A Framework of Virtual Collaboration Building Interdisciplinary Research

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Abstracts

The transformative potential of virtual communication argues for extending interdisciplinary collaboration. Due to the complexity of the topic, there is a need to establish a common base to understand the emergence and sustainability of virtual research collaboration, informally between networks of colleagues and formally within established teams and organizations. Thus, the authors developed a framework addressing virtual collaboration effectiveness for interdisciplinary research and choose a new emerging field of engineering education research as the context.

Introduction

Much scholarly work has been done on the topics of virtual team, but there is little consensus among researchers on the holistic and working dynamics for the sustainability of virtual organizations. There have been several comprehensive reviews about how to promote collaborative performance capabilities within entrepreneurial situations focusing on individual perceptions about team communication (e.g. leadership, trust, conflict management, etc.) (Jarvenpaa & Leidner, 1999; Hollingshed et al. 1993; Steinfeld, 2002). These works are mostly based on the classic works of researchers such as McGrath (1984), Hackman (1987), and so on, who expressed the nature of team performance following the systems theory in which inputs lead to processes, which in turn lead to outcomes: Input-Process-Output (IPO) model. The IPO model explains the causal effect in a linear direction (e.g. the process can’t influence the inputs). However, virtual collaboration is complex adaptive systems, in which processes also influence the inputs over time, and the relationship is not linear. Therefore, this type of linear approach is difficult to capture the full dynamics of virtual collaboration highlighting the reciprocal interaction of human actors and structural features of organizations over time, especially in the context of research enterprises.

For any interdisciplinary discipline, it is critical to chart its birth and growth to understand where the discipline stands and what innovative endeavors lead to the creative accomplishments currently witnessed in its knowledge products. But, it is challenging to have well-described bodies of knowledge for their research, and an accepted terminology and vocabulary. Because, first of all, neither there is consensual agreement on the definition of interdisciplinary research, nor are there widely recognized, valid, and reliable measures of interdisciplinary research activity or output. Even what to consider as the “disciplines” among which interdisciplinarity would occur is messy. Then, how do we know when large-scale interdisciplinary research collaborations are happening? Also, how do we know that research utilizing large datasets attracts a large number of researchers to utilize these datasets? Can we take a data-driven approach to clearly point out trends in interdisciplinary research productivity and collaboration?

To explore these ideas, it is attempted that a theoretical base is established to empirically investigate the evolution from loose network into more purposeful virtual organizations in one particular interdisciplinary setting: engineering education research (EER). EER aims to produce empirical results to advance the teaching and learning of engineering by conducting interdisciplinary research. According to the call for radically rethinking education research to include large scale data and collaborations, there is an urgent need to understand the boundaries of the EER field, its contributors and, structures and processes underlying the collaborations between researchers. In response to the urgent need, the focus of this paper was on ‘virtual research collaboration’ and ‘interdisciplinary knowledge producing interaction’ within EER.

Literature Review

Scientific Collaboration

Collaboration plays a critical role for scientific research, which is dominated by complex problems, rapidly changing technology, dynamic growth of knowledge, and highly specialized areas of expertise. Scientific discoveries are considered collaborative products of scientists working together rather than in isolation. Scientific
collaborations are thus simultaneously shaped by social norms of practice and prevailing knowledge structures as well as available and evolving technological infrastructure within and across scientific disciplines. Scientific collaboration has been defined in the bibliometric literature as the set of interaction taking place within a social context among two or more scientists that facilitate the sharing of meaning and completion of tasks with respect to mutually shared, super ordinate goals. For research on scientific collaboration, documents are considered as valuable sources to constitute a core knowledge repository as they detail important scientific investigations or development efforts, and report key experiments or analysis results.

There are three major streams using these documents in terms of the analysis of scientific productivity: text mining, information visualization, and network analysis (Chen & Paul, 2001). Text mining extracts important relationships or patterns from a collection of textual documents, and evaluates and interprets those patterns (Chen & Chau, 2004). It reveals important subjects or topics embedded in the title, abstract, or main body of documents. Information extraction is capable of extracting important entities of interest from structured texts effectively and efficiently. The authors document on the basis of author, institution, topic area, and region, and analyzes them to identify important themes, patterns, or trends (Chen & Paul, 2004). Network analysis is also central to knowledge mapping as it can be used to segment subgroups of scientists and researchers, identify key people in a network, reveal their interaction (e.g. collaboration) patterns, and depict the overall network organization or structure (Chen & Paul, 2004). Several essential measures have been developed to characterize each individual node’s role in a network; e.g. degree, betweenness, and closeness (Wasserman & Faust, 1994). The degree of a node describes the number of direct links it has. The betweenness of a node depicts the number of geodesics, i.e., the shortest path between any two nodes passing through the node. And the closeness of a node denotes the number of all the geodesics between that node and every other node in the network (Hu et al., 2011).

Organizational Network Analysis

To understand the overall knowledge landscape, the authors empirically explored scientific collaboration in the EER at the different levels; the individual level, the group level, the organizational level or at the level of the scientific institutions. Classifying engineering education research organizations into specific categories on the basis of organizational structure presents a challenge to existing theoretical frameworks on account of the multiple levels of analysis at which network and other organizational structures may be characterized within the trans-disciplinary domain of engineering education.

In order to research the emergence of a larger community we have to take into account that networks and organizational structures do not fit neatly into established schema provided by established literature on virtual organizations and network structures. Organizational structures within the domain of engineering education include: (a) Intra-university organizational structures such as engineering education departments (e.g. at universities such as Purdue and Virginia Tech) and other organizations which exist at the intra-university level (e.g. the Engineering Education Research Center (EERC) at Washington State University and the Institute for P-12 Engineering Research and Learning (INSPIRE) at Purdue), (b) Inter-university organizations which exist as collaborations between researchers across U.S. universities (e.g. the Center for the Advancement of Engineering Education (CAEE) and the Center for the Integration of Research, Teaching, and Learning (CIRTL), (c) Network organizational structures which emerge and exist at the national and international level (e.g. the ASEE and its various divisions, SEFI, IGEP, and REEN).

Given the breadth of organizational structures which exist within the EE and EER domain the central problem from an analytic perspective is to employ theoretical constructs relevant to the structure of organizations, and the process of organizing. Such constructs will provide a unit of analysis (such as a team, a virtual organization or a network) that is meaningful and relevant to an analysis of the emergence and sustainability of various types of organizations within the domain of engineering education. Given the need for studying organizational structures flexibly across multiple levels of analysis, we propose to study the emergence and sustainability of these organizations using four distinct conceptualizations of organizational structures and the organizing process.

Personal Network Analysis

The personal network analysis in our research focuses on the collaboration in engineering education research and the components included in our analysis follow Chiu, Hsu & Wang (2006)’s knowledge sharing model, which is based on the social cognitive theory and social capital theory. The social cognitive theory defines “human behavior as a triadic, dynamic, and reciprocal interaction of personal factors, behavior, and social network (system)” (Chiu et al., 2006: 1873). According to the gist of this theory, personal outcome expectations and community-related outcome expectations are the factors that influence human functions (Chiu et al., 2006).
In our research framework, the personal outcome expectations and the community-related expectations make up the first part of the personal network analysis. The personal outcome expectations refer to a member’s judgment of the likely consequences that his/her membership will bring to himself/herself. The community-related outcome expectations refer to a member in a virtual engineering education research and collaboration’s judgment of the likely consequences that his/her membership will bring to the organization.

The second part of the components in the personal network analysis complements the outcome expectations to measures the influence of social networks of virtual engineering education research communities on individuals’ behavior. The components herein are based on the social capital theory. As social capital is the “features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit” (Putnam, 1995: 66), it is a relevant notion to virtual communities because it indicates an abstract hidden source that can be tapped when members in a virtual community interact and collaborate with each other (Chiu et al., 2006; Daniel, McCalla & Schwier, 2002). Based on our review of the social capital literature, we will be employing the following operational definition for social capital in virtual engineering education research communities: a common social resource for people conducting engineering education research to support information exchange, knowledge sharing, and knowledge construction through interaction, built on shared understanding and emotional connection, trust, mutuality, professional identity, subjective norm and maintained through social participation, plurality and social protocols. The following table demonstrates the operational definitions of components included in our framework:

- **Social Interaction Ties:** Strength and depth of the relationship and communication frequency among members in a virtual scientific research organization and collaboration. They are the channels for information and resource flows in virtual communities where members seeking for knowledge-based communication (Chiu et al., 2006; Peters & Manz, 2007; Chen et al., 2009; Tsai & Ghoshal, 1998; Nahapiet & Ghoshal, 1998; Wasko & Faraj, 2005)
- **Shared Understanding:** A member’s knowledge of the strategic direction of the virtual community; other members’ roles, responsibilities, specific expertise and needs; research tasks; and the virtual environment of scientific research (Peters & Manz, 2007; Schwier & Daniel, 2006)
- **Shared Emotional Connection:** Shared history and crisis, investment of time and resources, honor and humiliation, and spiritual bonds among members of virtual scientific research organization and collaboration (McMillan & Chavis, 1986)
- **Trust:** A member’s expectation that other members in a scientific research organization and collaboration will follow a set of values and principles. It is the level of certainty that one community member uses to assess the action of another member (Chiu et al., 2006; Schwier & Daniel, 2006; Peters & Manz, 2007).
- **Mutuality:** A members of a virtual scientific research organization and collaboration construct purposes, intentions, and the types of interaction interdependently. The information exchanges and the research collaboration are mutual and reciprocal among members (Chiu et al., 2006; Schwier & Daniel, 2006)
- **Professional Identity:** A member’s sense of belonging to a virtual scientific research organization and collaboration and his/her positive feeling towards the community (Chiu et al., 2006).
- **Subjective Norm:** A member’s perceptions of whether the behavior is accepted, encouraged, and implemented by virtual scientific research organization and collaboration (Chen, Chen, & Kinshuk, 2009).
- **Social Participation:** A member’s social participation in a scientific research organization and collaboration, especially the participation that sustains the virtual community (Schwier & Daniel, 2006).
- **Plurality:** A member’s “intermediate associations” such as families, friends and other peripheral groups that he/she uses to enrich the virtual scientific research organization and collaboration (Schwier & Daniel, 2006).
- **Protocols:** Social protocols refer to the rules of engagement, acceptable and unacceptable ways of behaving in a virtual community of scientific collaboration (Schwier & Daniel, 2006).

**Preliminary Results**

Building on prior theoretical and methodological insights from social studies of science and bibliometrics, we address here a keyword-based scheme to identify significant trends and patterns in EER. We selected K-12 Engineering Education (K-12 ENE) as a sub-discipline in the EER research arena. Most K-12 ENE relevant publications have been published in the past 10 years, indicating that the field of K-12 EER is relatively new. The authors conducted a bibliometric analysis to discover the emergence and development of this sub-discipline by
establishing a keyword-based scheme. The keyword-based scheme offered the benefit of defining K-12 EER in terms of its vocabulary and offered a universal approach that is currently primarily used for most electronic sources. And this bibliometric data gathered using keywords was used to conduct a field analysis and a social network analysis.

Keyword Creation/Refinement/Classification

In order to begin, it was necessary to create a list of keywords by using the 66 keywords from the literature (e.g. Katehi, 2009, 2010). The finalized keyword sets are: K-12, kindergarten, elementary school, middle school, high school, pre-college, children, and P-12. These words also came from the previous two sources. Next, all the keywords were put into three online databases, Web of Science®, Compendex®, and EbscoHost®. These searches also allowed for the addition of words such as, advocat*, student engag*, cooperat*, implement*, facult*, etc. A list of 43 selective and effective (meaning on which produces relevant results) keywords was established. Then, the frequency of each keyword was split into three columns based on decades. These keywords were also divided based on the classification defined earlier; as a result was obtained. Figure 2 shows the cumulative distribution of keywords into the aforementioned categories for the entire duration of 1980-2010.

Keyword Analysis

The analysis of bibliometric data was first done via keyword. An excel file was created with the keywords down the first column and the years broken down into periods of three years from 1980-2010. In addition to the keywords, the narrowing words, teachers, counselors, and pupils, were added to the keyword column. The Web of Science® database sub-database was sorted by year in ascending order. The ‘Keywords’ section of the WoS
database was filtered via ‘Contains…’ for each individual keyword along with the narrowing words. The number of times each word occurred per decade was calculated by Excel and manually inputted into the new Excel file in the corresponding keyword and year range cell. This information was used to create figures 1 and 2.

Social Network Analysis

NodeXL was used for the analysis of author contributions. All co-author relationships were mapped manually. For example, John, Jane, and Grace are authors. As shown in Figure 2, the relationships would be as follows: (1) John-Jane, (2) John-Grace, and (3) Grace-Jane. Single authors were mapped as self-loops (i.e., Bob-Bob). The co-author relationships were inputted into NodeXL®. The data was then mapped. The overall metrics were calculated via ‘Overall Metrics’. Due to the density of the map, it was necessary to choose the top ranked 50 authors based on their degree (i.e., the authors that had the highest degree were used). The map was condensed to these authors by used the ‘Dynamic Filter’ tool in NodeXL® to choose the degree minimum and maximum (11-23). The data was then analyzed manually.

![Figure 2. Social Network Map of K-12 ENE](image)

Research Productivity

The keyword analysis showed that over the past 10 years, there is a spike in K-12 ENE research producing most research and publication in this area. The most frequent keywords are educat*, STEM, stud*, teach*, and curricul*. But, at the same time, the K-12 ENE research began with research that had a very narrow perspective. For example, while in 1980s little or no research had been done in the area of K-12 engineering education and in 1990s research in this area began covering 13 keywords, the research in the 2000s rose dramatically to encompass 42 keywords. Another example is that, whereas there were only 25 keyword occurrences in publications in the 1990s on K-12 ENE in WoS, in the 2000s, this number expanded to 736 keywords occurrences. The keywords and the decades they occurred in has the potential to reveal current trends in K-12 EER. However, this is up for interpretation. The progress of this new field as a whole can be located in figure 3.

![Figure 3. Number of Keyword Relevant Results vs. Decade](image)
Limitations

Limitations in this specific research project include that only one database, the Web of Science database, was used. This is an ongoing research project and more databases will be analyzed later. Also a large limitation is the possibility that 43 keywords did not capture all K-12 ENE relevant articles from the pre-existing database. However, to cover more articles a larger list of keywords with greater variety would be needed. This could be done by using a greater variety of literature to develop the keywords. An alternate solution would require checking a very large amount of publications (at least thousands) manually for any correlation. This solution was not time effective for the timeline of this project. So it was assumed that the keywords did capture all relevant articles from the pre-existing database. In addition to this, for the demographic analysis a total of 494 articles were captured in acquiring the data. However, it is assumed that this analysis is still accurate, because the other articles could be general to K-12 ENE as a whole.

Figure 4. Word Cloud from the Publications 1980-2010

Conclusion

The bibliometric analyses show that engineering education research began in the last 10 years and has developed to cover a greater number and variety of keywords in the more recent years, which indicates how the field has reached a high level of academic standard. The word cloud (figure 4) reveals that the most popular words were engineering, education, learning, science, school, STEM, outreach, K-12, children, development, design, robotics, gender and many more.

The classification and demographic analysis show that most researchers have an interest in high school ENE. For this reason, it is safe to assume that many believe high school might be the most vital to the implementation of K-12 ENE. Furthermore, epistemologies and learning mechanisms have been the most widely researched. This may reveal that the field is moving toward implementing K-12 ENE standards, which is why the class of educator’s practice curriculum has been so neglected. The groundwork has been set and now the research on an ENE curriculum will begin.

This reveals that the field of Education, Scientific Disciplines is looking into the benefits of K-12 ENE on their field. This may be the field that will be most impacted and it may be the field that many standards relate to due to the large amount of researchers in this field.

The social network analysis results reveal that there is a high trend of collaboration between authors in the K-12 EER community. Krause, S. was found to be the most collaborative author— who also had a significant position as a bridge for communication for other authors in this field in addition to Roberts, C. The fact that the two most collaborative authors are connected is a good sign; however, more collaboration could greatly improve the field as a whole. Overall, more work needs to be done in this field in order to make more progress.

References


