WEB-BASED COLLABORATIVE WRITING IN L2 CONTEXTS: METHODOLOGICAL INSIGHTS FROM TEXT MINING

Soobin Yim, University of California at Irvine

Mark Warschauer, University of California at Irvine

The increasingly widespread use of social software (e.g., Wikis, Google Docs) in second language (L2) settings has brought a renewed attention to collaborative writing. Although the current methodological approaches to examining collaborative writing are valuable to understand L2 students' interactional patterns or perceived experiences, they can be insufficient to capture the quantity and quality of writing in networked online environments. Recently, the evolution of techniques for analyzing big data has transformed many areas of life, from information search to marketing. However, the use of data and text mining for understanding writing processes in language learning contexts is largely underexplored. In this article, we synthesize the current methodological approaches to researching collaborative writing and discuss how new text mining tools can enhance research capacity. These advanced methods can help researchers to elucidate collaboration processes by analyzing user behaviors (e.g., amount of editing, participation equality) and their link to writing outcomes across large numbers of exemplars. We introduce key research examples to illustrate this potential and discuss the implications of integrating the tools for L2 collaborative writing research and pedagogy.

INTRODUCTION

Developing collaborative writing skills is an important prerequisite for the extensive coauthoring that occurs in most academic and career settings. In the fast-paced knowledge economy, collaborative writing tasks are increasingly popular due to the practical benefits of task efficiency and productivity (Jones, 2007). Collaborative writing skills are particularly important in academic settings: they are essential, both in accessing and participating in an academic community and in contributing to the knowledge-building process in scholarly disciplines. To equip students with collaboration skills essential for academic and career excellence in the 21st century, educators have integrated collaborative group work as a core component of instructional strategies and curriculum standards across multiple disciplines (e.g., Bunch, Kibler, & Pimentel, 2012; Koehler, Bloom, & Milner, 2015).

Recently, the widespread availability of technology-enhanced writing platforms, such as wikis, blogs, or Google Docs, has expanded the range, scope, and pattern of collaboration even more dramatically. Research suggests that collaborative online writing can be particularly beneficial for second language (L2) learners because it can provide them with communicative opportunities to practice English in a non-threatening and engaging environment with little restriction on time and space (Sun & Chang, 2012; Warschauer, 1997). Drawing from sociocultural theories of L2 learning, several studies have discussed the positive impacts of L2 collaborative writing, such as enhanced writing quality (Storch, 2005), increased writing fluency (Bloch, 2007), a sense of audience (Sun & Chang, 2012), the pooling of

knowledge and ideas (Donato, 1994), and socialization opportunities with specific discourse communities (Yang, 2014).

The language learning benefits of collaborative writing, as well as the practical needs to prepare students to keep up with the essential 21st century literacy demands, continue to draw a great deal of research attention. However, as most studies have used qualitative methods using a small sample size (e.g., Li & Zhu, 2013), they can be insufficient to capture the quantity and quality of writing in collaborative environments, particularly those involving large student populations or extended periods. This challenge, in turn, makes it difficult to compare and synthesize findings and to explore how students' collaborative behaviors may relate to writing outcomes or perceptions. To better understand the characteristics of collaborative scaffolding and mediation, the field may benefit from quantifiable information that can provide a layer of data triangulation to the qualitative evidence.

Recent advances in text mining, which refers to the technique of converting text into data for measurable analysis (Srivastava & Sahami, 2009), can provide a viable methodological alternative for researching collaborative writing. Text mining encompasses a wide range of data mining techniques, which include text categorization, information extraction, and visualization (Feldman & Sanger, 2006). Although text mining has been widely utilized for analyzing data in diverse fields including information search, marketing, and bioinformatics, we have seen little use of text mining for understanding learning processes in education. Particularly, the potential of using text mining as a research tool for L2 collaborative writing research is still largely underexplored.

In this article, we first synthesize the current methodological approaches to investigating collaborative writing based on major research strands. Then we discuss how new text mining tools specifically designed to analyze writers' collaboration patterns in a cloud-based writing system (i.e., Google Docs) can expand the research capacity. Particularly, we introduce research examples to illustrate the potential of using text mining to advance the field by (a) extracting collaboration-related variables from large datasets, (b) visualizing collaboration patterns of emerging documents, and (c) facilitating reflective discussion on collaborative writing process through a stimulated recall. We will also discuss the implications of integrating the tools for collaborative writing research and pedagogy.

MAJOR RESEARCH STRANDS AND METHODOLOGICAL APPROACHES

Research from a sociocultural perspective of L2 acquisition suggests that collaborative writing involving two or more writers working together (Ede & Lunsford, 1990) pushes learners to reflect on their language use and solve their language-related problems (Swain, 2000). Recent advancements in collaborative technology, such as computer-mediated communication and social software, have expanded the forms and patterns of collaborative group work. This technology has the potential to render human interaction as something easily transmitted, archived, reevaluated, and edited (Warschauer, 1997), all of which lead to new discourse practices, norms, and communicative processes (Dobson & Willinsky, 2009). In educational settings, the value of technology-based collaborative writing has been increasingly recognized as a way to apprentice L2 learners into new literacies practices (Thorne & Black, 2007), or the transformation of literacy practices through the affordances of new media technology (Lankshear & Knobel, 2007).

Drawing from these sociocultural views, L2 researchers have examined the affordances of technology-based collaborative writing, mainly in three research strands. These include studies that focus on (a) collaborative writing processes, (b) collaborative writing outcomes, and (c) perceptions of collaborative writing. In this review, relevant studies published between 2000 and 2015 were selected via keyword search using major databases (e.g., ProQuest, Google Scholar, ERIC, JSTOR Education) and fourteen journals in the fields of computer-assisted language learning (CALL) and applied linguistics (e.g., *CALICO Journal*, *Computer Assisted Language Learning*, *Language Learning & Technology*, *System*, *Journal of Second Language Writing*, *Language Learning*; selection of journals guided by Smith &

Lafford, 2009).

Guided by Chapelle's (1997) CALL evaluation principles, we included studies that address either (a) the descriptive nature of the language learning process during computer mediated collaboration or (b) the effect of collaboration on L2 learning. Using a grounded approach, we identified the major research strands and limited the review to include empirical studies. Where applicable, we included L1 studies, as well as studies on face-to-face collaboration, in order to diversify the review base and gain a comprehensive understanding of available methodological approaches that can be incorporated in L2 settings. The Appendix summarizes the key information about the representative studies for each strand, including their research contexts and methods. This review is not intended to be a comprehensive literature review, but rather to selectively discuss research examples that represent specific methodological approaches.

Collaborative Writing Processes

Studies that analyze collaborative writing processes usually focus on the strategies, behaviors, roles, and responsibilities of collaborators, as well as the collaborative structure underlying writing tasks. In an attempt to capture the diverse types of collaboration, these studies are often carried out in naturalistic settings by observing how writers collaborate or by using self-reported data (e.g., interview, survey) from writers engaged in collaborative writing. Studies examining collaborative writing processes can be divided into two categories: (a) patterns of collaboration and (b) phases of collaboration.

Patterns of Collaboration

The term *patterns of collaboration* refers to the ways students negotiate the writing tasks and jointly construct text to convey their negotiated meaning (Li & Zhu, 2013). Most common methods include qualitative observation and analysis of participants' group behaviors based on oral (peer talk) and written (comments, chats, documents) interaction data (Storch, 2002), interviews (Posner & Baecker, 1993), and surveys (Noël & Robert, 2004). For example, Noël & Robert (2004) analyzed survey data from 42 professionals who undertook collaborative writing projects online, and identified three distinct patterns with differing levels of collaboration: sequential writing (i.e., frequent exchange of ideas and co-construction of texts), parallel writing (i.e., cooperative text construction by individuals working in a parallel fashion), and single author writing with peer feedback.

In an L2 context, several studies examined interactional patterns in collaborative writing tasks using transcribed peer talk and observations. For example, Storch (2002) identified four patterns of face-to-face interactions in her longitudinal case study of ESL pair writing work: collaborative, dominant–dominant, dominant–passive, and expert–novice. In the collaborative pattern, pairs work in a mutually supportive manner, whereas in the dominant–dominant pattern, pairs contribute equally to the task, yet with little signs of interaction. The dominant–passive pattern is characterized by an authoritarian–subservient role, but in expert–novice pattern, a higher ability peer supports and facilitates the participation of a less-able peer. By relating the interactional patterns to writing outcomes (i.e., analysis of instances suggesting the take-up of language learning opportunities in a subsequent task), she concluded that students in the collaborative pattern and expert–novice pattern performed better in writing tasks than pairs observed in the other patterns.

Using a small group case study, Li and Zhu (2013) found similar patterns of group dynamics in wiki-based essay composition. Their analysis of data from the wiki modules and interviews suggested that in each pattern (i.e., collectively contributing or mutually supportive, authoritative–responsive, and dominant–withdrawn), L2 group members exhibited differences in their roles and task approaches, which in turn influenced their perceived learning experiences. Although the results provide valuable insights into the scaffolding benefits as posited in the sociocultural learning theory, they contain limited generalizability due to their small sample sizes.

Other studies noted a distinct pattern of online collaboration, potentially due to the availability of web

features that allowed both synchronous and asynchronous collaboration. For example, Lund (2008) examined high school EFL learners' wiki-based collaborative writing process using a videotaped corpus of group interaction and wiki activity logs. He also analyzed two types of collaborative activity that differ in terms of the level and scope of the collaboration: local collaborative mode (i.e., members working to develop topics in an autonomous mode) and distributed collective mode (i.e., jointly constructing new information in a synchronous, interdependent mode). The findings suggest that the cloud-based features helped students easily transition from local collaboration to collective networked production, and also from consecutive to mixed activity mode, which implied the fluid and flexible nature of knowledge co-construction processes in online contexts.

Phases of Collaboration

Researchers have emphasized the importance of considering the developmental phases in collaborative writing research, arguing that the sub-processes of writing place different demands on the writers (Hayes & Flower, 1980) and may involve different interactional patterns for each sub-process (Onrubia & Engel, 2009). Several studies report the existence of distinct phases in technology-based collaboration. For example, based on the qualitative analysis of wiki revision histories, the L2 study by Kessler and Bikowski (2010) identified three consecutive phases of collaboration during a group essay composition: build and destroy (i.e., initial content constantly being deleted and rebuilt), full collaboration (i.e., iterative revision of content, yet without a large-scale deletion), and informal reflection (i.e., exchanging personal reflections using the commenting function). These phases are characterized by wiki functionalities that allow iterative revision and commenting. Student interviews and analysis of wiki archives revealed an increasing participation rate and students' growing comfort as the phases progressed.

In another study on collaborative writing in a virtual class taught through Moodle, Onrubia and Engel (2009) analyzed multiple data sources, including chats, comments, group documents, interviews, and self-reflections, and found four distinct stages of L1 collaborative writing processes (i.e., initiation, exploration, negotiation, and co-construction). The results suggest that the groups tended to stay at the second of the four established phases, exploration, with few reaching the highest phase of co-construction. The authors explain that this was partly due to the collaborative writing strategies implemented in phases. Most groups utilized the cooperative strategy (i.e., division of labor) in the exploration phase and settled with a summative product, whereas only a few groups moved forward to the more advanced phases of collaborative knowledge construction, where they employed mutually-supportive strategies for group revision of the document.

Other studies on face-to-face collaboration raised similar concerns, reporting the complexity and difficulty in transitioning from the initial phases to more advanced phases of collaborative knowledge construction (Dillenbourg, 2002). The results also align with Storch's (2005) claim that collaborative writing tends to occur only within a limited range of writing processes, rather than across all writing processes. Collaborative scaffolding tends to be limited to the brainstorming or to the final stages of writing—the peer review stage when students review each other's written texts and make suggestions on how they could be improved.

Unlike previous findings that identified the distinct phases of collaborative writing in a wiki, Strobl (2014) reported that the collaborative writing stages in Google Docs are hardly distinguishable. Using the Google Docs revision history function, she found that the group writing process was characterized by a constant intertwining of writing and revising (e.g., deleting, rewriting, reshuffling) activities, potentially because of the synchronous writing and editing functionality of Google Docs. The results indicate that the technological characteristics of a collaborative platform can bring about new forms of collaboration, which illustrates the point that technology tools do not merely serve as a medium for collaboration, but as an integral part of collaboration (Thorne, 2003; Brodahl, Hadjerrouit, & Hansen, 2011).

The new patterns and processes of collaborative writing brought by increasingly widespread use of synchronous interaction can be arduous and insufficient to interpret with qualitative text analysis (e.g.,

analysis of written interaction, final text) alone. Although several studies have provided descriptive data on collaborative behavior by analyzing data archives in wikis or blogs (e.g., Arnold, Ducate, & Kost, 2012), these studies carry low statistical power due to their small sample sizes. This is understandable given how manual coding of group interactions can be intensive and time-consuming. When triangulated with a computational technique that automatically generates usage statistics related to collaborative writing and revision behaviors, the insightful results from qualitative approaches can be enhanced to gain greater reliability and interpretive power.

Collaborative Writing Outcomes

Previous research has long highlighted the benefits of collaboration in terms of both L2 learning and text quality (e.g., Elola & Oskoz, 2010; Kost, 2011; Storch, 2005). When it comes to online collaboration, empirical studies on the effects of the collaboration process on writing products are scarce (Wang & Vásquez, 2012). Existing studies typically utilized descriptive textual (e.g., Elola & Oskoz, 2010; Mak & Coniam, 2008) or quasi-experimental analyses (e.g., Strobl, 2014; Wichadee, 2011) of small samples, with few studies involving a control condition (see Appendix).

Mak and Coniam (2008) authored one of the earliest studies that examined the textual quality of technology-based collaborative products. In their study of ESL secondary students' wiki-based collaborative writing, they traced textual changes in the amount and the types of writing (e.g., word count, t-unit, purpose of revision) that one group produced across multiple phases of collaboration. Using both descriptive textual analysis and qualitative analysis, the authors suggested that the students produced increasingly complex and coherent texts in greater quantity due to the collaborative nature of the task and the presence of authentic purpose.

Other studies adopted quasi-experimental designs to understand the differences between individual and collaborative writing outcomes. Findings from these studies suggest that the strength of collaborative writing primarily lies in improving content and organization. For example, using a quasi-experimental design, Arslan and Şahin-Kizil (2010) examined how blog-based writing instruction affects EFL students' writing performance, controlling for participants' age, educational background, and baseline language proficiency. Compared to the control group, the blog intervention group displayed greater improvement in content and organization, but not in other areas such as vocabulary and grammar. Findings from other studies (e.g., Wichadee, 2011) suggest that using collaborative online platforms may heighten students' awareness of audience, which helps them focus on the clarity of their message and organization.

Kuteeva's (2011) discourse analysis study conducted in an English for Academic Purposes setting also advocates for a stronger reader–writer relationship in collaborative environments. She employed meta-discourse textual analysis to compare the use of reader-oriented features and interactional meta-discourse markers in individual and collaborative corpora (i.e., compilation of collaboratively-written texts). The results that revealed a higher use of engagement markers (i.e., personal pronouns, questions) in the wiki-based argumentative texts, combined with participants' questionnaire responses, suggested that writing on the wiki can contribute to raising students' audience awareness, resulting in more reader-oriented texts.

In addition to examining the differences in the outcome texts, several studies indicated how writing processes or behaviors during collaboration could be related to writing outcomes. For example, Strobl (2014) used a quasi-experimental design to examine the processes and outcomes of individual versus collaborative writing. Using taxonomy-based analysis of revision histories and peer discussion produced by L2 undergraduate students, the researcher suggested that the in-depth discussions that typically occur during the planning phase of collaboration might have led to an improvement in content and organization of the group documents. This aligns with previous findings that suggest the important role of the planning phase as a predictor of writing quality (e.g., Saddler et al., 2004), and also as the most time-consuming and valued activity during the collaborative writing process (Storch, 2005).

Elola and Oskoz (2010) raised a similar point in a L2 wiki-based study that compared writing outcomes

between individual and collaborative modes. Although they did not find notable differences in writing outcomes (i.e., fluency, complexity, accuracy)—admittedly due to a small sample size ($N = 8$)—their in-depth qualitative analysis of wiki drafts and chats noted the differences in the participants' strategies for producing a text between the two modes. When working individually, learners tended to wait until the final drafts for close editing of grammar and vocabulary, whereas such adjustments appeared at multiple points in the collaborative writing process. This difference in the correction pattern could have been due to the presence of readers in the collaborative mode, which may have encouraged writers to pay attention to grammatical accuracy throughout the process of composing multiple drafts.

The diversity and complexity of collaboration context (e.g., task type, students' language proficiency), as well as the different outcome measures used across the studies, may account for the mixed results on collaborative writing outcomes. Moreover, the lack of measurable data on writers' collaborative behavior (e.g., the amount of writing, revision, feedback) makes it challenging to understand how these characteristics may contribute to writing outcomes. This calls for the need to implement more objective measurements of writers' collaborative behaviors. For example, as we possess little empirical data about how much—and in what ways—diverse students collaboratively write and revise their work, it is unclear how these collaborative behaviors may contribute to students' writing outcomes (Olson, Wang, Zhang, & Olson, 2017).

Perceptions of Collaborative Writing

Researchers have examined L2 students' perceptions of collaborative writing through surveys, interviews, and observations primarily using qualitative approaches (see Appendix), producing evidence both for and against the pedagogical argument for utilizing collaborative technology. A salient characteristic of social media that L2 learners perceive as beneficial is the presence of a real audience. For example, Turgut's (2009) analysis of EFL students' wiki posts, interviews, and reflective journals revealed that students found the presence of a real audience to be helpful to improve their writing skills by raising their awareness of local issues, such as word choice. Students also claimed that the wiki was a generative source for creative ideas, helping them gain more confidence in experimenting with their writing.

Students' positive perceptions toward web-based collaborative writing were also noted in Kessler, Bikowski, and Boggs' (2012) study on the use of Google Docs in an L2 academic context. Content analysis of participants' in-text communication showed that students maximized the collaborative space for a wide range of purposes, such as planning logistics and sharing strategies in handling writing concerns, which the students perceived to make the writing process more effective. Sun and Chang (2012) similarly argued for the potential of web-based collaboration for developing academic literacy skills. Based on content analysis of blog pages produced by L2 graduate students, they suggested that informal writing practices provide a non-threatening environment where L2 students experiment with the academic genre and bridge the gap between their home languages and academic English.

Despite the overall positive attitudes toward technology-based collaborative writing, there are several noteworthy cautions in using collaborative technology for writing. Based on the analysis of a videotaped corpus of student face-to-face interactions and interviews, Lund (2008) has suggested that students express reluctance towards having their unfinished work seen by others and editing others' work due to concerns regarding their own editing inexperience. Other L2 studies suggest the psychological ownership of a text might lead to hesitancy to change another writer's contribution, particularly in content revision (e.g., Arnold et al., 2012), thus displaying more of a cooperative work pattern (i.e., editing one's own text) than a collaborative pattern (i.e., editing others' texts). One of the students' major concerns centered around the overriding of each other's ideas, as the networked online tools permit more than one person to edit the same text simultaneously (Lee, 2010).

The lack of student accountability and unequal contributions to the collective product has also been raised as an issue. In Strobl's (2014) study based on survey and document analysis, collaboration failed in one group due to some free riders. Given that accountability is an important prerequisite for successful

collaboration, it is important to design tasks and evaluation strategies that encourage balanced participation (Hew & Brush, 2007).

METHODOLOGICAL CHALLENGES

The reviewed studies suggest important implications on the affordances of technology-based collaborative writing in three different, yet related, areas: writing processes, outcomes, and perceptions. The Appendix shows that most studies have typically analyzed student interaction (e.g., comments, chats, discussions), text (student-produced documents), interviews, and surveys to qualitatively examine collaborative writing processes or perceptions in small group settings. The role of in-depth, qualitative studies will continue to be important in understanding how L2 learners negotiate meaning and scaffold each other in collaborative online contexts. This is especially so as ecological approaches that value the particularities of contexts and the social embeddedness of technology (van Lier, 2000; Warschauer, 1997) are generally deemed more appropriate than experimental studies that test the efficacy of integrating tools (Chapelle, 2009).

Yet, the use of quantifiable data on writers' collaborative behavior as a triangulation source is valuable. For example, since there is lack of measurable data available about how much, and in what ways, diverse students collaboratively write and revise their work, how these collaborative behaviors may contribute to students' writing development and learning outcomes remains unclear (Olson et al., 2017). Several studies have provided measurable data on students' revision behaviors or quantity of contribution (e.g., Arnold et al., 2012) with manual coding of data archives in wikis or blogs; however this in-depth text analysis may be challenging with large-scale datasets.

Research in L1 contexts has also underscored the need to monitor groups' actual usage of Google Docs and measure writers' collaborative behavior in order to better capture collaborative writing processes (Zhou, Simpson, & Domizi, 2012) or the conditions affecting writers' perceptions (Birnholtz, Steinhardt, & Pavese, 2013). For example, the recent experimental study by Birnholtz et al. (2013) on L1 learners' synchronous collaborative writing on Google Docs suggests that the quantity of collaboration (e.g., number of comments, edits) may affect writers' perceived ownership of the document and attractiveness of the group task. The findings suggest that the amount of total editing positively affected participants' perceptions of group ownership. However, the amount of peer edits negatively affected one's perceived attraction to the task, which may indicate some perceived invasiveness of edits directly done by others.

Next, increasingly diversifying types and capacities of collaborative technologies also presents challenges in collaborative writing research. For example, the use of simultaneous writing and editing features in cloud-based systems, such as Google Docs, often leads to new ways of collaborative writing, characterized by non-linear interaction. Such iterative practices often involve mixed modes of collaboration and coordination, therefore making it difficult to identify patterns in these practices. These challenges call for alternative sources of data for triangulating the qualitative evidence typically seen in collaborative writing research.

Insights from Text Mining Approach

Recent advances in text mining techniques can provide a viable methodological option to address the aforementioned challenges. In collaborative writing research, new text mining tools specifically designed to extract information on writers' collaboration patterns can help elucidate processes of collaboration by quantifying or visually representing the collaborative writing patterns, particularly across large numbers of exemplars. Several text mining tools have been widely integrated and researched in the fields of computer science and engineering to improve the design and support features utilized in collaborative writing systems (Olson et al., 1993). For example, visualization programs have been developed to understand the evolution of software code (i.e., CVSscan; for more details, see Voinea, Telea, & Van Wijk, 2005) and collaborative revision in Wikipedia (i.e., HistoryFlow; for more details, see Viégas, Wattenberg, & Dave, 2004). Yet collaborative writing research that has integrated text mining systems in

educational contexts has only recently emerged. Below we introduce three prominent research examples of integrating text mining tools that are specifically designed for analyzing group documents in Google Docs, one of the most widely applied collaborative writing tools.

Example 1: Quantifying the Amount of Collaboration

An open source text mining tool called SCAPES[1] (Studying Collaborative Authoring Practices in Educational Settings) possesses the capacity to download and analyze revision history on Google Docs up to 100 documents at a single run. This tool automatically produces revision history spreadsheets reporting the version, date and time, authors, word count, words added, and words deleted (see Figure 1). Based on these data, researchers can extract collaboration-related variables such as the number of contributors, editing sessions (i.e., how many times authors made changes to a document), and edits (i.e., how many times a specific document was edited), as well as the number of words individuals added, deleted, or moved. These variables can be utilized to examine the characteristics of writers' collaborative behaviors and how their writing and revision may relate to their writing outcomes.

Figure 1. SCAPES' revision history spreadsheets report version, date and time, authors, word count, words added, and words deleted.

Using these variables available in *SCAPES*, Zheng, Lawrence, Warschauer, and Lin (2015) analyzed 3,537 Google documents collaboratively written by 257 sixth-grade L1 students for an academic year. As the first attempt to use large-scale datasets to empirically examine students' long-term engagement with collaborative writing, this study revealed several key aspects of collaboration that would have been hard to track with qualitative data analysis or observations that typically involve small sample sizes or short-term, experimental tasks. For example, the authors found that during an academic year, an average of 1.4 co-authors and a maximum of six co-authors, collaborated on the document of various genres in English Language Arts classes. Student writers produced an average of 13.76 documents averaging 248 to 430 words, and 67.84 edits (i.e., adding, deleting, moving) per document, working on each document for an average of 15 days during the school year. These extensive writing practices suggest a significant improvement from the typical literacy practices in middle schools, where students produce a page or less of text during a nine-week period (Applebee & Langer, 2011). The findings imply the potential of cloud-based technology in supporting the continuity of writing and revision due to its accessible and interactive features.

Using longitudinal growth models, Zheng et al. also examined writing growth trajectories across edit sessions and found that documents with multiple contributors were drafted more slowly and had fewer words added during each editing session than did single-authored documents. In addition to the text mining results on the quantity of writing and revision, the researchers manually coded the types of feedback using the revision histories (e.g., comment, direct edit, compliment). These data were then related to students' standardized writing achievement, but there was no significant correlation. Instead of

using standardized test scores alone, future studies may use more robust measures of writing outcomes, such as individual or group essay grades with analytic rubrics. These detailed measures can reveal which components of writing are affected by certain collaborative behavior.

In L2 learning contexts, the quantifiable information about collaborative writing and revision both at the individual and document level can help researchers empirically understand the contextual factors of collaboration, an important consideration in sociocultural views of second language acquisition (SLA). For example, the variables extracted from text mining tools can help us understand more specifically what factors or conditions (e.g., group size, group members' language proficiency, task types) may facilitate or constrain L2 students' collaborative writing behaviors, subsequently affecting their writing quality. Particularly given that text mining tools can handle large samples, integrating the tools may enhance the explanatory power of the suggested benefits of technology-based collaboration for L2 learners.

Example 2: Visualizing the Collaborative Writing Patterns

Another text mining tool that can help address the methodological challenges in collaborative writing research is a document visualization tool called DocuViz.[2] Using information from the revision histories and tracking changes on Google Docs, this tool produces a visual history chart across different time points, indicating the authors, their portion of writing, and time (Wang, Olson, Zhang, Nguyen, & Olson, 2015). This data enable researchers to examine how simultaneous editing and writing may affect the patterns of collaboration in an emerging document, and their subsequent effect on document quality (Wang et al., 2015). This is particularly helpful in understanding both simultaneous and developmental collaborative writing processes, as it provides multiple views of the emerging document (see Figure 2) across different time points. Because DocuViz provides usage statistics (e.g., sources, amount, and timing of revision), researchers can track the intensity of simultaneous editing activities at a certain phase of the collaborative writing process or how patterns of revision activities may change over time.
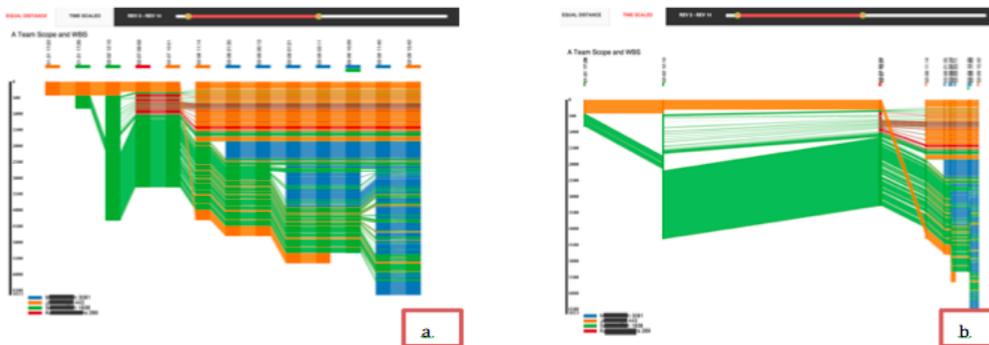

Figure 2. Views of participation in co-authoring a document. Vertical bars are the slices with authors noted in colors; the size of their contribution is the size of the bar. (a) shows the slices in order of appearance; (b) shows the slices on a timeline, where one can see bursts of activity and then delays. The key at the bottom shows which person corresponds to which color and how many characters in the final document they contributed (Olson et al., 2017; author permission granted).

The developers of DocuViz (Olson et al., 2017) analyzed collaborative writing patterns and outcomes of 96 Google Docs written by engineering undergraduate majors. Using a combination of DocuViz and qualitative coding of in-text communication, they found six different patterns of collaboration (i.e., *from scratch*, *outline*, *assignment*, *example*, *assign people*, and *informal discussion*; see Figure 3), which otherwise would have been difficult to analyze due to iterative revisions and edits. What is also noteworthy is that DocuViz assists in extracting variables that might be hard to identify without visualizing or quantifying these patterns and thus enables researchers to examine the link between the writing patterns and the writing quality. For example, Olson et al. utilized DocuViz data to develop a

variable called *evenness of participation*, which measures the degree to which the group work is collaboratively distributed. The evenness of participation is also visualized in DocuViz and can be calculated using a researcher-developed measure (i.e., the proportion of the final document produced by each team member and the variance of the proportions). Using hierarchical linear regression, the researchers found that the evenness of participation is positively associated with the writing quality.
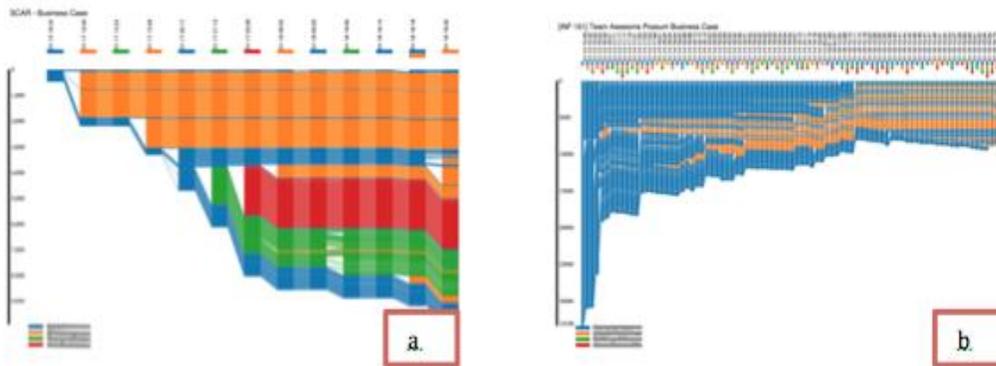

Figure 3. Outline (a) and Example (b) pattern. In (a), the leader (in blue) wrote a short chunk in the first slice, an outline of the document. Then all of the co-authors (other colors) wrote separate sections of the document. In (b), students pasted an example text (starting document, in blue) and then shortened and modified it (Olson et al., 2017; author permission granted).

The mixed-methods study by Yim, Wang, Olson, Vu, and Warschauer (in press) extended this line of inquiry by examining how collaboration-related behaviors (e.g., the evenness of participation, editing quantity) in a synchronous, collocated setting may relate to writing quality and quantity. Using multiple methods including document visualization (i.e., DocuViz), computational text analysis (i.e., Coh-Metrix), and rubric-guided quality assessment, this study examined L1 undergraduates' in-class synchronous writing processes and outcomes in Google Docs. The authors found that balanced participation and amount of editing led to longer texts with higher quality scores for content and evidence, as well as more diverse use of vocabulary in group texts. Unlike previous findings on asynchronous feedback that supported the benefits of collaboration on organization (e.g., Arslan & Şahin-Kizil, 2010), however, Yim et al. (in press) found that the synchronous collaboration practices did not enhance organization. The results suggest that balanced pooling of ideas from multiple authors may enhance the diversity of content and vocabulary, but that careful attention is needed to polish the structure for improved organization, particularly in synchronous modes of collaboration.

The use of visualization tools is critical to understand the emerging document development processes and outcomes in cloud-based platforms such as Google Docs, particularly those that evolve over extended periods. In L2 contexts where issues such as mutuality and equality affect group dynamics (see discussion in Storch, 2002, 2005), balance in contribution and participation carries even greater weight and thus needs a special attention and emphasis. Inspecting the collaboration process using visualization tools can help identify and examine such patterns, thus informing the design of instructional tasks and strategies to accommodate L2 writers with diverse capacities and backgrounds.

Example 3: Stimulated Recall on the Collaborative Writing Processes

Document visualization tools can also be effective instruments for stimulated recall, which refers to a subset of retrospective research methods that accesses participants' reflections on mental processes (Lindgren, Sullivan, & Stevenson, 2008). Traditionally, the writing process has been examined using think-aloud protocol, direct observations, text analysis, stimulated recalls with both audio and video recording, or photography (Stapleton, 2010). More modern methods include keystroke logging software

(Lindgren et al., 2008), but it is often difficult to sift through the fine-grained, disconnected data generated by keystroke logging to interpret complex writing processes, especially with long-term projects involving multiple authors.

DocuViz can be a user-friendly instrument for stimulated recall on collaborative writing behaviors or processes. In particular, its pop-up feature allows the users to view actual revision histories to track the changes when they hover their mouse over a portion of a column slice. In a stimulated recall interview using DocuViz, one L2 undergraduate student provided a detailed explanation on her groups' collaboration process during an academic essay task (Yim & Warschauer, 2016). Looking at the visualization chart (Figure 4) that marks a simultaneous expansion and subsequent reduction of the size of different bars, she discussed how her group members practiced the divide-and-conquer strategy (e.g., each member writing one paragraph) and then revised the completed essay together to make it succinct and coherent. Another participant discussed the value of using DocuViz for reflecting upon her collaboration process: "I didn't realize how much of a contribution people had on the groups. I kind of knew as we were typing, but just seeing it here like this helps me to understand what changes we've made and why."
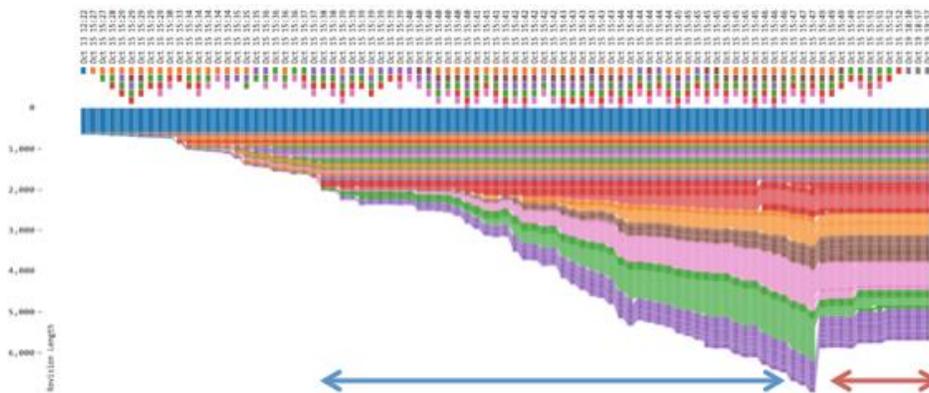

Figure 4. Simultaneous writing and revising of paragraphs by six group members indicated by expansion (blue arrow: the size of each bar simultaneously expanding) and reduction (red arrow: the size of each bar simultaneously reducing) of bars of six different colors (Yim & Warschauer, 2016; author permission granted).

Another open-source visualization tool called AuthorViz[3] can also be useful for stimulated reflection on L2 collaborative writing. As this tool color-codes sections written by each author in the final document in Google Docs (Wang, 2016), it is helpful to identify writers' different linguistic contributions. In the study by Yim and Warschauer (2016), an undergraduate student noticed the colorful mark-up of sentences in AuthorViz, and discussed how her group did not divide any roles or sections, but spontaneously began to write sentences together and to build off in a synchronous hands-on pattern (see Figure 5). Looking at the AuthorViz view of her group document, she also discussed how her group members, including an L2 student, provided editing support for each other regardless of their writing capacities. She added that these direct edits did not come across as offensive because the group members had an intuitive consensus that they were building the sentences together. In L2 research, integration of these visualization tools can be particularly valuable not only for stimulated reflection, but also for tracking and analyzing writers' language use (e.g., language related episodes; Swain & Lapkin, 1995) in group documents with multiple revisions.

Glen Bledsoe's elements of collaborative digital writing show similarities with the task group essays through the element of pitching ideas. In both groups, each member started to brainstorm ideas for the prompt individually. They started off with their own ways of interpreting the concept. Another similarity of Bledsoe's analysis was that the students made friendly amendments when coming together collaboratively. The groups were able to check their organization of their own essays with others' essays in order to find what they lacked. To polish the essay, the group often uses feedback from peer reviews to make the essays more specific, so that is also one of the similarities between our model and Bledsoe's elements of collaborative writing. The core difference between these two models is that the groups lacked the patience that Bledsoe states is crucial to collaborative writing. They were more driven independently in the beginning and looked at collaboration as a second nature. Only when things got difficult they started to collaborate.

Figure 5. AuthorViz view of a collaboratively written paragraph in Google Docs. Different colors denote writing and revision made by each contributor. One sentence written by an L2 student (noted in red) is edited by three other native-speaking peers (noted in green, orange, and blue) for grammar. In the following sentence, the L2 student edits her native-speaking peer's text (Yim & Warschauer, 2016; author permission granted).

DISCUSSION AND FUTURE DIRECTIONS

Text mining provides fine-grain analysis of collaborative writing processes that were once hidden in research that relies mainly on traditional methods of observation, survey, or qualitative document analysis. For example, cloud-based text mining tools can provide important usage statistics at the individual and group level, such as amount of writing and revision and number of edit sessions. These usage statistics can also be studied over the course of time, providing rich insights about L2 students' participation or writing trajectories. Access to additional sources of data on learners' technology use not only feeds back into enhancing pedagogy but also contributes to SLA theories (Garrett, 1991).

Using the additional layer of information available from text mining, future studies may better examine the specific mechanisms through which technology-based collaboration affects language development and the implications of these relationships for SLA. For example, sociocultural theories of SLA underscore the importance of contextual factors that influence the affordances and constraints of mediating technologies (Chapelle, 2009; Warschauer, 1997). Previous research suggests that factors such as members' language proficiency (Wigglesworth & Storch, 2012) or task type (Aydin & Yildiz, 2014) may impact the degree and level of collaboration. The impacts of these factors on social interaction processes or outcomes, particularly with large datasets, will be better understood when in-depth qualitative analyses are supported by quantification and visualization of collaboration using text mining techniques. These investigations will help researchers identify the role of diverse socio-emotional or environmental characteristics (e.g., efficacy, aptitude, anxiety, strategy, technology skills, curriculum)—critical factors in L2 acquisition (Skehan, 1991; Ellis, 1994)—in mediating their quality and quantity of peer collaboration, writing, and subsequent language development.

It should be noted, however, that text mining alone may not be sufficient to provide insights into complex collaborative writing behavior and development. Researchers have warned that carefully controlled studies of language learning driven by quantitative analysis do not align with the ecological approach of CALL (van Lier, 2000) which values the particularities of technology use in contextually rich and naturalistic environments (Warschauer, 1997). Therefore, balanced use of qualitative as well as quantitative evidence made available by integrating text mining tools is necessary to investigate multiple aspects of social interaction and language learning processes including the collaboration trajectories, such as changes in written participation (e.g., amount of writing, revision) across different phases of collaboration, and how students' scaffolding and mediation in oral discussion may impact the amount of their written contribution.

Careful triangulation of multiple sources is particularly desired in using text mining, as its current form provides statistics based on the amount of written interaction—only one of the dimensions of

collaboration. Given that one of the critical concerns in SLA is the role of linguistic input, we need to understand how learners explore the different processing conditions of interactions (e.g., written vs. spoken, synchronous vs. asynchronous), whether these conditions modify linguistic input differently, and to what extent they subsequently affect language development (Chapelle, 2009). Therefore, diverse channels of student collaboration (e.g., verbal discussion, commenting, chat) and the context-specific factors (e.g., participant background, curriculum context, teacher role) should be taken into account when examining student participation and collaboration using text mining.

The pedagogical implications of using text mining tools in collaborative writing instruction are also significant. For example, text mining tools can help instructors monitor how much each author contributed to the final version of the writing as well as any changes made throughout the composing process. The multiple aspects of usage information gathered from these tools can be exercised as rich sources for evaluating collaborative group works. For students, incorporating these tools into reflective group activities can help alleviate students' concerns about accountability, a primary concern about collaborative writing as revealed in previous studies (e.g., Strobl, 2014).

Integrating text mining can also help increase students' collaboration awareness—that is, the awareness of what each group member is doing or has done so they can better coordinate (see Wang et al., 2015). For example, the use of DocuViz during collaborative group work can help group members to identify the parts of the document with the most revisions for reaching consensus or restructuring ideas (Olson et al., 2017). Research indicated that collaboration awareness helps reduce co-authors' frustrations, which leads to an improvement in writing efficiency and quality (e.g., Olson & Olson, 1995). Considering that balanced participation tends to be associated with higher textual quality, particularly in content and evidence (Yim et al., in press), future tools can provide a dashboard or a summary table that helps to raise awareness of participation equality by visualizing each member's amount of writing and editing in real-time.

Furthermore, advances in text mining can contribute to the development of instructional tools that support collaborative writing. A recent example is iWrite, a cloud-based academic writing tool designed for engineering students. Using text mining techniques, this tool provides support for assigning topic-specific writing tasks, as well as analyzing group revision behaviors and patterns of collaboration through functions such as revision maps and topic evaluation charts (Calvo, O'Rourke, Jones, Yacef, & Reimann, 2011). In addition to promoting students' self-and group-reflection on their collaboration, the use of these features provides a valuable assessment resource because student progress and quality of collaborative work can be tracked across time through students' compilation of works. Future text mining tools may also integrate computational text analysis tools such as Text Easability Assessor, which calculates the textual characteristics of a given text and compares them to large corpora means. Collaborators can use this information to reflect on multiple aspects of their joint texts (e.g., by identifying weak areas of text) and plan for further revisions.

In the 21st century, the ability to communicate through mediating technologies is an integral part of collaboration, as well as of communicative competence (Chapelle, 2009). L2 students engage in a variety of digital genres and new forms of discourse, which demands appropriate support for coping with new communicative processes, as well as new ways of participating in knowledge and identity construction (Thorne & Black, 2007). The rapid changes in L2 literacy practices in collaborative digital environments also require methodological innovations in research. Careful integration of advanced technology tools such as text mining will help us better understand these evolving L2 literacy experiences in networked environments and their impacts on language development.

APPENDIX.

The studies with an asterisk mark had multiple research questions that were addressed using either a qualitative or quantitative method within a mixed-methods approach. In this review, we focus on the methodological approach employed in addressing each research question within the study.

Research Strand	Study	Theoretical Framework	Technology Type	Key Research Question	Participants	Research Design	Methods
Collaborative Writing Outcomes	Strobl (2014)*	Not specified	Google Docs	Differences in writing quality between collaborative and individual documents	49 university students of German L2 learners	Quasi-experimental	T-test on text quality measures (i.e., complexity, accuracy, fluency, holistic score)
	Wichadee (2011)	Not specified	Wiki	Writing improvement after a wiki-based group work	35 Thai ESL university students	Quasi-experimental	T-test on single group pre- and post- test
	Mak and Coniam (2008)	Not specified	Wiki	Changes in writing quantity and quality in a wiki-based group document	4 Hong Kong ESL secondary students (1 group)	Descriptive, qualitative	Descriptive report on the proxy measures of quantity, complexity, and coherence
	Arslan and Sahin-Kizil (2010)	Not specified	Blog	Differences in writing improvement between blog and non-blog group	50 Turkish EFL university students	Quasi-experimental	T-test on experiment/control groups' pre- and post-test and ANOVA
	Kuteeva (2011)	Not specified	Wiki	Difference in metadiscourse features in collaborative versus individual corpora	14 EFL Stockholm university students	Descriptive text analysis	Metadiscourse analysis based on coding taxonomy
Collaborative Writing Process	Li and Zhu (2013)	Sociocultural	Wiki	Patterns of group interaction	9 EFL Chinese university students (3 groups)	Qualitative	Text analysis based on coding taxonomy and interviews
	Lund (2008)	Sociocultural	Wiki	Types of collaborative activity	31 high school EFL students (use of class wiki)	Qualitative	Content analysis of videotaped interactions and wiki logs based on coding taxonomy
	Strobl (2014)*	Socio-constructivist	Google Docs	Differences in writing process between collaborative and individual composition	49 university students of German L2 learners	Qualitative	Qualitative analysis using Google Docs revision histories
	Kessler and Bikowski (2010)	Not specified	Wiki	Collaborative writing process and group behavior in wiki	40 non-native pre-service EFL teachers	Qualitative	Qualitative analysis using wiki revision history function

Research Strand	Study	Theoretical Framework	Technology Type	Key Research Question	Participants	Research Design	Methods
Perceptions of Collaborative Writing	Turgut (2009)	Socio-constructivist	Wiki	Student perceptions of wiki use for writing	77 EFL college prep students	Qualitative	Text analysis using wiki revision history function, interviews
	Sun and Chang (2012)	Socio-constructivist	Blog	The role of collaborative dialogues in facilitating academic writing skills and authorship	7 international graduate students	Qualitative	Content analysis of interviews, blog pages
	Kessler et al. (2012)*	Sociocultural	Google Docs	Student perceptions of collaborative writing using Google Docs	38 international graduate students	Descriptive, qualitative (content analysis)	Survey, in-text communication
	Lund (2008)	Sociocultural	Wiki	Student perceptions of collaboration using wiki	31 high school EFL students	Qualitative	Content analysis of interviews
	Lee (2010)	Socio-constructivist	Wiki	Student perceptions of the effectiveness of wiki use for writing	35 university students of Spanish L2 learners	Descriptive, qualitative	Content analysis of interviews, surveys, wiki pages
	Arnold et al. (2012)	Socio-contructivist	Wiki	Group work mode (collaboration vs. cooperation) and student perceptions	53 university students of German L2 learners	Descriptive, qualitative	Content analysis of wiki text, revision histories, surveys
	Strobl (2014)*	Socio-contructivist	Google Docs	Student perceptions of strengths and weaknesses of collaborative writing	49 university students of German L2 learners	Descriptive, qualitative	Text analysis of revision history, surveys
	Wang (2014)	Socio-constructivist	Wiki	Types of revision (peer vs. self-edit)	42 EFL college students	Qualitative	Content analysis of interviews, surveys

NOTES

1. SCAPES is available here. This tool was developed by the SCAPES research team at the School of Education at UC Irvine.

2. DocuViz is available here. This open-source tool is developed by Hana Research Group at the School of Informatics at UC Irvine. It is also available as a Chrome application.

3. AuthorViz is available here. This open-source tool was developed by Hana Research Group at the School of Informatics at UC Irvine.

ACKNOWLEDGEMENTS

ABOUT THE AUTHORS

Soobin Yim is a doctoral student in the School of Education at the University of California, Irvine specializing in language, literacy, and technology. Her research interests include technology-based collaboration, digital literacy development, and second language writing.

E-mail: soobiny@uci.edu

Mark Warschauer is a Professor of Education and Informatics, and Director of the Digital Learning Lab and the Teaching and Learning Research Center at the University of California, Irvine. His research focuses on digital media and literacy development.

E-mail: markw@uci.edu

REFERENCES

Applebee, A., & Langer, J. (2011). *The national study of writing instruction: Methods and procedures*. Albany, NY: Center on English Learning & Achievement.

Arnold, N., Ducate, L., & Kost, C. (2012). Collaboration or cooperation? Analyzing group dynamics and revision processes in wikis. *CALICO Journal*, *29*(3), 431–448.

Arslan, R. Ş., & Şahin-Kizil, A. (2010). How can the use of blog software facilitate the writing process of English language learners? *Computer Assisted Language Learning*, *23*(3), 183–197.

Aydin, Z., & Yildiz, S. (2014). Using Wikis to promote collaborative EFL writing. *Language Learning & Technology*, *18*(1), 160–180. Retrieved from http://llt.msu.edu/issues/february2014/aydinyildiz.pdf

Birnholtz, J., Steinhardt, S. B., & Pavese, A. (2013). *Write here, write now! An experimental study of group maintenance in collaborative writing*. Paper presented at the CHI 2013, New York, NY.

Bloch, J. (2007). Abdullah's blogging: A generation 1.5 student enters the blogosphere. *Language Learning & Technology*, *11*(2), 128–141. Retrieved from http://llt.msu.edu/vol11num2/pdf/bloch.pdf

Brodahl, C., Hadjerrouit, S., & Hansen, N. K. (2011). Collaborative writing with web 2.0 technologies: education students' perceptions. *Journal of Information Technology Education*, *10*, 73–103.

Bunch, G. C., Kibler, A., & Pimentel, S. (2012). *Realizing opportunities for English learners in the common core English language arts and disciplinary literacy standards*. Stanford, CA: Understanding Language Initiative.

Calvo, R., O'Rourke, S. T., Jones, J., Yacef, K., & Reimann, P. (2011). Collaborative writing support tools on the cloud. *IEEE Transactions on Learning Technologies*, *4*(1), 88–97.

Chapelle, C. (1997). CALL in the year 2000: Still in search of research paradigms? *Language Learning & Technology*, *1*(1), 19–43. Retrieved from http://llt.msu.edu/vol1num1/chapelle/default.html

Chapelle, C. (2009). The relationship between second language acquisition theory and computer‐ assisted language learning. *Modern Language Journal*, *93*(S1), 741–753.

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed.), *Three worlds of CSCL. Can we support CSCL?* (pp. 61–91). Heerlen, Netherlands: Open Universiteit Nederland.

Dobson, T., & Willinsky, J. (2009). Digital literacy. In D. R. Olson & N. Torrance (Eds.), *The Cambridge handbook of literacy* (pp. 286–312). Cambridge, UK: Cambridge University Press.

Donato, R. (1994). Collective scaffolding in second language learning. In J. P. Lantolf & G. Appel (Eds.), *Vygotskian approaches to second language research* (pp. 33–56). Norwood, NJ: Ablex.

Ede, L. S., & Lunsford, A. A. (1990). *Singular texts/plural authors: Perspectives on collaborative writing*. Carbondale, IL: SIU Press.

Ellis, R. (1994). *The study of second language acquisition*. Oxford, UK: Oxford University Press.

Elola, I., & Oskoz, A. (2010). Collaborative writing: Fostering foreign language and writing conventions development. *Language Learning & Technology*, *14*(3), 51–71. Retrieved from http://llt.msu.edu/issues/october2010/elolaoskoz.pdf

Feldman, R., & Sanger, J. (2006). *The text mining handbook*. New York, NY: Cambridge University Press.

Garrett, N. (1991). Technology in the service of language learning: Trends and issues. *Modern Language Journal*, *75*(1), 74–101.

Hayes, J. R., & Flower, L. S. (1980). *Identifying the organization of writing processes*. In L. W. Gregg & E. R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 3–30). Mahwah, NJ: Lawrence Erlbaum.

Hew, K. F., & Brush, T. (2007). Integrating technology into K–12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational Technology Research and Development*, *55*(3), 223–252.

Jones, R. W. (2007). Learning and teaching in small groups: Characteristics, benefits, problems, and approaches. *Anaesthesia and intensive care*, *35*(4), 587.

Kessler, G., & Bikowski, D. (2010). Developing collaborative autonomous learning abilities in computer mediated language learning: Attention to meaning among students in wiki space. *Computer Assisted Language Learning*, *23*(1), 41–58.

Kessler, G., Bikowski, D., & Boggs, J. (2012). Collaborative writing among second language learners in academic web-based projects. *Language Learning & Technology*, *16*(1), 91–109. Retrieved from http://llt.msu.edu/issues/february2012/kesslerbikowskiboggs.pdf

Koehler, C., Bloom, M. A., & Milner, A. R. (2015). The STEM Road Map for Grades K–2. In C. C. Johnson, E. E. Peters-Burton, & T. J. Moore (Eds.), *STEM road map: A framework for integrated STEM education* (pp. 41–59). New York, NY: Routledge.

Kost, C. (2011). Investigating writing strategies and revision behavior in collaborative wiki projects. *CALICO Journal*, *28*(3), 606–620.

Kuteeva, M. (2011). Wikis and academic writing: Changing the writer–reader relationship. *English for Specific Purposes*, *30*(1), 44–57.

Lankshear, C., & Knobel, M. (2007). Sampling "the new" in new literacies. *A New Literacies Sampler*, *29*, 1–24.

Lee, L. (2010). Exploring wiki-media collaborative writing: A case study in an elementary Spanish course. *CALICO Journal*, *27*(2), 260–276.

Li, M., & Zhu, W. (2013). Patterns of computer-mediated interaction in small writing groups using wikis. *Computer Assisted Language Learning*, *26*(1), 61–82.

Lindgren, E., Sullivan, K. P. H., & Stevenson, M. (2008). Supporting the reflective language learner with computer keystroke logging. In F. Zhang & B. Barber (Eds.), *Handbook of research on computer enhanced language acquisition and learning* (pp. 189–204). Hershey, PA: IGI Global.

Lund, A. (2008). Wikis: A collective approach to language production. *ReCALL*, *20*(1), 35–54.

Mak, B., & Coniam, D. (2008). Using wikis to enhance and develop writing skills among secondary school students in Hong Kong. *System*, *36*(3), 437–455.

Noël, S., & Robert, J. M. (2004). Empirical study on collaborative writing: What do co-authors do, use, and like? *Computer Supported Cooperative Work (CSCW)*, *13*(1), 63–89.

Olson, G. M., & Olson, J. S. (1995). The effectiveness of simple shared electronic workspaces. In S. Greenberg, S. Hayne, & R. Rada (Eds.), *Real time group drawing and writing tools* (pp. 105–126). London, UK: McGraw Hill.

Olson, J. S., Olson, G. M., Storrøsten, M., & Carter, M. (1993). Groupwork close up: A comparison of the group design process with and without a simple group editor. *ACM Transactions on Information Systems (TOIS)*, *11*(4), 321–348.

Olson, J. S., Wang, D., Zhang, J., & Olson, G. M. (2017). How people write together now: Beginning the investigation with advanced undergraduates in a project course. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 24(1).

Onrubia, J., & Engel, A. (2009). Strategies for collaborative writing and phases of knowledge construction in CSCL environments. *Computers & Education*, *53*(4), 1256–1265.

Posner, I. R., & Baecker, R. M. (1993). How people write together. In *Proceedings of the 25th Hawai'i International Conference on System Sciences* (pp. 127–138). Washington DC: IEEE Computer Sciences.

Saddler, B., Moran, S., Graham, S., & Harris, K. R. (2004). Preventing writing difficulties: The effects of planning strategy instruction on the writing performance of struggling writers. *Exceptionality*, *12*(1), 3–17.

Skehan, P. (1991). Individual differences in second language learning. *Studies in Second Language Acquisition*, *13*(2), 275–298.

Smith, B., & Lafford, B. A. (2009). The evaluation of scholarly activity in computer‑ assisted language learning. *Modern Language Journal*, *93*(S1), 868–883.

Srivastava, A., & Sahami. M. (2009). *Text mining: Classification, clustering, and applications*. Boca Raton, FL: CRC Press.

Stapleton, P. (2010). Writing in an electronic age: A case study of L2 composing processes. *Journal of English for Academic Purposes*, *9*(4), 295–307.

Storch, N. (2002). Relationships formed in dyadic interaction and opportunity for learning. *International Journal of Educational Research*, *37*(3), 305–322.

Storch, N. (2005). Collaborative writing: Product, process, and students' reflections. *Journal of Second Language Writing*, *14*(3), 153–173.

Strobl, C. (2014). Affordances of web 2.0 technologies for collaborative advanced writing in a foreign language. *CALICO Journal*, *31*(1), 1–18.

Sun, Y. C., & Chang, Y. J. (2012). Blogging to learn: Becoming EFL academic writers through collaborative dialogues. *Language Learning & Technology*, *16*(1), 43-61. Retrieved from http://llt.msu.edu/issues/february2012/sunchang.pdf

Swain, M. (2000). The output hypothesis and beyond: Mediating acquisition through collaborative dialogue. In J. P. Lantolf (Ed.), *Sociocultural theory and second language learning* (pp. 97–114). Oxford, UK: Oxford University Press.

Swain, M., & Lapkin, S. (1995). Problems in output and the cognitive processes they generate: A step towards second language learning. *Applied linguistics*, *16*(3), 371–391.

Thorne, S.L. (2003). Artifacts and Cultures-of-use in Intercultural Communication. *Language Learning & Technology*, *7*(2), 38–67. Retrieved from http://llt.msu.edu/vol7num2/pdf/thorne.pdf

Thorne, S. L., & Black, R. W. (2007). Language and literacy development in computer-mediated contexts and communities. *Annual Review of Applied Linguistics*, *27*, 133–160.

Turgut, Y. (2009). EFL learners' experience of online writing by PBWiki. In G. Siemens & C. Fulford (Eds.), *ED-MEDIA 2009–World conference on educational multimedia, hypermedia, & telecommunications* (pp. 3838–3847). Waynesville, NC: AACE.

van Lier, L. (2000). From input to affordance: Social-interactive learning from an ecological perspective. In J. P. Lantolf (Ed.), *Sociocultural theory and second language learning* (pp. 245–259). Oxford, UK: Oxford University Press.

Voinea, L., Telea, A., & Van Wijk, J. J. (2005). CVSscan: Visualization of code evolution. In T. Naps & W. De Pauw (Eds.), *Proceedings of the 2005 ACM symposium on software visualization* (pp. 47–56). New York, NY: ACM.

Viégas, F. B., Wattenberg, M., & Dave, K. (2004). Studying cooperation and conflict between authors with history flow visualizations. In E. Dykstra-Erickson & M. Tscheligi (Eds.), *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 575–582). New York, NY: ACM.

Wang, D. (2016). Exploring and Supporting Today's Collaborative Writing. In J. Kaye, A. Druin, C. Lampe, D. Morris, & J. P. Hourcade (Eds.), *Proceedings of the 2016 CHI conference extended abstracts on human factors in computing systems* (pp. 255–259). New York, NY: ACM.

Wang, D., Olson, J.S., Zhang, J., Nguyen, T., Olson, G.M. (2015). How students collaboratively write using Google Docs. Paper presented at iConference 2015, Newport Beach, CA.

Wang, S., & Vasquez, C. (2012). Web 2.0 and second language learning: What does the research tell us? *CALICO Journal*, *29*(3), 412–430.

Wang, Y. C. (2014). Using wikis to facilitate interaction and collaboration among EFL learners: A social constructivist approach to language teaching. *System*, *42*, 383–390.

Warschauer, M. (1997). Computer-mediated collaborative learning: Theory and practice. *Modern Language Journal*, *81*(4), 470–481.

Wichadee, S. (2011). Using wikis to develop summary writing abilities of students in an EFL class. *Journal of College Teaching & Learning*, *7*(12), 5–10.

Wigglesworth, G., & Storch, N. (2012). What role for collaboration in writing and writing feedback. *Journal of Second Language Writing*, *21*(4), 364–374.

Yang, L. (2014). Examining the mediational means in collaborative writing: Case studies of undergraduate ESL students in business courses. *Journal of Second Language Writing*, *23*, 74–89.

Yim, S., & Warschauer, M. (2016). *Challenges or opportunities? A case study of L2 undergraduates' synchronous collaborative writing*. Unpublished manuscript.

Yim, S., Wang, D., Olson, J., Vu, V., & Warschauer, M (in press). Synchronous writing in the classroom: Undergraduates' collaboration practices and their impact on text quality, quantity, and style. In *Proceedings of the 20th ACM conference on computer-supported cooperative work and social computing*.

Zheng, B., Lawrence, J. F., Warschauer, M., & Lin, C.-H. (2015). Middle school students' writing and feedback in a cloud-based classroom environment. *Technology, Knowledge, and Learning*, *20*, 201–229.

Zhou, W., Simpson, E., & Domizi, D. P. (2012). Google Docs in an out-of-class collaborative writing activity. *International Journal of Teaching and Learning in Higher Education*, *24*(3), 359–375.