsynapsis http://www.feelsynapsis.com

   Scispace http://www.scispace.com

   SciTopics http://www.scitopics.com

   2collab http://www.2collab.com

   epws http://epws.org/

   labmeeting http://labmeeting.com

   Lumifi http://lumifi.com/

2. Sites excluded because they are not intended for scholarly communication and

   collaboration

   Facebook http://www.facebook.com

   LinkedIn http://www.linkedin.com

   Ning http://www.ning.com

   Twitter http://twitter.com

   Google Docs http://docs.google.com

   Office Live Workspaces http://workspace.officelive.com

   Zoho http://docs.zoho.com

   Thinkfree Online http://www.thinkfree.com

   Box http://www.box.net

   Skydrive http://skydrive.live.com

   4shared.com http://www.4shared.com

   Mediafire http://www.mediafire.com

   Megaupload http://www.megaupload.com

Rapidshare http://www.rapidshare.com

SlideShare http://www.slideshare.net

Zentation http://www.zentation.com

Prezi http://prezi.com

Videolectures http://videolectures.net

Issuu http://www.issuu.com

Scribd http://www.scribd.com

Calameo http://es.calameo.com

Survey Monkey http://www.surveymonkey.com

Survey Gizmo http://www.surveygizmo.com

Free Online Surveys http://freeonlinesurveys.com

SurveysPro http://www.esurveyspro.com

Limesurvey http://www.limesurvey.org

Zoomerang http://www.zoomerang.com

E-surveys Pro http://www.esurveyspro.com

Kwik surveys http://www.kwiksurveys.com

Diigo http://www.diigo.com

Delicious http://www.delicious.com

H2O Playlist http://h2obeta.law.harvard.edu

StumbleUpon http://www.stumbleupon.com

AddThis http://www.addthis.com

Digg http://digg.com

Google Scholar http://scholar.google.com

Microsoft Academic Search http://academic.research.microsoft.com

CentralDesktop http://www.centraldesktop.com/

Saba http://saba.com/

3. Sites excluded because they do not offer free and open registration

Emerald Research Connections

http://info.emeraldinsight.com/research/connections/index.htm

Mister Wong http://www.mister-wong.es

DRIVER http://search.driver.research-infrastructures.eu

CollabRX http://www.collabrx.com/

Laboratree http://laboratree.org/

Pingsta http://www.pingsta.com/

arts-humanities.net http://arts-humanities.net/

4. Sites excluded because of the lack of user connection support

Refworks http://www.refworks.com

EndNote Web http://www.myendnoteweb.com/

Bibme http://www.bibme.org

CiteSeerx http://citeseerx.ist.psu.edu

GetCITED http://www.getcited.org

Scholarometer http://scholarometer.indiana.edu

Publish or Perish http://www.harzing.com/pop.htm

Science Blogs http://scienceblogs.com

Open Wet Ware http://openwetware.org/wiki

Nature blogs http://blogs.nature.com

OpenWetWare blogs http://openwetware.org/wiki/Blogs

ScienceDaily http://www.sciencedaily.com

Science News http://www.sciencemag.org

Science 2.0 http://www.science20.com

Research information http://www.researchinformation.info

Agencia DICYT http://www.dicyt.com

BASE – Bielefeld Academic Search Engine http://www.base-search.net

Public Library of Science http://www.plos.org

Sciyo http://sciyo.com

BUBOK http://www.bubok.com

OAIster Worldcat http://oaister.worldcat.org

OpenDOAR http://www.opendoar.org

SSRN http://www.ssrn.com/

globalEDGE http://globaledge.msu.edu/

5.  Sites excluded because they have 10,000 or less registered users. Sites with

unknown user population are also excluded.

Academici http://academici.tribe.net/

HUBzero http://hubzero.org

Bibsonomy http://www.bibsonomy.org

Lalisio http://www.lalisio.com

MyExperiment http://www.myexperiment.org

ScholarZ http://www.scholarz.net

Authoratory http://www.authoratory.com/

European Commission EURAXESS http://ec.europa.eu/euraxess/

SciLife http://scilife.net/

Connotea http://www.connotea.org

Methodspace http://www.methodspace.com

6.  Site excluded because the majority of features are implemented in standalone

software/widgets

Compendium http://compendium.open.ac.uk

FreeMind http://freemind.sourceforge.net

Mindomo http://www.mindomo.com

RefBase http://www.refbase.net

Citation gadget http://code.google.com/p/citations-gadget

Scholar H-Index Calculator

https://addons.mozilla.org/eseS/firefox/addon/scholar-h-index-calculator

eSciDoc https://www.escidoc.org

Zotero https://www.zotero.org/

7. Sites excluded because of the lack of English language support

MADRI+D http://www.madrimasd.org/blogs

Hypotheses.org http://hypotheses.org

Wiki Urfist http://wiki-urfist.unice.fr

Servicio de Información y Noticias Científicas http://www.agenciasinc.es

Wikio http://www.wikio.es

Scientific Commons http://www.scientificcommons.org

Hispana http://hispana.mcu.es

Recolecta http://www.recolecta.net

Appendix B <u>Interview questions</u>

This is the collaboration network among all authors who published in JEE over 2000-2010. Node is author and link is co-authorship in papers. For the purpose of this interview, when I talk about collaboration and professional network, I actually mean co-authorship on academic papers. According to social network theories, the engineering education research community is generally fragmented and therefore there is a need for more collaboration.

(1) What could increase collaboration in the engineering education research community?

(2) What efforts from the community in bringing researchers together do you appreciate the most?

(3) Could you name some of your most frequent or most recent collaborators?

(4) How did you meet A (collaborator) in the first place?

(5) Why did you make a decision to collaborate with A?

(6) How was your first collaboration experience with A?

(7) What made you continue to work with A since then?

(8) What were the primary computer-based technologies you used to get to know A, keep in touch with A, and collaborate with A?

(9) Why did you prefer it over other technologies?

(10) From first meeting A to now, what is easy in terms of communication and collaboration?

(11) From first meeting A to collaboration, what was the most challenging part for you?

(12) How did you go about solving it?

(13) Before I turn off the recording, do you have any additional comment to make regarding how you develop your professional network and what the engineering education research community could be improved?

Appendix C <u>Researcher memo</u>

I have been working on big-data quantitative research project over my entire PhD phase. I mainly work on analyzing the collaboration networks based on academic publications in engineering education. Documents and authors were all stable and definite measures with very little ambiguity. Therefore, I used to believe that everything can be measured precisely and research questions should be answered in a definite way. I learned some basic concepts about qualitative methods in my first year of PhD. I understood and appreciated the value of qualitative research. But this was my first interview experience and in fact, my first qualitative research study. As I designed the semi-structured interview, I immediately realized that there could be many unstructured and uncertain elements in my study, which were uncommon in my past projects. As I learned more about qualitative methods, I became more comfortable with this new territory. I started to see myself as a qualitative researcher.

I collected the participants' names, locations for our meetings, and their photos before the ASEE conference. Although I have not met my interviewees, I had a sense of who they were because I had data about their past publications and collaborators. I tried not to be biased by the data and kept treating all the participants the same. I was quite nervous until I talked with my first interviewee. Although all interview questions had been defined clearly beforehand, the way the interviewees replied was quite different from what I expected. Their replies often addressed questions that I would later ask. Or they might revisit questions that they already replied earlier in the interview. I kept myself as alert as possible to catch these messages and dynamically rearrange the

interview questions according to their replies. After two interviews, I felt much more experienced in dealing with such situations. As I interviewed more people, I started to see patterns from the data. However, I tried not to expect the same input from the subsequent interviewees. As themes started to emerge, the significance of time-related issues, importance of academic conferences, and participants' preferences towards using emails were all my expectations. Meanwhile, participants' strong resistance to social networking software and the variety of difficulties encountered during scholarly collaboration were beyond my expectation.

The experience I obtained from this study really has shaped my belief that qualitative research can be a powerful tool to address many questions that quantitative methods cannot answer. I can feel my growth and experience gain during this process. I also think that in the future, I will be prepared and very comfortable with conducting qualitative studies.

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VITA


Hanjun Xian
School of Engineering Education, College of Engineering, Purdue University


<u>Education</u>
B.S., Computer Science, 2006, South China University of Technology, Guangzhou, China
M.S., Computer Science, 2008, Sun Yat-sen University, Guangzhou, China
Ph.D., Engineering, 2013, Purdue University, West Lafayette, Indiana


<u>Research Interests</u>
Data mining, social network analysis, visual analytics, scholarly collaboration, and scientometrics.


<u>Honors and Awards</u>
Apple Academix 2009 Best Poster Award (3<sup>rd</sup> place)