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Automated Text Data Mining Analysis of
Five Decades of Educational Leadership Research Literature:
Probabilistic Topic Modeling of *EAQ* Articles from 1965 to 2014

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Abstract

Purpose: The purpose of this study is to describe the underlying topics and the topic evolution in the 50-year history of educational leadership research literature.

Methods: We used automated text data mining with probabilistic latent topic models to examine the full text of the entire publication history of all 1,539 articles published in *Educational Administration Quarterly* from 1965 to 2014. Given the computationally intensive data analysis required by probabilistic topic models, relying on high performance computing, we used a 10-fold cross validation to estimate the model in which we categorized each article in each year into one of 19 latent topics and illustrated the rise and fall of topics over the *EAQ*'s 50-year history.

Findings: Our model identified a total of 19 topics from the 1965-2014 *EAQ* corpus. Among them, five topics—inequity and social justice, female leadership, school leadership preparation and development, trust, and teaching and instructional leadership—gained research attention over the 50-year time period; whereas the research interest appears to have declined for the topic of epistemology of educational leadership since the 2000s. Other topics waxed and waned over the last five decades.

Implications: This study maps the temporal terrain of topics in the educational leadership field over the past 50 years, and sheds new light on the development and current status of the central topics in educational leadership research literature. More importantly, the panoramic view of topical landscape provides a unique backdrop as scholars contemplate the future of educational leadership research.

Keywords: text data mining, educational leadership, probabilistic latent topic modeling, literature review, high performance computing

INTRODUCTION

Since its inception, educational leadership has been an interdisciplinary field, closely interacting with other fields such as sociology, psychology, and economics, as well as the sub-fields of education such as urban education and teacher education (Bates, 1980; Haller, 1968; Oplatka, 2009; Wang & Bowers, 2016). Over the last 50 years, scholars have surveyed the landscape of educational leadership through examining its research literature (see Bates, 1980; Bridge, 1982; Campbell, 1979; Gunter & Ribbins, 2003; Haller, 1968; Hallinger & Chen, 2015; Hoy, 1994; Murphy, Vriesenga, Storey, 2007; Oplatka, 2009, 2014; Riehl, 2015; Wang & Bowers, 2016) to understand the *amorphous* nature of educational leadership, as termed by Bates (1980). Since the 1960s, educational leadership has evolved into a field with diverse conceptual lenses (Boyan, 1981; Donmoyer, 2001; Willower, 1975), various philosophical propositions (Willower, 1981; Evers & Lakomski, 2012), debatable epistemological issues (Oplatka, 2009; 2012), and diverse methods (Briggs, Coleman, & Morrison, 2011; Heck & Hallinger, 2005). Moreover, some researchers have noted that the education leadership field is subject to shifts and fads as politics and policies come and go and come back again with changes in the political and policy environment (Labaree, 2011; Tyack & Cuban, 1995). As a result, the diversification of the field has left scholars grappling with identifying the topic structure and knowledge base that could help inform not only the field of research in educational leadership, but also leadership practitioners in schools, policymakers, and the future development of the field (Heck, 2015; Oplatka, 2012). The continual development of educational leadership research pivots on an enriched understanding of the topics and topic evolution in the field, as researchers continue to search the field's epistemological identity and contemplate the future of the field.

To date, the common practice to identify the topics in the educational leadership literature is to allow the topics to emerge as researchers examine, code, and classify the literature, consisting mostly of journal articles (e.g., Campbell, 1979; Hallinger, 2013; Murphy et al., 2007; Oplatka, 2009). However, despite these valuable efforts, the understanding of all topics studied in the educational leadership research literature, and the extent to which they have been studied, has been weak to date. This has led to a lack of understanding of what the research literature in educational leadership has focused on, and has led to multiple critiques of the knowledge base as to the interdisciplinary nature of the field (Haller, 1968; Levine 2005; Wang & Bowers, 2016). In response to Hallinger's (2014) call for the improvement in the methodology of conducting systematic reviews of research in education leadership, in this study we build on recent innovations in the field of automated text data mining and machine learning to apply probabilistic topic modeling—a suite of automated text mining algorithms that computationally detect latent topic structures from a corpus of documents such as journal articles—to investigate the nature of topics in the educational leadership research literature. As *EAQ* has been consistently regarded as the most prestigious research journal in the field (Campbell, 1979; Cherkowski, Currie, & Hilton, 2011; Haas, Wilson, Cobb, Hyle, Jordan, & Kearney, 2007; Murphy et al., 2007; Richardson & McLeod, 2009; Wang & Bowers, 2016), we use probabilistic topic modeling to empirically derive the latent topics discussed by the research literature across the entire history of *EAQ* starting with volume 1 issue 1 in 1965 up through volume 50 issue 5 in 2014, as a means to build upon the past work of narrative reviews (e.g. Campbell, 1979; Haller, 1968; Murphy et al., 2007). We specifically seek to answer two research questions:

1. What are the topics in the educational leadership research literature over the last 50 years in *EAQ* from 1965 to 2014?

2. How do the topics in *EAQ* change over time, which topics come and go, and which are consistently researched in *EAQ* from 1965 to 2014?

In the subsequent pages, we begin with a literature review on the history of the epistemological identity of educational leadership research, followed by the methodological challenges of research reviews in the field to date. We then introduce probabilistic topic modeling as an innovative approach to analyze and empirically describe latent topics across articles, a technique developed in the field of text data mining and machine learning, which has been used in a wide variety of fields across the social sciences. Next, we provide details of how we applied the probabilistic topic modeling in mining the research literature in educational leadership. The study concludes with a discussion on how the findings of this study contribute to the educational leadership field.

LITERATURE REVIEW

So, one might ask, does the history of the scholarship of education leadership represent incremental change or... punctuated equilibrium? As Donald Willower noted, “the spirit of the times is a slippery concept” (1996, p. 346). Still, looking back, it is hard to characterize education leadership research, theory, and practice over the past several decades in terms of “equilibrium.” In numerous assessments of the field, scholars have portrayed a fairly constant churn of development, disagreement, outright conflict, or contestation (e.g., Willower & Forsyth, 1999). The situation has been stable: flux is constant. (Riehl, 2015, p. 225-248)

An Epistemological Identity of Educational Leadership

What is the epistemological identity (the fields' nature, purpose, knowledge base, interdisciplinary boundaries, etc.) of the field of educational leadership? Over the last 50 years, a stream of studies has been devoted to answering this question, as summarized in Table 1. Here we review in detail these prior studies that examined the topics and interdisciplinary nature in *Educational Administration Quarterly (EAQ)* and other educational leadership journals. Haller's (1968) study might be the first study that presented substantial evidence of the field's interdisciplinary ideology. To apply citation analysis techniques to the field of educational administration, Haller examined article citations in the first three volumes of *EAQ*, and found that 34.2% of citations referred to education, followed by sociology 32.1%, psychology and social psychology 12.8%, political science 7.0%, economics 2.9%, and anthropology 1.2%.

Insert Table 1 here

Along with the interdisciplinary nature of educational leadership, the scholarship in the field is characterized by diverse topics (Hoy, 1978, 1982; Haller & Knapp, 1985; Oplatka, 2009). Over the last 50 years, scholars have surveyed the research literature of educational leadership (see Bates, 1980; Campbell, 1979; Gunter & Ribbins, 2003; Haller, 1968; Hallinger & Chen, 2015; Murphy et al., 2007; Riehl, 2015; Wang & Bowers, 2016) to grasp the *amorphous* landscape of educational leadership, as termed by Bates (1980). As Hoy noted, the research in educational administration “is fragmented and lacks a systemic attack on a series of related problems” (Hoy, 1978, p. 5), and “systematic and cumulative knowledge building is conspicuously absent” (Hoy, 1982, p. 4). Writing more recently, Oplatka (2009) described the

over-diversification and the seemingly limitless expansion of the field as “the big bang” (p. 15). However, not all scholars hold such a pessimistic view. Rather, the diversity in scholarly inquiry in educational leadership “is all to the good. New and varied ideas and approaches, or old ones newly applied, and constructive controversy give a field vitality” (Willower, 1981, p. 115). McCarthy (1986) later echoed, the diversity in the field’s intellectual inquiry is “a positive development that reduces parochialism in the field as a whole” (p. 11). While whether topic diversification is instrumental to the educational leadership field is subject to debate, what scholars have agreed upon is the premise of the debate: the research in the field has been characterized by diverse topics. Below we not only review the studies that examined the research topics in educational leadership, but also present the methodological challenges these studies encountered as the topics continue to diversify across the 50-year history of educational leadership research literature.

At the fifteenth anniversary of the founding of *EAQ*, Campbell (1979), the first editor of *EAQ*, categorized the topics in the first 15 volumes of the journal (1965-1978). Campbell detailed his three attempts to categorize the broad topics addressed in *EAQ* articles, and concluded that developing the categories of topics was “a difficult task and relatively unrewarding” (p. 2). Ten topics (in the descending order of the percentage of *EAQ* articles addressing the topics) identified by Campbell were: politics/policymaking, school finance, decision making, motivation/satisfaction, preparation programs, leadership, administrative behavior, authority/bureaucracy, collective bargaining, and organizational structure.

To examine the state of the art of the research on school administration, Bridges (1982) analyzed 322 research reports published in *Dissertation Abstracts International (the Humanities and Social Sciences)* and seven journals in the field of educational administration (i.e.,

Educational Administration Quarterly, *Journal of Educational Administration*, *Administrative Science Quarterly*, *the Canadian Administrator*, *Administrator's Notebook*, *NASSP Bulletin*, and *the Alberta Journal of Educational Research*) from 1967 to 1980. Bridges outlined seven topics that emerged: attitudes, traits, behavior, impact, expectations, power, and effectiveness. Bridges harshly criticized that the “studies of school administrators are intellectual random events” (p. 22) and “the more things change, the more they remain the same. The state-of-the-art is scarcely different from what seemed to be in place nearly 15 years ago” (p. 24). According to Bridges at the time, given the field’s excessive obsession on the topics of administrators’ traits and attitudes, Bridges proposed that “studies that merely describe the traits or attitudes should be discontinued unless they shed light on a problem of practical, social, or theoretical significance” (p. 26).

Amid “a great uncertainty and lack of consensus about content—the relevant knowledge for practice and inquiry in educational administration” (Hoy, 1994, p. 178), the University Council for Educational Administration (UCEA) Executive Committee appointed seven study teams, each of which had three to six scholars, to “map the essential knowledge for educational leaders” (p. 179). The appointed 30 scholars worked for two years to define the knowledge base in the field. Despite the lack of unanimous agreement by the scholars in seven teams, seven domains of knowledge were identified as the essential knowledge for educational leadership: societal and cultural influences on schooling, teaching and learning processes, organizational studies, leadership and management processes, policy and political studies, legal and ethical dimensions of schooling, and economic and financial dimensions of schooling. Further, Hoy outlined three common themes across the seven knowledge domains in the educational leadership field: (1) goals of education; (2) the analytical paradigm tensions among the traditional methods to test and verify generalizations, theories of positivists sciences, and

emerging procedures and perspectives of interpretivists, constructivists, radical humanists, structuralists, and feminists; and (3) the elusive links between causes and effects.

Murphy et al. (2007) built upon Campbell's (1979) work to identify the topics in the field. Using the articles published in *EAQ* from 1979 to 2003, Murphy et al. coded the topics as they emerged across time. By doing so, twelve topics were identified: organizational theory, profession of school administration, politics, school reform, core technology, gender and race, personnel, law, economics and finance, work of school leaders, philosophy and ethics, and psychology. Murphy et al. also shared Campbell's (1979) lamentation that categorizing *EAQ* articles by topics was "exceedingly arduous" (Murphy et al., 2007, p. 619).

Most recently, Oplatka (2009) outlined the field's historical landscape and epistemological boundaries in his historical overview of educational leadership scholarship. Drawing upon the literature in the three oldest and prestigious journals in the educational leadership field (*Educational Administration Quarterly*, *Journal of Educational Administration*, and *Educational Management Administration & Leadership*), Oplatka used open coding to analyze the study purposes, arguments, epistemological questions, criticism, findings, and insights of the papers that addressed the philosophical, epistemological, and methodological issues in the field. Oplatka found that topics in the field evolved over time: from social science-based topics such as rational planning, democratic leadership, and school finance in the 1960s and the 1970s, education-oriented topics such as value and equity, motivation, organizational culture and climate, and management/policy interface in the 1980s, public and political pressure-driven topics such as policy studies, principal preparation programs, and the quality of research and programs in the 1990s, to the critical reflections on the field between 2000 and 2007 within the context of globalization. Despite Oplatka's comprehensive and exhaustive review, he noted

that it was impossible to adequately identify the tremendous variety of the topics that have been studied in the field, because of the continuously extended knowledge boundaries of educational leadership.

Building upon Campbell's (1979) and Murphy et al.'s (2007) work, Wang and Bowers (2016) constructed and visualized an educational administration journal citation network by extracting 157,372 citations from 5,359 journal articles in 30 educational administration journals from 2009 to 2013. The eight journal clusters detected in the citation network suggest that educational administration is a porous, outward-facing field, intimately interacting with the sub-fields of education (e.g., urban education and teacher education), other disciplines (e.g., economics, human resources, sociology, and psychology), and the research internationally.

Overall, across this line of literature there appears to be a consensus that the fuzzy epistemological boundaries are a major concern of the field, which has been inadequately addressed by the research community to date (Oplatka, 2009). Moreover, none of the previous studies longitudinally depicted the entire history of the topic evolution from the 1960s to this day, despite Oplatka's (2009) remarkable review from 1960s to 2007. This is probably because the ever-growing body of research literature poses enormous methodological challenges in conducting research reviews. Recently, Hallinger (2014) stated that reviews of research are critical for the educational leadership field in terms of knowledge generation and accumulation. However, this critical role of reviews of research has been underappreciated. After conducting a "methodological review of the reviews of research in educational leadership and management" (p. 539), Hallinger called for the improvement in the methodology of conducting systematic reviews of research in educational leadership. However, thus far no methodological approach in educational leadership and in education has surmounted the challenge of analyzing the sheer

massive amounts of text data represented across a large and complex body of research journal articles. Therefore, in the present study, we look to the emerging fields of text data mining and machine learning, because these fields are driven by the “big data” analytical and technical demands of the influx of high volume, high velocity, and high variety of data generated from digital devices, sensors, and social media (boyd & Crawford, 2012; Kitchin, 2014). Here we first introduce probabilistic topic modeling which is a scalable, algorithmic approach to analyze text data (Blei, 2012), and then discuss how we apply it to the educational leadership field as we traced the field’s roots back to the 1960s to examine the topic structure of the field.

Correlated Topic Modeling

Correlated topic modelling (Blei & Lafferty, 2007), a subdomain of latent semantic analysis, is a statistical model that automates text analysis, which we used in this study to empirically identify the latent topic structure across *EAQ* articles. The goal of topic modeling is to use the observed documents (in this case journal articles) to automatically infer a *latent topic structure*—the topics, per-document topic distributions, and the per-document per-word topic assignments (Blei, 2012). Traditionally, one does not know the topic of a journal article until we read and cognitively process the article. The distinguishing characteristics of topic modeling is a departure from a researcher’s cognitive process to a suite of automated algorithms, which computationally detects the topic structure without any prior annotation or labeling of the documents. Topic modeling analyzes the correlations and variance-covariance information between the sparse words by documents matrix, and then through matrix algebraic calculations, generates a matrix of terms by latent topics and a matrix of topics by documents. This technique is colloquially referred to in the latent semantic analysis literature as a “bag of words” model (Stein & Griffiths, 2007), as each document is considered to be a bag holding a jumbled set

of words, as the frequency of words found in each document is correlated to each of the other documents in the dataset, with no assumptions implied about word order or phrase linkages.

More specifically, probabilistic topic modeling is a statistical modeling technique that automates the analysis of detecting latent topics across documents in a large corpus of documents, such as across newspaper articles (see Yang, Torget, & Michalcea, 2011) or journal articles (see Blei & Lafferty, 2007). Topic modeling is predicated on the assumption that each document exhibits multiple topics; each topic is a distribution of words in the corpus; and the topics can be generated inductively based on the probability of co-occurrence of words (Blei, 2012).

In topic modeling, a *topic* is defined as a distribution over the words used in the corpus (Blei, 2012). These words are the only *observed variables*. For any given topic, there is a corresponding distribution over all the words in the corpus, and the topic modeling provides the most likely words with high probability with respect to each topic. For example, the high-probability terms, such as “life”, “abort*”, “babi*”, “life”, and “ban”, describe the *abortion* topic identified in Quinn et al.’s (2010)’s topic model of over 118,000 speeches in the U.S. Senate (Quinn, Monroe, Colaresi, Crespin, & Radev, 2010); the high-probability terms, such as “human”, “genome”, “dna”, “genetics”, and “genes”, describe the *genetic* topic identified in Blei’s topic model of approximately 17,000 articles from the journal *Science* (Blei & Lafferty, 2007); the high-probability terms, such as “facilities”, “acquiring”, “refurnishing”, “constructing”, and “equipping”, describe the *school facility equipment* topic identified in Bowers and Chen’s (2015) topic model of 1,210 school district capital facility bond election ballot proposals in Michigan. In this technique, the topics emerge from the high-probability terms.

Probabilistic topic modeling is different from conventional text data analysis in a couple ways. First, the scalable, algorithmic approach in topic modeling frees up human labor, and enables us to analyze large corpora at a scale that would be infeasible by human annotations, such as analyzing tens of thousands of journal articles (see Blei & Lafferty, 2007). Second, topic modeling prevents implicit manual coding bias. Instead of being predefined by researchers, the topics are generated inductively by the topic modeling algorithms, thus the latent topic identification is not subject to the constraints of researcher knowledge. To this end, topic modeling is well-suited to analyze large amount of text data, and has proved valuable in many fields in the social sciences. It was used to extract the latent topics from over 73 million words in 118,065 speech documents in the U.S. Senate as recorded from the 1995-2004 Congressional Record (Quinn et al., 2010), to study the history of topics in the field of computational linguistics from 1978-2006 (Hall, Jurafsky, & Manning, 2008), to identify the topics in 16,351 *Science* articles from 1990-1999 (Blei & Lafferty, 2007), and to detect public opinion in the field of public policy via the text data acquired from blogs and social networking sites such as Twitter and Facebook (Zhang & Ma, 2015).

While topic modeling is a rapidly developing field (Blei, 2011, 2012; Grün & Hornik, 2011; Hofmann, 1999; Junque de Fortuny, Martens, & Provost, 2013; Lee, Song, and Kim, 2010; Ponwiser, 2012, Steyvers & Griffiths, 2007), its scalable, algorithmic approach has received little attention among educational leadership scholars. The increasing applications of topic modeling in a variety of fields in the social sciences suggests the promising potential of applying topic modeling to the field of educational leadership. As a means to build upon the past research reviews of educational leadership research literature (e.g. Bridge, 1982; Campbell, 1979; Haller, 1968; Hoy, 1994; Murphy et al., 2007; Oplatka, 2009; Wang & Bowers, 2016) and to address the

methodological limitations of conventional text data analysis, we apply topic modeling to identify the latent topics in the research literature across the entire history of *EAQ* for the first time, starting with volume 1, issue 1 in 1965.

METHODS

The journal *Educational Administration Quarterly* (*EAQ*) was chosen because it has been consistently considered as the most prestigious journal in educational leadership research (Campbell, 1979; Cherkowski et al., 2011; Haas et al., 2007; Murphy et al., 2007; Richardson & McLeod, 2009; Wang & Bowers, 2016). Below we present in detail how we applied topic modeling to all articles published in *EAQ* from 1965 to 2014. We illustrate an overview of the research design in Figure 1.

Insert Figure 1 here

Data Collection

The collection of all *EAQ* text data itself was a non-trivial task. First, we assembled all *EAQ* articles. With the permission of the *EAQ* publisher Sage, the *EAQ* editor, and the UCEA Executive Director, we downloaded from the *EAQ* website (<http://eaq.sagepub.com/>) all articles from volume 1 issue 1 published in January 1965 to volume 50 issue 5 published in December 2014. To acquire *EAQ* text data in an efficient manner, we used Casper JS (Perriault, 2011)—an open source Java script—to automate the navigation of the *EAQ* website and the download of all *EAQ* articles. Next, we excluded articles that were announcements and calls for proposals, because the text data in these documents did not provide substantive content on research studies.

We did so by identifying whether the *EAQ* article titles contained the texts of “William J. Davis Memorial Award”, “Acknowledgement of Reviewers”, or “Call for Proposals”. It is worth noting that “The Editor’s Desk” and “Editor’s Foreword” were included in this study, because of the text data in these documents were considered closely related to the published articles in *EAQ*. “The Authors” were also included in this study’s data collection. This is because unlike the articles in 2003 and thereafter that include the authors’ biography in the same documents as the text of the article, *EAQ* compiled author biographies and published them in separate documents titled “The Authors” from 1987 to 2002 (i.e., from *EAQ* volume 23 to 38). To ensure the consistency of the data inclusion, we thereby included the “The Authors” in the *EAQ* corpus. Moreover, “Essay Reviews” and “Book Reviews” were also included, because a recent study suggested that books and reports have been the major source of the knowledge base in the field of educational leadership (Wang & Bowers, 2016).

Lastly, we used Optical Character Recognition (OCR) technology (Smith, 2015) to convert all of the text data in *EAQ* articles from PDF format to .txt (i.e., text) format. We used OCR to extract text data because not all *EAQ* articles were digitized, particularly the articles from volume 8 to 24 (see Fikis, Wang, & Bowers, 2015, for the evidence of digitized and undigitized *EAQ* articles according to the file size in bytes of the PDF text import). As a result, every word in each *EAQ* article was retrieved, including article title, author, main manuscript, in-text citations, and references. While some text mining studies in other disciplines only analyzed the text data in article abstracts (e.g., Evangelopoulos, Zhang, & Prybutok, 2012; Sidorova, Evangelopoulos, Valacich, & Ramakrishnan, 2008), we followed the current recommendations from the journal text-mining literature (Blei & Lafferty, 2007) and included the full text of all articles, because the data from full text articles provide a deeper analysis of each article than just

the abstracts alone. Further, given that the citation patterns in research literature manifest the knowledge structure of a field (Narin, Carpenter, & Berlt, 1972; Price, 1965), we included the text data regarding the in-text citations and references in our study. All text data in the 1,539 *EAQ* articles are termed as the *EAQ* corpus from here onward.

Data Processing

To prepare the *EAQ* corpus for probabilistic topic modeling, we performed several necessary text data processing operations, including word segmentation (Peña, Bonatti, Nespor, & Mehler, 2002; Yang, 2002), stemming (Hull, 1996; Porter, 1980), and stop-word removal (Baeza-Yates & Ribeiro-Neto, 1999; Manning, Raghavan, & Schütze, 2008). Thereafter, each *EAQ* articles' text data was represented by a vector of words (also called terms). We then generated the *EAQ* document-term matrix, in which each row represents an *EAQ* article and each column represents a unique word in the *EAQ* corpus. The dimension of the *EAQ* document-term sparse matrix is $1,539 \times 119,303$, with each of 1,539 *EAQ* articles as a row and each of 119,303 words in the *EAQ* corpus as a column.

Next, following the recommendations for probabilistic topic modeling (Steyvers & Griffiths, 2007; Grün & Hornik, 2011), we prepared the text data for analysis by removing extremely low frequency words as well as extremely high-frequency words—such as “and”, “the”, and “for” that contain little topical content by calculating an optimal $tf-idf = 0.0022$, which is the product of the overall term frequency (tf) by the inverse document frequency (idf). Setting $tf-idf$ slightly lower than the median $tf-idf = 0.002295$ allows us to exclude from the analysis both high and low frequency words in the *EAQ* corpus. Thus, the *EAQ* document-term matrix generated from the cleaned corpus for probabilistic topic modeling is $1,539 \times 100,766$, meaning 1,539 documents and 100,766 words are included for the analysis.

Data Analysis and Model Fitting

The data analysis and model fitting for the probabilistic *EAQ* topic modeling was performed using the open source statistical computing software *R* 3.1.3 (*R* Development Core Team, 2014). The *R* code for the data analysis and model fitting is given in the Appendix. As noted earlier, a *topic* is defined as a distribution over the words used in the corpus (Blei, 2012). In topic modeling, the words are the only *observed variables* (W); the *latent variables*, on the other hand, are the topic structure—the per-document topic proportions (θ), the per-document per-word topic assignments (Z), and the topics (β) (Blei, 2012). To generate the most likely words with high probability with respects to each topic, first, assuming each document (*EAQ* articles in this case) exhibits its topics in different proportions, a distribution over topics is randomly chosen, thus the topic proportions for the d th document are θ_d , where $\theta_{d,k}$ is the topic proportion for topic k in document d . Then in document d , a topic is randomly assigned for the n th word (W). Therefore, the joint distribution of the hidden variables (θ , Z , and β) and observed variables (W) is:

$$p(\beta_{1:K}, \theta_{1:D}, Z_{1:D}, W_{1:D}) = \prod_{i=1}^K p(\beta_i) \prod_{d=1}^D p(\theta_d) \left(\prod_{n=1}^N p(Z_{d,n} | \theta_d) p(W_{d,n} | \beta_{1:K}, Z_{d,n}) \right)$$

Note that the topic assignment $Z_{d,n}$ depends on the per-document topic proportions θ_d ; the observed word $w_{d,n}$ depends on the topic assignment $Z_{d,n}$ and all of the topics $\beta_{1:K}$. This process thus generates the high-probability terms that define a topic in the corpus (see Blei, 2012, for a thorough explication of probabilistic topic modeling).

Following the recommendations of the topic modeling literature (Arlot, 2010; Blei, Ng, & Jordan, 2003; Grün & Hornik, 2011), we applied a 10-fold cross validation to the dataset and examined the topic by perplexity plots, identifying $k=20$ as the optimal number of latent topics,

as this model had the lowest perplexity out of models from $k=2$ to $k=41$. However, this type of computation across this large of a dataset is highly computationally intensive, making it infeasible to run models on currently available individual computers. To address this issue, we conducted the data analysis using high performance computing (Fikis et al., 2015), through the Batch Linux Computer VELA which is comprised of ten mutually exclusive servers run in parallel (University Research Services & Administration, 2015). Thus, through leveraging high performance computing, the data analysis and model fitting in this study could be completed 40 times faster than a single desktop computer. Still, it took over 12 hours to finish the entire data analysis and model fitting using high performance computing, which is a non-trivial concern for future research in this area.

RESULTS

This study is the first text data mining analysis of the research literature in the field of educational leadership. The purpose of this study is to describe the underlying topics and topic evolution over the last 50 years. Here we first present our findings from the probabilistic topic models, describing 20 topics identified across the 1965-2014 *EAQ* corpus, and detail the longitudinal change of topics as a means to understand the development of the field since the 1960s. We then turn to a discussion of the findings and the potential applications of text data mining and probabilistic topic modeling in educational leadership research.

Major Topics

The topic model fit the data well. Our topic model identifies many of the topics previously suggested in the past literature (see Table 1), as well as some that have not been explicitly stated in the past. In addition to identifying the total number of latent topics, we also

identified the percentages of articles categorized to each topic and were able to plot the topic changes over time. Table 2 presents the high-probability terms from the $k = 20$ topic model for each of 20 topics in the 1965-2014 *EAQ* corpus. For each topic, we list the 10 high-probability terms that best distinguish the topics from one another. Overall, across the 50-year time period, we found 20 topics emerged from the *EAQ* corpus: inequities and social justice, epistemology of educational administration, district collective bargaining, female leadership, organizational studies, international context, research reviews and reflections, policymaking and government, faculty of educational leadership and higher education, profession of school leaders, school leadership preparation and development, trust, legal perspective and accountability, education finance, teacher recruitment and retention, qualitative method, teaching and instructional leadership, quantitative method, school effectiveness, and non-specific. Note that while our topic model identified Topic 20, labeled as the non-specific topic with the high-probability terms (teachers, leader, principal, pupil, achievement, etc.), no *EAQ* article was classified as this non-specific topic because none of *EAQ* articles' probability for this topic exceeded the rest of 19 topics. We thus, from here onward, focused on the 19 topics, each of which has a certain number ($n > 0$) of *EAQ* articles classified to a specific topic.

 Insert Table 2 here

Together, a quarter (23.4%) of all articles published in *EAQ* are classified as either the epistemology of educational leadership topic (topic 2, 12.7%) with high-probability terms such as “epistemology”, “philosophy”, “scientific”, “scholarship”, “paradigm” and “positivist”, or the research reviews and reflections topic (topic 7, 10.7%) with high-probability terms such as

“Campbell” (the first editor of *EAQ*), “dialogue”, “scholarship”, “manuscript”, and “reader”. To provide a close look at the topics, we present example articles with high probability in the *EAQ* corpus in Table 3. For instance, regarding the topic of epistemology of the field (topic 2), we found the articles in *EAQ*’s 1983’s special issue on the subject of “Educational Administration 1959-1981: A Profession in Evolution” (e.g., Fogarty, 1983; Culbertson, 1983). Regarding the topic of research reviews and reflections, we found the articles in which *EAQ*’s past, present, and future were reflected (see Pounder & Johnson Jr., 2007); *EAQ*’s influence on the field was assessed (see Haas et al., 2007); and the research in educational leadership was empirically reviewed (see Hallinger, 2013).

Insert Table 3 here

Research methods topics are also a highly represented set of topics across the documents. Specifically, the topics that are related to research methods make up 11.8% of the articles in the entire *EAQ* corpus: quantitative method (topic 18, 6.8%) with high-probability terms such as “variable”, “correlate”, “hypothesis”, “interdependent”, and “predictor”, and qualitative method (topic 16, 5.0%) with high-probability terms such as “cognitive”, “metaphor”, “symbol”, “trait”, and “artifact”. In the articles classified as the topic of quantitative method (topic 18), for instance, the methodological concerns in the study of school principals’ job satisfaction were discussed (see Friesen, Holdaway, & Rice, 1983); the scale of group-level organizational citizenship behavior was reconstructed and validated (see Vigoda-Gadot, Beerli, Birman-Shemesh, & Somech, 2007); the structural equation modeling was used to examine the influence of school leaders on student achievement (see Bruggencate, Luyten, Scheerens, & Slegers, 2012). In the

articles classified as the topic of qualitative method, for instance, the observational studies were critiqued (see Gronn, 1982) and defended (see Thomas, 1986); a method for sampling in case study research on administrative behavior was presented (see McClintock, 1985); and metaphor and reflective coaching were used to explore the principals' thinking process (see Dana & Pitts, Jr., 1993). These findings suggest that *EAQ*, as the most prestigious research journal in the field, has been continuously scanning the landscape of the field and has been devoted to publishing methodologically rigorous research as well as discussing and confronting a diversity of methodological perspectives.

In addition, the topics of social justice (topic 1, 5.7%) and female leadership (topic 4, 5.4%) have attracted much scholarly interest. In the *EAQ* corpus, a total of 11.1% of articles addressed these two topics. The social justice topic is described by the high-probability terms such as “inequity”, “justice”, “race”, “disability”, and “bilingual”, and the female leadership topic is described by the high-probability terms such as “women”, “gender”, “superintendent”, “career”, and “female”. As the example articles in Table 3 show, social justice has been examined from a critical ecological perspective (see Furman & Gruenewald, 2004) and transformative leadership framework (see Cooper, 2009); female leadership was probed from the lens of androcentric bias (see Epps, Sackney, & Kustaski, 1994) and resilience (see Christman & McClellan, 2008).

Evolution of Topics

Moving beyond a snapshot view, we probed into the entire *EAQ* corpus from volume 1 in 1965 to the recent volume 50 in 2014. To provide a panoramic view of the rise and fall of the topics in the corpus over time, we sorted the number of articles in each topic per year from 1965 to 2014, and illustrated the topic evolution in Figure 2 in which the *x*-axis represents the year and

y-axis the number of articles addressing the corresponding topic in a given year. As *EAQ* has transitioned over the past 50 years, the number of issues per year in the journal has shifted over time, to interpret the results of the topic evolutions illustrated in Figure 2, we need to take into account the change in the number of issue in *EAQ* per volume. That is, *EAQ* published only three issues per yearly volume from 1965 to 1980, four issues per yearly volume from 1981 to 1999, and five issues per yearly volume from 2000 to the present. With this caveat in mind, Figure 2 depicts the trend of how each of the 19 topics evolved over the past five decades.

Insert Figure 2 here

Across these 19 topics, five topics have gained attention from researchers over time. These topics include inequities and social justice (topic 1), female leadership (topic 4), school leadership preparation and development (topic 11), trust (topic 12), and teaching and instructional leadership (topic 17). An increasing number of articles attended to these topics over 50 years, defining the emerging forefront in the terrain of the educational leadership field. Of particular note, for many of these topics that rose over time, there were special issues of *EAQ* devoted to these topics, such as the special issues on school leadership preparation in 2011 (volume 47 issue 1), social justice in 2004 (volume 40 issue 1), as well as the concentration of articles on the topics regarding trust in 2009 (volume 45 issue 2) and instructional leadership in 2012 (volume 48 issue 2). As a means of promoting attention to special topics that had not received adequate attention in the past, this finding shows that publishing special issues appears to be a useful strategy by journal editors to grow the diversity of topics in a field and bring attention to under-attended topics.

In comparison, the topic of epistemology of educational leadership (topic 2) attracted high attention in the research community in the first four decades of *EAQ*, but then the attention began to decline after 2005. In the early era of *EAQ*, our findings suggest that this line of inquiry appeared to be of vital importance to define the epistemological boundaries of educational leadership as a field, and thus to establish and retain a foothold among other fields in academia. Then over the past decade, the epistemology topic has attracted less attention in the educational leadership research community as represented by the small number of articles in *EAQ*. This finding suggests multiple, and perhaps competing hypotheses: Was the recent decline because epistemology has become a well-established, settled topic in the field of educational leadership after 40 years' inquiry and development? There is emerging literature on the temporal nature of the sociology of research findings, which has found that over time in a research domain topics can become "settled" and the field moves on (Shwed & Bearman, 2010). Alternatively, a competing hypothesis may be that the change is due to the research community becoming distracted by other intellectual inquiries. A third explanation could be due to the influence of different journal editors and editorial boards over time, and a shift in purpose and attention for the journal as different editors and institutions take the helm.

The remainder of the topics waxed and waned over the five decades between 1965 and 2014, as evidenced by large variations in the number of articles without a consistent pattern, as displayed in Figure 2. The legal perspective and accountability topic (topic 13) provides a good example of this pattern. In the 1960s, the articles on this topic mostly discussed an array of issues, namely, the neutrality principle in the U.S. Supreme Court cases dealing with religion and education (see Katz, 1965), church-state relations (see Reutter Jr., 1965), the legal definition of disruptive student behavior (see Ladd, 1971), the significance of the Fourteenth Amendment on

public school educators (see La Morte, 1974), school desegregation/integration litigation (see Brown, 1979), and teachers' religious freedom (see Beezer, 1982). The topic of legal perspective and accountability then tapered off in the 1980s and the 1990s, and then rose again in 2003 with a special issue on law and education. This again highlights the powerful role of special issues of the journal. The detection of special issues also suggests the robustness and validity of our topic models.

DISCUSSION

The purpose of this study was to describe the underlying topics and the topic evolution over the 50-year history of the educational leadership field in *EAQ*. Applying automated text data mining, we provide the first evidence to date demonstrating the total number of topics in the entire 1965-2014 *EAQ* corpus, what each topic represents, the distribution of articles across the topics, and how these topics have changed and evolved over the 50 years since the first issue of *EAQ*. We turn next to discuss how the findings of this study map the temporal terrain of topics in the field of educational leadership, shed light on the future of the field, and the potential of applying text data mining and topic modeling to educational leadership research.

Temporal Terrain of Topics of the Field

Tracking the historical development of the field, our findings reveal the unfolding landscape of 19 topics in the educational leadership field. The breadth of topics, along with the rise and fall of the topics, have charted the intellectual progress in educational leadership research since the 1960s. The 19 topics' interdisciplinary boundaries are, to a large extent, congruent with the fields that closely align with educational leadership (Haller, 1968; Wang & Bowers, 2016). For instance, teacher recruitment and retention (topic 15) and teaching and

instructional leadership (topic 17) are related to the fields of teacher education and human resources; education finance (topic 14) is related to economics; trust (topic 12) is related to psychology.

How did the topics in *EAQ* evolve over time? In comparison with the topics identified in prior studies summarized in Table 1, the 19 topics identified in our study provide us with a more panoramic view of the temporal terrain of the field. This is partly because the literature examined in our study stretches 50 years spanning from 1965 to 2014, and partly because the probabilistic topic modeling used in our study is not subject to the cognitive and labor constraints imposed by reviewing over 1,500 articles. The 19 topics identified in this study surpass the number of topics in the prior literature (see Table 1). Some topics—such as decision making, administrative behavior, authority/bureaucracy, and power (Bridges, 1982; Campbell, 1979)—did not gain sustained attention from the research community. Yet all the topics identified by Hoy (1994) and Murphy et al. (2007) were present in our findings. In addition to the topics that have already been identified in the prior literature, we found some topics that were not noted explicitly in prior literature, such as inequities and social justice (topic 1), epistemology of educational leadership (topic 2), international context (topic 6), research reviews & reflections (topic 7), trust (topic 12), qualitative method (topic 16), and quantitative method (topic 18).

These 19 topics across the 1965-2014 *EAQ* corpus provide a uniquely valuable backdrop to examine the current status of educational leadership, to reflect upon the development of the field over the last 50 years, and more importantly, to contemplate advances and next steps. Our findings on the topics and topic evolution not only validate the statement made by Willower (1981) three decades ago that “the intellectual scene in educational administration is characterized by diversity and change” (p. 115), but also suggest that the trend of topic

diversification has remained strong since the recent comprehensive review by Oplatka (2009). The continued diversification of the topics is likely because education is inherently political (Labaree, 2011). That is, the scholarly inquiry in educational leadership has been “more affected by changes in politics and societal values (e.g., efficiency, equity, accountability)” (Heck, 2015, p. 58). For instance, instead of a sustained research focus on “a set of well-defined disciplinary problems” (Heck, 2015, p. 58), the external policies that governed the educational leadership field include the National Defense Education Act of 1958, the Elementary and Secondary Education Act of 1965, the Education for All Handicapped Children Act of 1975, which was later replaced by the Individuals with Disabilities Education Act of 1990, A Nation at Risk of 1983, the No Child Left Behind Act of 2001, the Race to the Top of 2011, and the Every Student Succeeds Act of 2015, among many others. In such a policy and political environment where education problems and solutions are constantly changing (Berliner & Biddle, 1995), scholars have faced challenges in producing sustained empirical inquiry into educational leadership.

An intriguing, if not concerning, finding is the conspicuously diminishing research interest in the epistemology of the field (topic 2) in recent years. Specifically, between the 1960s and the 2000s, the topic of epistemology remained relatively active. It might be explained that in *EAQ*'s 1965-1978 “formative years” and 1979-2003 “adolescent years” (Murphy et al., 2007, p. 626), the scholars had been searching for and defining the epistemological identity of educational leadership research. However, these epistemological efforts did not persist into the present after 2000. Instead, the educational leadership research community showed a heightened awareness of inequities and social justice (topic 1), drawing attention to historically disadvantaged community and schooling issues. Moreover, a changing social and international context in the US and globally (Leithwood & Hallinger, 2002; Leithwood, Chapman, Corson, Hallinger, & Hart, 1996;

Heck & Hallinger, 2005) was likely a driver for the growing interest in several topics, namely, school leadership preparation and development (topic 11), trust (topic 12), teaching and instructional leadership (topic 17), and international context (topic 6). These topics are indeed valuable to advance the field; however, we posit the decent of the epistemological topic merits attention from the educational leadership research community. For a porous field of education leadership (Wang & Bowers, 2016), it is particularly important for the field to stay focused by a continual examination of the fields' nature, purpose, knowledge base, topical contours, and interdisciplinary boundaries.

How do the topics identified in this study demonstrate *EAQ*'s mission? As stated on its website, *EAQ* “presents prominent empirical and conceptual articles focused on timely and critical leadership and policy issues facing educational organizations” (*EAQ*, n.d., para 1). *EAQ*'s mission, to a large extent, is manifested by the scope of the topics in Figure 2, and is attested by the rise of the topics in the evolving social and political context, including inequities and social justice (topic 1), international context (topic 6), legal perspective and accountability (topic 13), and school effectiveness (topic 19). Considering the intertwined relationship between the field and the journals—“the journal defines the field, the field defines the journal” (Fitz, 1999, p. 316), *EAQ*, as the most prestigious journal in a field that has been persistently criticized for lacking a focused research agenda (Bridges, 1982; Erickson, 1979; Hoy, 1982; Oplatka, 2009; Rowan, 1995), could play a pivotal role to shape a focused, robust agenda for the field. The topical landscape identified in this study presents ample opportunities for researchers to establish individual research agendas, and more importantly, for *EAQ* and perhaps other related journals to shape a collective, focused research agenda for the field. A common perception is the tendency for research to be siloed into a given topic, creating an echo chamber as researchers are left

talking to themselves, which then may hinder synergy among the topics. We posit here that a focused research agenda for the field of educational leadership may perhaps be better shaped by encouraging synergy and collaboration across the 19 topics identified in this study rather than the promotion of a few siloed topics.

Educational Leadership Research: Where to Go From Here?

Our findings pose important questions for the future research not only in *EAQ* but also in educational leadership: Where should the field of educational leadership go from here? What is/are the field's vision(s) for the future? And what are the "settled" topics, versus what are the emerging, disputed, or conflicting topics? As noted by past authors in educational leadership, advances in any field need a concrete cumulative knowledge base to attend to the field's future direction; otherwise we run the risk of allowing the field to decline and demise (Heck, 2015; Heck & Hallinger, 2005; Tschannen-Moran, Firestone, Hoy, & Moore-Johnson, 2000; Oplatka, 2009, 2010). The continued and strengthened topic diversification trend may warrant that the educational leadership research community focuses on sustained research efforts to resolve a set of well-defined problems in the field, as proposed by Heck (2015). By bringing a tighter focus while marshalling resources to tackle the main unsolved questions that the educational leadership field has historically wrestled with, scholarship in the field might be able to depart from "intellectual random events" (Bridge, 1982, p. 22) or continually debating reoccurring issues. As noted by Oplatka (2009), "the field is typically embedded with debates over similar ideas, assumptions, and insights about educational administration as a field of study throughout the last five decades" (p. 26). As a result, a sustained focus on a set of research questions in the field would be able to create cumulative knowledge that practitioners can directly use to improve school leadership (Heck, 2015). Indeed, some scholars have already taken on sustained efforts to

unpack the relationship between school leadership and student achievement: Hallinger and Heck (1996) examined the theoretical and empirical models; Witziers, Bosker, and Kruger (2003) conducted a meta-analysis; Leithwood and Mascal (2008) examined the relationship from a distributed leadership perspective; Dumay (2009) tested the relationship between school leadership, school culture homogeneity, and student achievement; Bruggencate et al. (2012) found an indirect school leadership-student achievement relationship which is mediated by development-oriented school organizational and classroom practices. As we can see in this line of research, scholars' sustained research focus on the same problem helped to advance our understanding of the relationship between school leadership and student achievement.

Further, sustained, focused research efforts will only speed up knowledge accumulation in conjunction with being open to diverse ideas. As we take a sanguine view on the continued and strengthened topic diversification in educational leadership research, we found that the current state of the art in the educational leadership field is far from what Bridge (1982) described, "The state-of-the-art is scarcely different from what seemed to be in place nearly 15 years ago" (p. 24). Instead, the topic evolution illustrated in Figure 2 fits precisely the description by Boyan (1981) that the current state of the art in the field is "several freeways which run through the territory, with only a few crossover and intersections available" (p. 8). Educational leadership, as a porous, outward-facing field (Wang & Bowers, 2016), embraces diverse philosophical paradigms, pluralistic theoretical underpinnings, and emerging methodological approaches. It is thus pivotal for the field to strike a balance between being open to new ideas and the rigorous scrutiny of all ideas (Makel & Plucker, 2014; Sagan, 1997).

Yet how do we know our field's topic diversification is not too diverse for an outward-facing field as porous as educational leadership (Oplatka, 2010; Wang & Bowers, 2016)? Said

another way, a critique of the present study is to ask how this analysis and the number of topics compare with other research fields and journals in which text data mining has been used. Are 19 topics a lot, a little, or normative for the field of educational leadership? While of interest, however, we envision that these questions can be answered in the near future as the field of journal text data mining is just beginning to mature, and the present study provides the first evidence in education leadership using this type of technique. We also posit that it would be impractical to set an arbitrary cutoff point of the number of topics based on other fields' topical landscapes, as each research field has a unique epistemological identity, especially across social sciences. However, in comparison with the typology of seven, ten, and 12 topics postulated in the past research from the manually coded typologies of topics in *EAQ* from Table 1, our finding of 19 topics appears reasonable, as it is not less than these previous studies and neither is it more than double, demonstrating the strong value of the triangulation, hard work of the previous authors in this domain, and the validity of our findings. Additionally, perhaps a more important question lies not with topic diversification or over-diversification, but whether the topics address the core of the applied field of educational leadership—the leadership that promotes teaching and learning, whether the topics bridge the disconnect between leadership research and practice, and whether the topics accomplish *EAQ*'s goal to foster the dialogue among scholars and practitioners (*EAQ*, n.d.) and the University Council for Educational Administration's mission of "advancing the preparation and practice of educational leaders for the benefit of schools and children" (UCEA, n.d., para. 1).

An additional critique of the findings in this study is that they might have overly focused on the concerns of researchers, rather than those of practitioners in educational leadership. Given the inherent nature of educational leadership as an applied field (Campbell, 1981; Glatter, 1987;

Riffel, 1986; Rowan, 1995), it is of great importance to engage leadership practitioners, who are knowledge consumers, to evaluate the progress of knowledge accumulation in educational leadership. We acknowledge that as a research journal, the findings from the present study of *EAQ* are necessarily focused on issues of concern to the research community, we see this method as providing an exciting opportunity to explore the topics in other journals, including practitioner oriented journals, such as *Educational Leadership*, published by the Association for Supervision and Curriculum Development, to examine the intersection of topics over time between research and practice.

Text Data Mining and Topic Modeling in Educational Leadership Research

Using an innovative methodological approach of probabilistic topic modeling, we mapped the terrain of topics in *EAQ*. To our knowledge, this is the first work that captures topics, along with topic evolution over time in the entire 1965-2014 *EAQ* corpus spanning 50 years. To overcome the limit of labor-intensive manual coding in traditional analyses, we mobilized a repertoire of analytical and technological resources in the fast-growing fields of text data mining and machine learning. Without manual coding or prior annotation, we identified the latent topics in the *EAQ* corpus based on high-probability terms and the probability of each *EAQ* article to the 19 topics. These analytic techniques of topic modeling provide an alternative approach to analyze text data in educational leadership research. Since the topic modeling algorithms are highly scalable, topic modeling has been increasingly used to analyze massive amounts of text data in the social sciences. Thus, there are tantalizing possibilities of applying topic modeling to educational leadership research. In addition to identifying the latent topics in the ever-growing volumes of scholarly literature, topic modeling is a viable analytic tool to help extract latent topics in text data in real time. This is of particular value to extract real-time information from

the vast trove of digital text data such as blogs, microblogs (also called tweets), and online comments which are generated by millions of Internet users (Wang & Fikis, 2016). By doing so, topic modeling holds great potential to bolster the research potential in the field of educational leadership research, allowing us to detect topics that would otherwise be difficult to identify in the raw data. In our increasingly digitized educational environment, applying topic modeling in educational leadership and policy research is certainly a growth area to watch for in the future.

Limitations and Suggestions for Future Inquiry

One limitation of this study is that we only examined a single journal's entire corpus of articles. We acknowledge that the focus on a single journal limits the scope of the results. As the first application of automated text mining to identify topics in an educational leadership journal, this study lays the foundation for text mining of a larger set of journals. We therefore recommend future research to apply topic modeling to explore the topical landscape across multiple journals. Further, we also acknowledge the practical limitations of text mining which are non-trivial, as researchers must first gain copyright approval from each journal and editor, and then download and convert the entire full text of all articles from a journal. Also, as noted in the Methods, we relied on a high performance computing (HPC) solution (also known as a "super computer") to analyze the data, because current desktop computers would have taken multiple days or weeks to run the model. Even so, our analysis of just a single journal took 12 hours to complete on an HPC. Considering very few examples in the research literature of collaborations between educational leadership researchers and HPC centers, we provide the *R* code in the Appendix to help provide a strong starting point for future researchers who wish to take on such a highly computationally intensive modeling tasks.

Additionally, as Hallinger (2013) noted in his proposed conceptual framework for systematic reviews of research in educational leadership, whether using a single source type or mixed sources in review studies “depends largely on the *density* and *quality* of relevant literature identified in the domain” (p. 133). For instance, using a single data source was well-justified in Hallinger’s (2011) review of doctoral studies using the Principal Instructional Management Rating Scale, as well as Leithwood and Sun’s (2012)’s review of unpublished research on transformational school leadership. In our study, we consider that all the *EAQ* articles published over the past 50 years provide the sufficient density of educational leadership research literature. Further, regarding the quality of relevant literature, *EAQ* has been consistently considered as the most prestigious research journal in our field of educational leadership (Campbell, 1979; Cherkowski et al., 2011; Haas et al., 2007; Murphy et al., 2007; Richardson & McLeod, 2009; Wang & Bowers, 2016), in which prior literature justifies the “most prestigious” moniker through journal citation analyses, impact factors, as well as surveys and interviews of researchers in the field. Nevertheless, we acknowledge that the literature published in *EAQ* does not demonstrate an exhaustive knowledge base of educational leadership research. For instance, recent evidence suggests that despite *EAQ* being consistently considered as the most prestigious research journal in educational leadership, others leading journals—such as the *Journal of Educational Administration*, *Educational Management Administration and Leadership*, and the *Journal of School Leadership*—are more interdisciplinary than *EAQ* (Wang & Bowers, 2016). More importantly, the majority (54.71%) of citations in educational leadership research literature rely on non-journal sources such as books and reports (Wang & Bowers, 2016). We therefore encourage future researchers to apply topic modeling to the text data from extensive and diverse literature sources across the field of educational leadership.

Another limitation of our study is that, as with other latent variable methods, such as factor analysis and latent class analysis, the topic labeling process is subject to the authors' interpretation of the results. The results of topic modeling provide high-probability terms of each topic, along with the probability of each article to the topics in the corpus, but it takes the authors' interpretation to label the thematic topics from these results. Data in the social sciences are socially-constructed, thus the data lose their meaning and value when they are taken out of context (boyd & Crawford, 2012). Despite the automated data mining process, researchers must carefully unpack the meaning behind the data in a given context. Therefore, like all social science studies, the subjectivity in the sensemaking of the topics in this study needs to be taken into consideration as the readers interpret the findings.

The third limitation is that the findings of this study provide a coarse-grained projection of the field's topic landscape. One of the assumptions of topic modeling is that each document is assumed to be described as multiple topic probabilities, and the document is assigned to a given topic according to a posterior probability (Blei, 2011; Chang Gerrish, Wang, Boyd-Graber, & Blei, 2009). In this study, we followed the recommendations of the research methods in text mining, such that the topic with the highest posterior probability was assigned to the document. For instance, if an *EAQ* article has 18% of chance to be assigned to the trust topic, and has only a 4% chance to be assigned to the rest of topics, our model assigned the article to the trust topic. Across the 19 topics, articles have about a 5% chance of being assigned to any random topic if all topics were equally probable, which they were not as evidenced by the result that none of *EAQ* articles was classified as the non-specific topic (topic 20). Indeed, the field of automated text mining is a rapidly developing methodological subfield within the broader text data mining literature (Blei, 2012; Lee, Song, & Kim, 2010; Steyvers & Griffiths, 2007). As the techniques

and models in automated text mining continue to advance, we look forward to future research in which documents may be assigned across multiple topics and discussed, as well as the hierarchical structure of the topics are explored.

And finally, while the techniques in topic modeling—as an exploratory tool to infer topics from large corpora (Blei & Lafferty, 2007, 2011; Chang et al., 2009)—are innovative and sufficiently useful to extract the topics that are otherwise hard to uncover, the probabilistic approach clearly loses rich information contained in text data from which the traditional qualitative methods can enable researchers to generate a fine-grained depiction. Hence, we encourage future inquiry to continue to examine the rich social, philosophical, economic, and political context in which the field of educational leadership is embedded.

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Table 1 *Summary of Topics or Interdisciplinary Nature in the Educational Leadership Research Literature*

	Literature sources	Literature timeframe	Topics or fields
Haller (1968)	<i>EAQ</i>	1965-1967	fields: education and sociology, psychology and social psychology, political science, economics, and anthropology
Campbell (1979)	<i>EAQ</i>	1965-1978	10 topics: politics/policymaking, school finance, decision making, motivation/satisfaction, preparation programs, leadership, administrative behavior, authority/bureaucracy, collective bargaining, and organizational structure
Bridges (1982)	<i>EAQ</i> , 6 journals, and <i>Dissertation Abstracts International</i>	1967-1980	7 topics: attitudes, traits, behavior, impact, expectations, power, and effectiveness
Hoy (1994)	N/A	N/A	7 topics: societal and cultural influences on schooling, teaching and learning processes, organizational studies, leadership and management processes, policy and political studies, legal and ethical dimensions of schooling, and economic and financial dimensions of schooling
Murphy et al. (2007)	<i>EAQ</i>	1979-2003	12 topics: organizational theory, profession of school administration, politics, school reform, core technology, gender and race, personnel, law, economics and finance, work of school leaders, philosophy and ethics, and psychology
Oplatka (2009)	<i>EAQ</i> , <i>JEA</i> , and <i>EMAL</i>	First volume-2007	diverse topics
Wang & Bowers (2016)	<i>EAQ</i> and 29 journals	2009-2013	fields: urban education, teacher education, economics, human resources, sociology, psychology, etc.

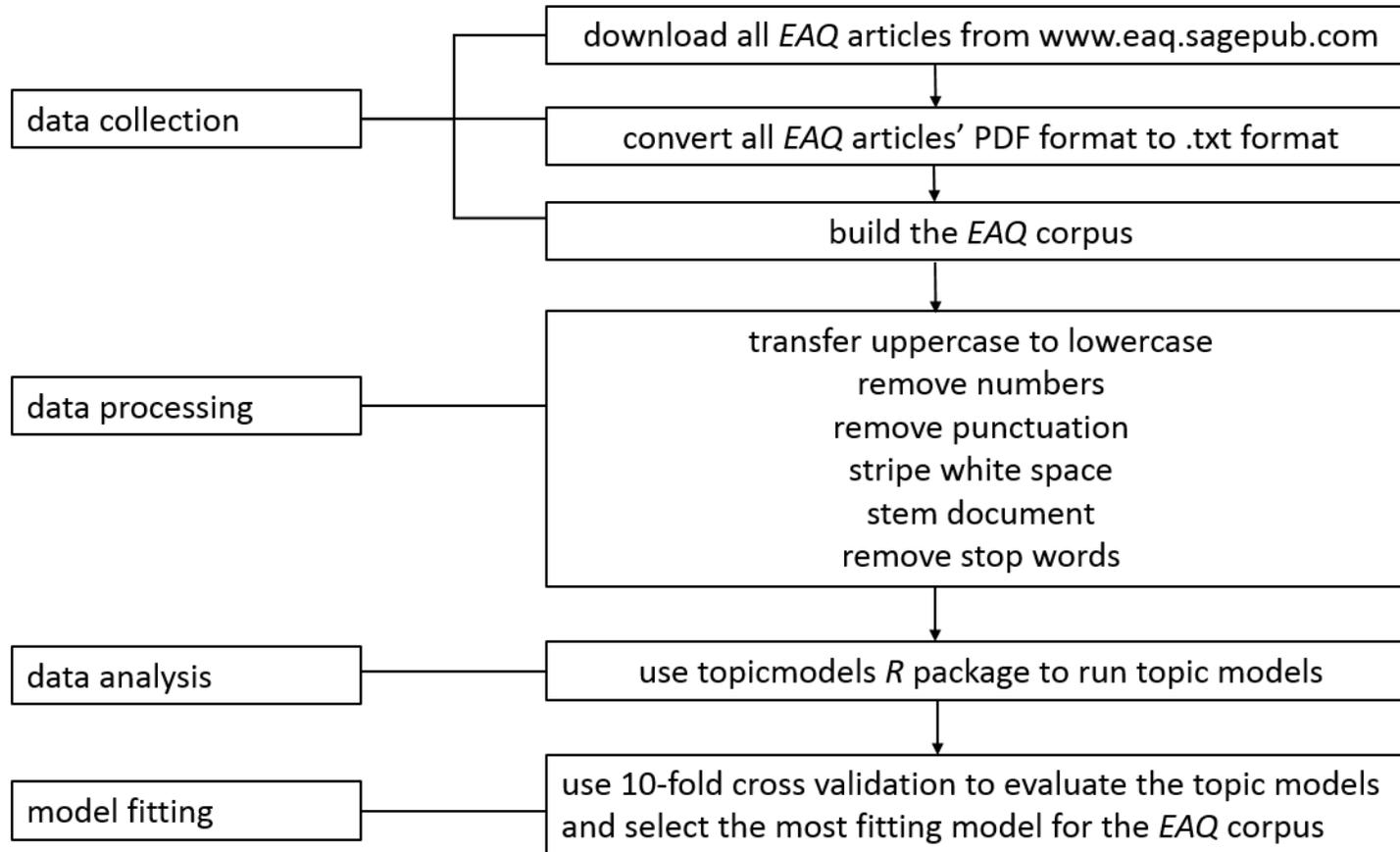
Figure 1 *Overview of research design.*

Table 2 *Topics in the 1965-2014 EAQ Corpus*

	Topic labels	% of articles	High-probability terms
1	inequities & social justice	5.7%	inequity, justice, race, disability, bilingual, deficit, oppress, multicultural, cross-cultural, sociocultural
2	epistemology of educational leadership	12.7%	epistemology, philosophy, scientific, scholarship, paradigm, positivist, Dewey, UCEA, Foucault, administration
3	district collective bargaining	4.8%	bargain, negotiate, union, contract, strike, district, schools, dropout, consolidate, reform
4	female leadership	5.4%	women, gender, superintendent, career, female, male, feminist, mother, sexism, masculine
5	organizational studies	6.8%	teacher, innovate, bureaucracy, in-service, turnover, authority, reword, stressor, collaborate, change
6	international context	3.7%	Israeli, Asia, Hispanic, Mexico, region, Schechter, migrant, score, ministry, decentralization
7	research reviews & reflections	10.7%	Campbell, dialogue, scholarship, manuscript, reader, community, collaboration, Murphy, Sergiovanni, Michael
8	policymaking & government	3.9%	federal, legislature, policymaking, governor, Senate, congress, vote, tax, lobby, coalition
9	faculty of educational leadership & higher education	4.1%	faculty, rank, department, discipline, supervisor, instructor, online, bureaucracy, deficit, culture

Table 2 *Topics in the 1965-2014 EAQ Corpus (continued)*

	Topic labels	% of articles	High-probability terms
10	profession of school leaders	2.5%	principal, superintendent, district, teacher, mentor, reform, restructure, collaborate, culture, problem-solving
11	school leadership preparation & development	2.7%	leader, candidate, portfolio, licensure, internship, proficiency, accredit, specialist, redesign, Wallace
12	trust	2.6%	principal, trust, leadership, teacher, climate, Hallinger, Hoy, Heck, Bryk, Tschannen-Moran
13	legal perspective & accountability	5.3%	court, supreme, judicial, amendment, statute, regulatory, oversight, charter, punish, board
14	education finance	4.4%	district, cost, finance, expenditure, bond, county, revenue, wealth, equity, fiscal
15	teacher recruitment & retention	4.6%	teacher, salary, recruit, market, compensate, certificate, retention, wage, vacancy, shortage
16	qualitative method	5.0%	cognitive, metaphor, symbol, trait, artifact, naturalist, speech, vignette, ethnography, actor
17	teaching & instructional leadership	4.5%	leadership, teacher, efficacy, learning, school-wide, self-efficacy, Leithwood, coach, collaborate, innovate
18	quantitative method	6.8%	variable, correlate, hypothesis, interdependent, predictor, beta, Cronbach, alpha, questionnaire, coefficient
19	school effectiveness	3.7%	output, bureaucrat, simulate, variable, efficiency, employee, zone, subsystem, leader, focal
20	non-specific	0%	teacher, reform, leader, principal, interpersonal, achievement, pupil, subgroup, score, collaboration

Table 3 *Example Articles Assigned to Each Topic by Probability*

Topic labels	Example articles
topic 1: inequities & social justice	Furman et al. (2004). Expanding the landscape of social justice: A critical ecological analysis. Scanlan et al. (2012). ¡Vamos! How school leaders promote equity and excellence for bilingual students. Cooper, C. W. (2009). Performing cultural work in demographically changing schools: Implications for expanding transformative leadership frameworks.
topic 2: epistemology of educational leadership scholarship	Fogarty, B. M. (1983). Educational administration 1959-1981: A profession in evolution. Culbertson, J. A. (1983). Leadership horizon in education. Willower, D. J. (1996). Inquiry in educational administration and the spirit of the times.
topic 3: district collective bargaining	Vantine, A. W. (1972). Toward a theory of collective negotiations. Shedd, J. B. (1988). Collective bargaining, school reform, and the management of school system. Blumberg, et al. (1980). When the union has something the school board wants: Role reversal in collective bargaining.
topic 4: female leadership	Epp et al. (1994). Reassessing levels of androcentric bias in <i>Educational Administration Quarterly</i> Shakeshaft, C. (1989). The gender gap in research in educational administration. Christman et al. (2008). “Living on barbed wire”: Resilient women administrators in educational leadership programs.
topic 5: organizational studies	Goodson et al. (2006). Teacher nostalgia and the sustainability of reform: The generation and degeneration of teachers’ missions, memory, and meaning. Giles et al. (2006). The sustainability of innovative schools as learning organizations and professional learning communities during standardized reform. Coughlan, R. J. (1970). Social structure in relatively closed and open schools.

Table 3 *Example Articles Assigned to Each Topic by Probability (continued)*

Topic labels	Example articles
topic 6: international context	Onguko et al. (2012). Walking in unfamiliar territory: Headteachers' preparation and first-year experiences in tanzania. Chapman, D. W. (2000). Trends in educational administration in developing Asia. Shin et al. (2012). Principal perceptions and student achievement in reading in Korea, Mexico, and the United States: Educational leadership, school autonomy, and use of test results
topic 7: research reviews & reflections	Haas et al. (2007). Assessing influence on the field: An analysis of citations to <i>Educational Administration Quarterly</i> , 1979–2003. Pounder et al. (2007). Reflections on <i>EAQ</i> 's past, present, and future. Hallinger, P. (2014). Reviewing reviews of research in educational leadership: An empirical assessment.
topic 8: policymaking & government	Karper et al. (1988). Interest groups and the changing environment of state educational policymaking: Developments in Pennsylvania. Milstein, M. M. (1973). Educational interest group leaders and state legislators: Perceptions of the educational policymaking progress. Masters et al. (1966). Some changing patterns in educational policy making.
topic 9: faculty of educational administration & higher education	Rebne, D. (1989). Faculty consulting and scientific knowledge: A traditional university-industry linkage. Gregg et al. (1972). Quality of faculties and programs of graduate departments of educational administration. Hendrix, V. L. (1965). Academic personnel policies and student environmental perceptions.
topic 10: profession of school leaders	Ehrich et al. (2004). Formal mentoring programs in education and other professions: A review of the literature. Daresh, J. (2004). Mentoring school leaders: Professional promise or predictable problems? Nestor-Baker et al. (2001). Tacit knowledge of school superintendents: Its nature, meaning, and content.

Table 3 *Example Articles Assigned to Each Topic by Probability (continued)*

Topic labels	Example articles
topic 11: school leadership preparation & development	Barnett et al. (2000). Cohorts in educational leadership programs: Benefits, difficulties, and the potential for developing school leaders. Perez et al. (2011). Foregrounding fieldwork in leadership preparation: The transformative capacity of authentic inquiry. Jackson et al. (2002). Exceptional and innovative programs in educational leadership.
topic 12: trust	Adams et al. (2009). The formation of parent-school trust. Adams et al. (2014). Collective student trust: A social resource for urban elementary students. Owens et al. (2009). From calculation through courtship to contribution: Cultivating trust among urban youth in an academic intervention program.
topic 13: legal perspective & accountability	Vergari, S. (2000). The regulatory styles of statewide charter school authorizers: Arizona, Massachusetts, and Michigan. Beezer, B. (1982). Religion and employment: How extensive is a teacher's religious freedom? Seigler, T. J. (2003). Understanding original intent and stare decisis: Two methods of interpreting the Establishment Clause.
topic 14: education finance	Picus, L. O. (1995). Cost and service delivery trade-offs in providing educational services for students with severe disabilities. Bowers et al. (2013). Carried or Defeated? Examining the factors associated with passing school district bond elections in Texas, 1997-2009 Dembowski, F. L. (1981). An inventory-theoretic approach to school district cash management.
topic 15: teacher recruitment & retention	Winter et al. (2005). Teacher recruitment in a school reform state: Factors that influence applicant attraction to teaching vacancies. Kelley et al. (2002). Teacher motivation and school-based performance awards. Opfer, D. (2011). Defining and identifying hard-to-staff schools: the role of school demographics and conditions.
topic 16: qualitative method	Weick, K. E. (1996). Fighting fires in educational administration. Gronn, P. C. (1982). Neo-Taylorism in educational administration? Thomas, A. R. (1986). Seeing isn't believing? Neither is hearing! In defense of observational studies.

Table 3 *Example Articles Assigned to Each Topic by Probability (continued)*

Topic labels	Example articles
topic 17: teaching & instructional leadership	Skinner et al. (1999). Using interdependent contingencies with groups of students: Why the principal kissed a pig. Blasé et al. (2002). The micropolitics of instructional supervision: A call for research. Smith et al. (2005). Extended learning time and student accountability: Assessing outcome sand options for elementary and middle grades.
topic 18: quantitative method	Somech, A. (2008). Managing conflict in school teams: The impact of task and goal interdependence on conflict management and team effectiveness. Schmidt, G. L. (1976). Job satisfaction among secondary school administrators. Vigoda-Gadot et al. (2007). Group-level organizational citizenship behavior in the education system: A scale reconstruction and validation.
topic 19: school effectiveness	Immegart et al. (1970). Assessing organizational output: A framework and some implications. Anderson et al. (1998). Efficiency and effectiveness analysis of Chicago public elementary schools: 1989, 1991, 1993. Bessent et al. (1983). Evaluation of educational program: proposals by means of DEA.
Topic 20: non-specific	none

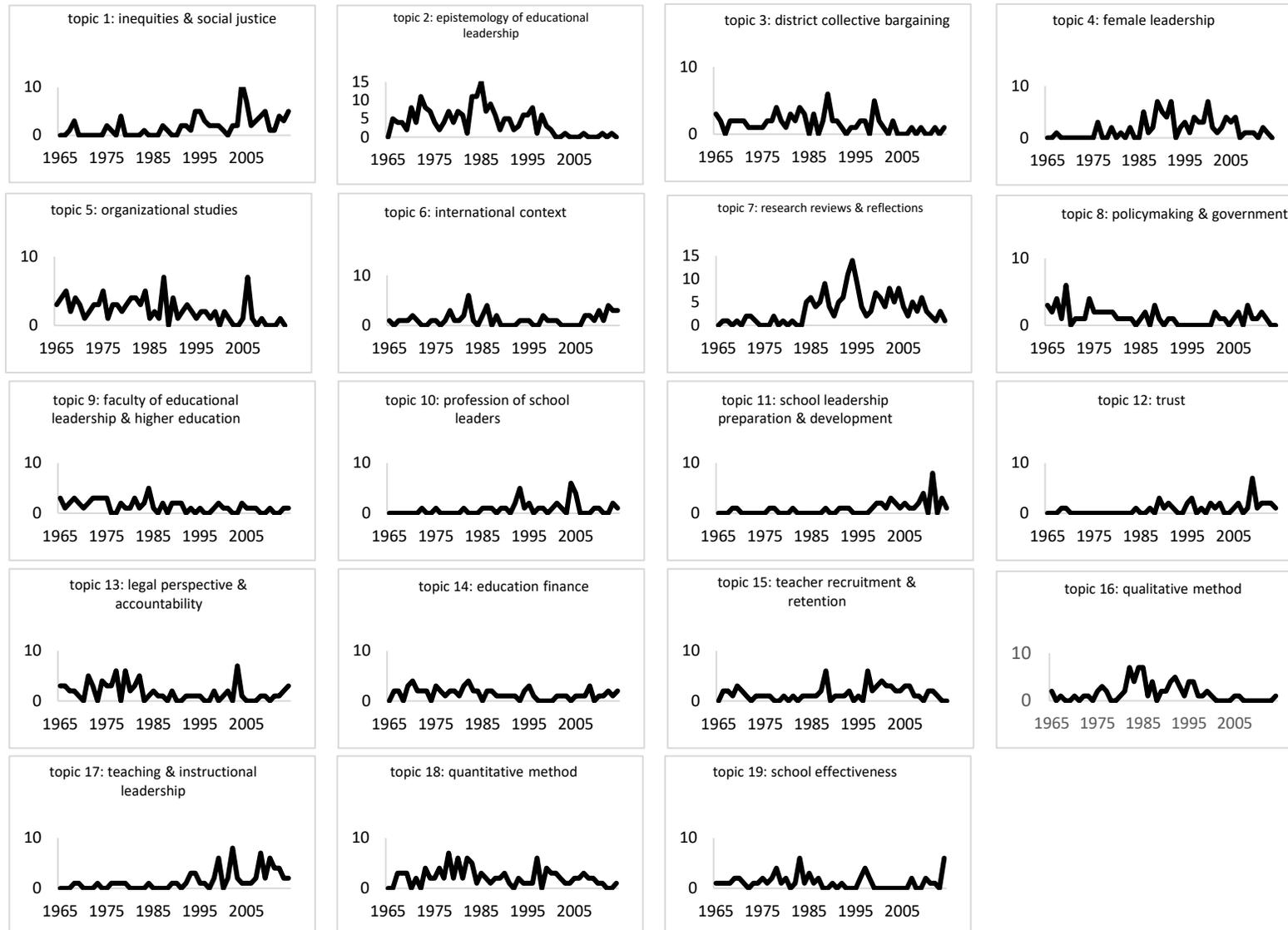


Figure 2 *Evolution of topics in the EAQ corpus from 1965 to 2014. In each line graph, the y-axis indicates the number of articles addressing the corresponding topic in a given year.*

Appendix: Code for Probabilistic Topic Modeling of the *EAQ* Corpus Using *R*

```
#loading packages
require(NLP)
require(tm)
require(topicmodels)
require(SnowballC)
require(slam)
require(ggplot2)
require(scales)
require(grid)
require(lattice)
require(RGraphics)
require(tau)
require(stringr)
require(parallel)

#A safety check.
CPU_CORES <- 40

#Chunk size defines how many rows' (K) repetitions are analyzed at once by
the multithreader.
CHUNK_SIZE <- 4

#Validation degree (folds) defines how many columns are in the row
(repetitions)
VALIDATION_DEGREE <- 10

LIMIT <- FALSE
LOG_FILE <- paste("EAQ_CTM_Analysis_",format(Sys.time(), "%Y-%m-
%d"), ".txt", sep="")
PERPLEXITY_OUTPUT <- "EAQ_CTM_perplexity.csv"
mydata <- file.path("eaq_corpus")

setwd("~/")
sink(file = LOG_FILE, split = TRUE)

if (CHUNK_SIZE*VALIDATION_DEGREE > CPU_CORES) stop("CPU_CORES is not
greater than CHUNK_SIZE * VALIDATION_DEGREE. Code would be inefficient and
potentially dangerous to execute. Stopping.")

MY_START <- Sys.time()

cat("Importing corpus: ")
MY_TIME <- Sys.time()
corpus <- Corpus(DirSource(mydata))
print(Sys.time() - MY_TIME)
cat("Corpus Length: ",length(corpus),"\n")
if (LIMIT == TRUE) corpus <- corpus[1:20] #Trim the corpus for debugging
purposes.

#data processing
#The approach below resulted in much faster clock times than approaches
used in prior literature.
```

```

REPLACE_STRING <- content_transformer(function(x, pattern, y) gsub(pattern,
y, x, perl = TRUE))
cat("Removing hyphens: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, REPLACE_STRING, "\\s*â€"\\s*", "")
print(Sys.time() - MY_TIME)

```

#The approach below resulted in much faster clock times than approaches used in prior literature.

```

cat("Removing punctuation: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, REPLACE_STRING, "[[:punct:]]", "")
print(Sys.time() - MY_TIME)

```

We found no improvements in speed for the process below.

```

cat("Removing numbers: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, REPLACE_STRING, "[[:digit:]]", "")
print(Sys.time() - MY_TIME)

```

We found no real way to speed up and retain Porter's stemming algorithm

```

cat("Stemming: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, stemDocument)
print(Sys.time() - MY_TIME)

```

We found no improvements in speed for the process below.

```

cat("Stop word removal: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, removeWords, stopwords("english"))
corpus <- tm_map(corpus, removeWords, c("downloaded", "download", "table",
"figure", "ohiolink", "eaqsagepubcom", "pdf", "januari", "january",
"quarterly", "Vol", "No", "sage", "georgia", "eaq", "citat", "sagebrush",
"tion", "ing", "pro", "tional", "con", "tra", "tive", "prac", "edg", "cal",
"com", "ment", "dis", "tor", "dent", "ter", "iti", "stu", "enc", "tice",
"pub", "duc", "ver", "fes", "ner", "ple", "sion", "ate", "com", "ment",
"uah", "dddm", "ftes", "dpd", "unp", "toom", "ild", "tive", "est", "siti",
"eaq", "cit", "rst", "ofce", "ofth", "ibid", "eld", "log", "ocb", "ilds", "sfa", "et
al"))
print(Sys.time() - MY_TIME)

```

#The approach below resulted in much faster clock times than approaches used in prior literature.

```

cat("Collapse spaces: ")
MY_TIME <- Sys.time()
corpus <- tm_map(corpus, REPLACE_STRING, "\\s+", " ")
print(Sys.time() - MY_TIME)

```

#The approach below resulted in much faster clock times than approaches used in prior literature.

```

cat("Replace words converted incorrectly: ")
MY_TIME <- Sys.time()
REPLACE_STRING_FAST <- content_transformer(function(x, pattern, y)
gsub(pattern, y, x, fixed = TRUE))

```

```

corpus <- tm_map(corpus, REPLACE_STRING_FAST, "postmodem", "postmodern")
print(Sys.time() - MY_TIME)

#using the EAQ corpus to create the document-term matrix
cat("Generate the document-term matrix from the cleaned corpus: ")
MY_TIME <- Sys.time()
Sys.setlocale("LC_COLLATE", "C" )
system.time(EAQ_dtm <- DocumentTermMatrix(corpus, control =
list(minWordLength = 3)))
cat("(EAQ_dtm dimensions: ",dim(EAQ_dtm),") ")
print(Sys.time() - MY_TIME)
print(EAQ_dtm)
cat("Column Sums:\n")
print(summary(col_sums(EAQ_dtm)))

#setting an optimal term frequency by the inverse document frequency to
exclude from the analysis both high and low frequency words in the EAQ
corpus
cat("Set tf-idf:\n")
MY_TIME <- Sys.time()
term_tfidf <-
  tapply(EAQ_dtm$v/row_sums(EAQ_dtm)[EAQ_dtm$i], EAQ_dtm$j, mean) *
  log2(nDocs(EAQ_dtm)/col_sums(EAQ_dtm > 0))
print(Sys.time() - MY_TIME)
summary(term_tfidf)
EAQ_dtm <- EAQ_dtm[, term_tfidf >= 0.0022]
EAQ_dtm <- EAQ_dtm[row_sums(EAQ_dtm) >0,]
cat("New EAQ_dtm dimensions: ",dim(EAQ_dtm),"\n")
cat("New Column Sums:\n")
print(summary(col_sums(EAQ_dtm)))

#running correlated topic models
cat("Correlated topic models:\n")
MY_TIME <- Sys.time()
control_CTM_VEM <- list(
  estimate.beta = TRUE, verbose=0, prefix=tempfile(),save=0,keep=0,
  seed=as.integer(Sys.time()),nstart=1L,best=TRUE,
  var=list(iter.max=100,tol=10^-6),
  em=list(iter.max=500,tol=10^-4),
  cg=list(iter.max=100,tol=10^5)
)
print(Sys.time() - MY_TIME)

#using 10-fold cross validation to find the most fitting model for the
corpus
cat("VALIDATION_DEGREE, "-fold cross-validation with ",CHUNK_SIZE," folds
analyzed at a time.\n")
MY_TIME <- Sys.time()

EAQ_dtm$FOLD <- as.factor(sample(1:VALIDATION_DEGREE, size = nrow(EAQ_dtm),
replace = TRUE))
CHUNKED_K <- matrix(c(K,rep(0,if ((CHUNK_SIZE-(length(K)%CHUNK_SIZE)) !=
CHUNK_SIZE) ((CHUNK_SIZE-(length(K)%CHUNK_SIZE))) else 0)),
ncol=CHUNK_SIZE, byrow= TRUE)

```

```

PERPLEXITY_TABLE <- do.call(rbind, apply(X = CHUNKED_K, MARGIN = 1, FUN =
function(CHUNK) {
  cat("Current K Cluster: ", CHUNK, "\n")
  CHUNK_CLUSTER <- makeCluster(CHUNK_SIZE)
  clusterExport(CHUNK_CLUSTER,
varlist=c("control_CTM_VEM", "EAQ_dtm", "VALIDATION_DEGREE"),
envir=environment())
  MY_TABLE <- do.call(rbind, parLapply(CHUNK_CLUSTER, CHUNK, function(ROW)
{
  if (ROW == 0) return(NULL)
  require(parallel)
  MY_COL_CLUSTER <- makeCluster(VALIDATION_DEGREE)
  clusterExport(MY_COL_CLUSTER,
varlist=c("control_CTM_VEM", "EAQ_dtm", "ROW"), envir=environment())
  PERPLEXITY_ROW <- parLapply(MY_COL_CLUSTER, levels(EAQ_dtm$FOLD),
function(COL) {
  require(topicmodels)
  EAQ_FOLD <- EAQ_dtm[EAQ_dtm$FOLD == COL,]
  TRAINING <- CTM(EAQ_FOLD, k = ROW, control = control_CTM_VEM)
  TESTING <- CTM(EAQ_FOLD, k = ROW, model = TRAINING, control =
control_CTM_VEM)
  return(perplexity(TESTING))
}))
  stopCluster(MY_COL_CLUSTER)
  return(PERPLEXITY_ROW)
}))
  stopCluster(CHUNK_CLUSTER)
  cat("Time so Far:")
  print(Sys.time() - MY_TIME)
  return(MY_TABLE)
}))
)

```

```

PERPLEXITY_TABLE <- apply(PERPLEXITY_TABLE, c(1,2), as.numeric)
PERPLEXITY_TABLE <- PERPLEXITY_TABLE[nrow(PERPLEXITY_TABLE):1,]
write.csv(PERPLEXITY_TABLE, file=PERPLEXITY_OUTPUT, row.names = FALSE)
print(Sys.time() - MY_TIME)

```

```

cat("Perplexity Matrix:\n")
print(PERPLEXITY_TABLE)

```

```

MY_TIME <- Sys.time()
cat("Generating models for export:\n")

```

```

ALL_CTM <- list()
ALL_CTM_CORES <- CHUNK_SIZE * VALIDATION_DEGREE
ALL_CTM_K_CHUNKS <- matrix(c(K, rep(0, if ((ALL_CTM_CORES -
(length(K)%%ALL_CTM_CORES)) != ALL_CTM_CORES) ((ALL_CTM_CORES -
(length(K)%%ALL_CTM_CORES))) else 0)), ncol=ALL_CTM_CORES, byrow= TRUE)
ALL_CTM_K_CHUNKS <- lapply(1:nrow(ALL_CTM_K_CHUNKS), function(x)
(ALL_CTM_K_CHUNKS[x,]))

```

```

ALL_CTM <- lapply(ALL_CTM_K_CHUNKS, function(CHUNK_ROW) {

```

```

CHUNK_CLUSTER <- makeCluster(ALL_CTM_CORES)
clusterExport(CHUNK_CLUSTER,
varlist=c("control_CTM_VEM", "EAQ_dtm", "CHUNK_ROW"), envir=environment())
ALL_MODELS_CHUNK <- parLapply(CHUNK_CLUSTER, CHUNK_ROW, function(MY_K)
{
  if (MY_K == 0) return(NULL)
  require(topicmodels)
  TRAINING <- CTM(EAQ_dtm, k = MY_K, control = control_CTM_VEM)
  TESTING <- CTM(EAQ_dtm, k = MY_K, model = TRAINING, control =
control_CTM_VEM)
  MY_LIST <- list()
  MY_LIST[[MY_K]] <- TESTING
  return(MY_LIST[MY_K])
})
stopCluster(CHUNK_CLUSTER)
return(ALL_MODELS_CHUNK)
})

CTM_MODELS <- list()
lapply(ALL_CTM, function(CHUNK_ROW) {
  lapply(CHUNK_ROW, function(MY_K) {
    if(!is.null(MY_K[[1]])) {
      TRUE_K <- MY_K[[1]]@k
      CTM_MODELS[[as.character(TRUE_K)]] <<- MY_K[[1]]
    }
    return(NULL)
  })
  return(NULL)
})
rm(ALL_CTM)
cat("Time difference:")
print(Sys.time() - MY_TIME)

cat("Done.\n")

cat("Total process: ")
print(Sys.time()-MY_START)
sink()
save.image(file = paste("EAQ_CTM_Analysis_", format(Sys.time(), "%Y-%m-%d"), ".RData", sep=""))

```