UNIVERSITY OF CALIFORNIA,
IRVINE

Exploring and Supporting Today's Collaborative Writing

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Information and Computer Science

by

Dakuo Wang

Dissertation Committee:
Professor Judith S. Olson, Chair
Professor Gary M. Olson
Senior Research Scientist Daniel M. Russell

2016

DEDICATION

To

my beloved son, Charles, who came to this world

and my grandmother, who left this world

during my Ph.D. life

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to express my deepest appreciation to my committee chair, Professor Judith S. Olson, who opened the door to the academic world for me. Throughout my Ph.D., she continually guided me, taught me, supported me, trusted in me, and fed me. Without her guidance and persistent support, none of my achievements including this dissertation would have been possible. In addition to the academic training, the most important, she taught me and exemplified how to become a better person.

I would like to thank my other committee members, Professor Gary M. Olson and Dr. Daniel M. Russell, who provided incredibly valuable guidance and encouragement.

In addition, I would also like to thank many colleagues and friends for their professional and moral support over the past few years. In particular, I thank Professor Gloria Mark and Professor Geof Bowker in UCI Informatics. I learned a lot from the early collaborations with them. I also thank my lab mates in the Hana Research Lab, including Julia Haines, Martin Shelton, Jingwen Zhang, Simone Lanette, and Yao Li. They are like family members to me. I really appreciate the guidance and support from my research cohorts at UCI and many other institutions, including but not limited to: Jed Brubaker, Lynn Dombrowski, and Bart Knijnenburg when they were at UC Irvine, Vera Liao at UIUC, Youyang Hou at UMich, and Haodan Tan at Indiana University.

In the past two years, I had a great pleasure in working with many bright undergraduate students, including: Trung Nguyen, Kenny Pham, Paul An, Bing Han, and Xiaoyun Huang. Although they called me mentor, I was the one who was learning.

Importantly, this research would not have been possible without the help and support of many participants and interviewees. A huge thank you to all of you for participating in my studies and sharing your stories with me.

I owe everything to my family who has supported me throughout this long journey of pursuing a Ph.D. My parents, Xuewen Wang and Xiaoqing Kong, encouraged me to persist in the hard way, even when all the others mistrusted me and asked me to take the easy way out. And especially to Xian Zhang, who helped me from the very beginning of my Ph.D. life, and raised Charles on her own so that I can focus on my research.

CURRICULUM VITAE

Dakuo Wang

2009	B.S. in Computer Science, Beijing University of Technology, China
2010	Diplôme d'Ingénieur (M.S.) in Management Information Systems, Ecole Centrale d'Electronique Paris, France
2012	M.S. in Electrical and Computer Engineering, University of California, Irvine
2016	M.S. in Information and Computer Sciences (Informatics), University of California, Irvine
2016	Ph.D. in Information and Computer Sciences (Informatics), University of California, Irvine

FIELD OF STUDY

Human-Computer Interaction

PUBLICATIONS

Peer-Reviewed Publications

Wang, D. and Mark, G. (2015). Internet Censorship in China: Examining User Awareness and Attitudes. ACM Trans. on Computer-Human Interaction. 22, 6, Article 31 (November 2015), 22pages.

Wang, D., Hou, Y., Luo, L., & Pan, Y. (2016). Answerer Engagement in an Enterprise Social Question & Answering System. In Proc. iConference, 2016.

Wang, D., Olson, J. S., Zhang, J., Nguyen, T., & Olson, G. M. (2015). DocuViz: Visualizing Collaborative Writing. In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15). ACM, New York, NY, USA, 1865-1874.

Conference and Workshop Papers without Proceedings

Wang, D. (2016). Understanding and Supporting Collaborative Writing on Google Docs. AAAI Spring Symposium on "Intelligent systems for supporting distributed human teamwork", Stanford, CA.

Wang, D. (2015). How to use visualizations to analyze students' collaborative writing? Presented at the UCI Data Science Initiative Year-End Event, University of California Irvine, Irvine, CA.

Zhao, M. and Wang, D. (2014) A Doodled "Us": A Design Case Study on Urban Collaborative Art with Arduino. CHI 2014 Workshop on "Socially Engaged Arts Practice", Toronto, Canada.

ABSTRACT OF THE DISSERTATION

Exploring and Supporting Today's Collaborative Writing

By

Dakuo Wang

Doctor of Philosophy in Information and Computer Science

University of California, Irvine, 2016

Professor Judith S. Olson, Chair

Collaborative writing has become increasingly common and complex. Many researchers in Human Computer Interaction (HCI) have conducted extensive research on this topic for the last 25 years. Technologies were built and tested in the laboratory. I continue this stream of work by revisiting computer-supported collaborative writing within today's context. Today, many commercially available word processors have built-in features to support collaboration, such as supporting synchronous editing and archiving editing history. Now that these features are available outside laboratories, how are people actually using these new capabilities in the wild? In my dissertation project, I aim to explore this question using both quantitative and qualitative research methods. In addition, to analyze the collaborative writing practices utilizing the detailed behavioral data traces, I have built an information visualization system, DocuViz, that complements existing research methods. This dissertation work contributes both a visualization system and the novel research approach of using these visualizations to study collaborative writing. This work also reveals various features and practices that people use to write collaboratively. By quantifying collaboration markers, such as styles of work or participation equity, the statistical analyses reveal the relationships between the practices that people use and the quality of the documents that they produce. Our results suggest that people write collaboratively more often than they used to, and they use various styles of working (e.g., outline then divide and conquer or template) to coordinate their collaborations. A few factors (e.g., power dynamics, privacy, and community's norms) influence the practices that people choose. Some group behaviors (e.g., having a leader or equal participation) are associated with higher quality outcomes. In summary, I construct a holistic understanding of the users' perceptions and practices that they developed in adapting to today's collaborative writing technology. By synthesizing both the findings from my research and previous literature, I extend the existing research framework of collaborative writing, propose behavioral guidelines for users who want to write together better, and generate design implications for system designers. In addition, I offer two visualization tools used in this research that might be useful to authors themselves as well as to future research.

CHAPTER 1. INTRODUCTION

In recent decades, collaborative writing has become common and important in many professions. Researchers are encouraged to write papers and proposals with others (Sharples et al. 1993). Therefore, academic publications are co-authored more than ever before (Wuchty et al. 2007). Middle school students and second-language learners are also using online editors to practice their English writing skills together with their instructors, as it is easy for instructors to either comment or directly edit students' writing (Yim et al. 2014). College students are taught how to write class assignments in groups, partially because companies expect employees to be capable of writing documents (e.g., progress reports and meeting minutes) with their colleagues (Calvo et al. 2011). These are just a few instances from innumerable collaborative writing cases happening everyday.

There has been a large amount of research on collaborative writing over the last few decades (e.g., Dourish and Bellotti 1992; Noel and Robert 2003, 2004; Olson et al. 1993; Posner and Baecker 1992; Sharples et al. 1993; Storch 2005; Tammaro et al. 1997). Empirical work focused on people's various practices in collaborative writing (e.g., Mitchell et al. 1995; Olson et al. 1993) and descriptive frameworks were proposed (Posner and Baecker 1992; Lowry et al. 2004). In the 1990s, a number of experimental systems (e.g., PREP and ShrEdit) offered specific features (e.g., role assignments and version control) to assist writers.

Today, features designed to explicitly support collaboration have come out of the laboratories and into the real world. For example, Microsoft Word (Word) and Google Docs (Docs) are two among many commercially available word editors that people use widely in today's collaborative writing, both of which have specific features developed to support collaboration. For example, to support collaboration awareness, Word tracks any changes made to a text, and Docs shows where another author is in a document with a colored cursor and shows revision histories. But how these features are used by users in collaborative writing is unclear. The goal of this study is to explore and support today's collaborative writing.

Although many Computer-Supported Cooperative Work researchers and designers explored this topic in the last 25 years, I believe it is critical to revisit it now. The two major reasons are:

- the commercially available technologies have become more advanced and widely adopted; and
- users have become more skilled with using these technologies.

First, today's technologies are very different than 25 years ago. Many features that support collaboration only existed in experimental word processors back then, whereas today most of the commercially available editors have features to support collaboration to some extent. Second, more people today have higher "technology-readiness" (Olson and Olson 2013) than before. Decades ago, only a small group of professional writers and researchers had access to the collaboration-supported editors over local networks, whereas today millions of users are writing collaboratively and even synchronously using online editors on the Internet. A few researchers have reported some recent cases of their collaborative writing experiences (Boellstroff et al. 2013; Olenawa et al. under review); these experiences are indeed different than they were described in the previous body of work. For example, Boellstorff and his colleagues wrote a whole book using Docs remotely with some intense sessions in which all the authors wrote simultaneously (Boellstroff et al.

2013). Because of both the technology changes and people's technical-readiness changes, we need to refresh our knowledge of collaborative writing to further improve the design of existing tools and to help users know how to work together better.

This dissertation project tackles the collaborative writing research topic from three angles. The project first started with exploring what people do in collaborative writing and why they choose to do so. I conducted interviews with 30 participants from various professions to explore how they think of collaborative writing. The analyses reveal that people choose different ways of working together because they have different levels of privacy concerns, social norms imposed by the work context, or different power dynamics.

In addition to understanding what people think, it is also important to understand what people actually do when they write together now. Thanks to today's cloud computing infrastructure, many online editors are able to capture users' behavioral footprints at the keystroke-level and at the millisecond-level. These data traces can tell for each character in a document by whom it was written, when, and where. Thus, it is a privilege to look at how a group of people actually write in the real world. However, these data traces are too fine-grained to be interpreted by a human. A new research tool is required. In line with the line of work that uses visual analytics to interpret human behaviors, my research team and I built an information visualization system, DocuViz (inspired by HistoryFlow (Veigas et al. 2004)), to help with this research. This system might be useful for co-authors as well, a topic for future research.

My research team and I then collected the detailed data traces of 96 class assignment documents co-authored by 33 groups of 4-6 students using Docs. By aggregating individual team members' behaviors, a set of markers was generated to depict the group collaboration. Then, both visual analytics and statistical analysis methods were used to explore this dataset: DocuViz was used to reveal commonly used styles of working; A hierarchical linear regression was used to explore the relationship between various collaboration markers and the quality of the final document. The results suggest that there are six commonly-used styles of collaboration in this dataset of 96 documents, and certain ways of working together are related to quality. For example, the documents in which each team member contributes a fairly equal amount of content are rated as higher quality.

The findings from this dissertation work can inform design implications for collaborative writing systems, and these design implications can be generalized to many other collaborative contexts, such as collaborative ideation, collaborative problem solving, or even team-based online games. For example, the design implications of revealing evenness of participation leading to quality may also apply to other collaboration-supported systems.

In my analysis, I am particularly interested in the ways in which people write together differently than they did 25 years ago, what tools and features are they using, why they have various styles of working, which styles of collaboration might lead to a better outcome, and whether visualization can help with researchers of collaborative writing or not. The five major theme questions are:

- Collaborative Writing Tools and Practices: What tools do co-authors use and what do they do in today's collaborative writing? Why they choose to do so?
- Framework of Collaborative Writing: Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?

- Visual Analytics: How can we build a useful information visualization tool to help with the research on collaborative writing?
- A Better Collaboration: What specific ways of working are related to higher quality outcomes? And, what do we recommend as behavioral guidelines?
- New Features to Support Collaboration: How can we improve the design of the systems to better support collaborative writing?

Table 1.1 summarizes the three projects included in this dissertation, with its research method and the data collected. In what follows, the rest of this dissertation covers the background literature for these projects in Chapter 2, then goes into detail about each of the studies in Chapter 3, 4, and 5. The dissertation collects the implications and concludes with limitations and future research directions in the final Chapter 6.

Table 1.1: Brief Summary of Projects, Methods, and Collected Data

Projects	**Research Method**	**Collected Data**
Interview study of people's perception and collaborative writing practices	Interviewing and iterative coding. All based on what people said.	Over 23 hours of interview data from 30 participants, half of whom are from academia, and the other half from various other occupations.
DocuViz	Building an information visualization system as a visual analytics tools to study fine-grained data traces of collaborative writing	
Analyses of students' group writing in a Project Management class at UC Irvine	Hand-coding plus automated coding the collaborative writing process, then using hierarchical linear regression to analyze the relationships between practices and the document's quality. All based on what people actually did.	Ninety-six co-authored student assignments with detailed behavioral data traces.

CHAPTER 2. BACKGROUND AND RELATED WORK

This dissertation work exploring and supporting collaborative writing builds upon existing literature on computer supported collaborative writing. In addition to traditional research methods, an information visualization system was built to support the research. Therefore, this work also fits into Information Visualization research. The literature from these areas of research inform my research questions as well as the design of the studies.

The existing research on collaborative writing generated empirical findings as well as descriptive frameworks. This dissertation is guided primarily by Posner and Baecker's seminal work on collaborative writing (1992). This work applied their taxonomy to the present context of collaborative writing, and extended it by adding understandings from recently emerged practices made possible by today's commercially available systems (e.g., Word and Google Docs) that support collaborations. As a starting point of the dissertation project, I adopted their research method of interviewing people on their reported perceptions and practices of collaborative writing.

Much of the research that built systems to support collaborative writing or conducted user studies of those systems informed the hypotheses about today's collaborative writing in this study. For example, early work on synchronous versus asynchronous styles of collaboration inspired my focus on the different practices and outcomes of these two ways of working.

The information visualization systems that were built to study or support group collaborations inspired our design of the system. Our systems were mainly influenced by the work that has been done in the context of software engineering or the context of collaborative writing. Many visualization systems have been built and used to study and support software engineer teams' collaboration. Within the context of collaborative writing, HistoryFlow (Viegas et al. 2004) is one key work that inspired our design of the information visualization system, DocuViz. Viegas et al. (2004) also illustrated how to use visualizations to explore understanding of collaborations at a higher level.

In what follows, the rest of this section covers the collaborative writing research and then the literature on information visualizations of group work.

2.1 The History of Collaborative Writing Research

HCI researchers have been studying collaborative writing for almost 30 years. In what follows, this subsection summarizes the history of collaborative writing research chronologically. Much of the pioneering research generated fruitful findings and built prototype systems to support collaborative writing. These research findings and design implications were extremely valuable given that at the time (30 years ago), computer technology and networking infrastructure were less elaborate. In the meantime, computer technology and the underlying infrastructure has changed considerably and yet collaborative writing research has not caught up. One example is that people used to collaborate by using a private editor (e.g., Word) and distributing files through email attachments, whereas now people can share files through a common online repository like Google Drive or Dropbox, or collaborate using an online editor to edit a file synchronously as well as asynchronously (e.g., Google Docs).

We have learned much about the first way of writing given that it was the only way to work for many years. However, now that both types of technology exist, which way of collaborating do people prefer? Are there new ways of working together? Which way of collaborating might lead to higher quality outcomes? And once we refresh our understandings about today's collaborative writing, what design implications can we generate to improve the systems? These questions remain unanswered. Only a few recent works have begun to revisit this research topic within today's context. Judging from this trajectory, now is the time to step back and construct a holistic understanding of the topic of collaborative writing.

2.1.1 Collaborative Writing Research in the 1990s

2.1.1.1 Early Exploratory Work

Many people have explored the question of collaborative writing in the 1980s to the 1990s. For example, they found that people wrote together because collaboration can improve work efficiency and the quality of the writing (Johansen 1989, Rada 1996). Ede and Lunsford did a large-scale survey and found that almost every participant reported that they needed to write together with others at some point (Ede and Lunsford 1990), with the types of document varying from student homework to business reports.

In the early 1990s, Posner and Baecker were among the first generation of researchers in Human Computer Interaction (HCI) who studied collaborative writing (Baecker et al. 1993; Neuwirth et al. 1992; Olson et al. 1993; Posner and Baecker 1992; Rice and Huguley 1994). They proposed a framework to talk about collaborative writing (Posner and Baecker 1992). Before that, the designers of collaborative writing systems mainly relied on the findings from research about individual writing (Flower and Hayes 1981; Sharples et al. 1993) and group writing with pen and paper (Haas 1989). In 1992, their classic paper, "*How people write together*," reported the results from interviews of 10 people who had participated in 22 collaborative writing projects. Their participants were from the fields of medicine, computer science, psychology, journalism, and freelance writing. From the interview data, Posner and Baecker sought to answer a number of questions about collaborative writing: what are users' expectations about collaborative writing; what are the social dynamics (e.g., authorship and trust); what are the technologies the users used to write and to communicate; and what writing strategies do users use. The authors then developed a framework to describe various aspects of collaborative writing, as summarized in Table 2.1.

Table 2.1: Posner and Baecker's (1992) Framework of Collaborative Writing

Roles:		Activities:	
	Writer		Brainstorm
	Consultant		Research
	Editor		Planning
	Reviewer		Writing
	Equal Work		Editing
Document Control Methods:			Reviewing
	Centralized	Writing Strategies:	
	Relay		Single author (i.e., Scribe)
	Independent		Horizontal division
	Shared		Reactive writing
Work Modes:			Parallel writing (different roles)
	Degree of proximity		Sequential writing
	Degree of synchronicity		Mixed mode (using more than one styles)

Posner and Baecker divided the collaborative writing process into 6 activities: brainstorm, research, plan (for the content and for the process), write, edit, and review. They noted the roles people played: writer, consultant, editor, reviewer, and equal work. They went on to describe document control methods and writing strategies (i.e., style of work). For example, horizontal division, which we can also call divide and conquer, requires the group to plan and divide the work, with each of the co-authors writing a section so that they can work in parallel.

2.1.1.2 Early Systems Building

Many researchers from psychology, computer science and engineering studied collaborative writing. Many systems were built and tested in the lab (Ellis and Gibbs 1989; Neuwirth et al. 1992; Leland et al. 1988; McGuffin and Olson 1992; Beck 1993; Michailidis and Rada 1996; Olson et al. 1993). Although some systems were proved to be useful in increasing the collaboration efficiency or the quality of the final product, none of these systems was adopted outside laboratories (Grudin 1988). For example, SASSE was one of the experimental systems to support collaborative writing, developed by Posner and Baecker. They felt it addressed some aspects missing in the other prototypes. It had explicit assignment of roles, enhanced communication, and collaborator awareness (Baecker et al. 1993).

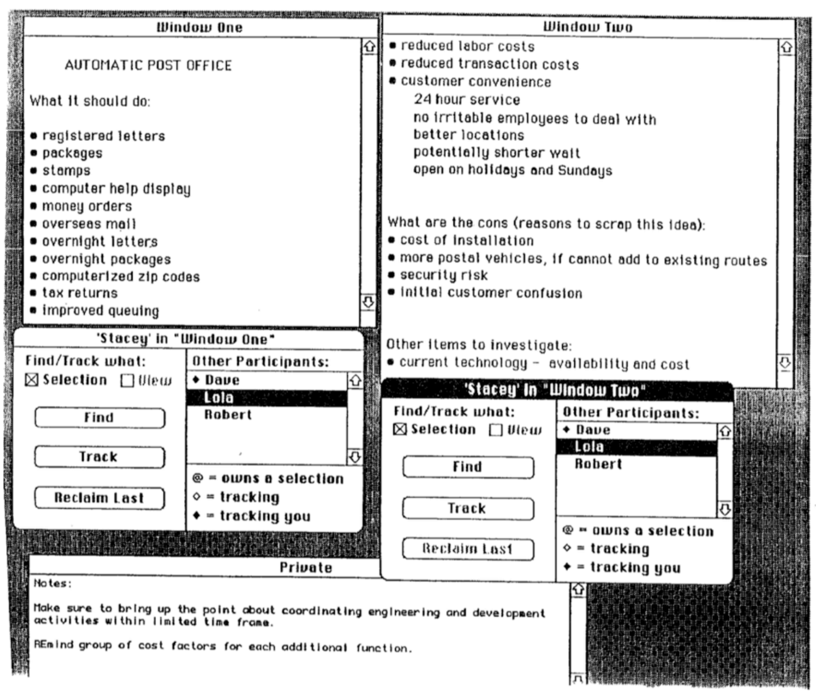


Figure 2.1: The User Interface of ShrEdit (Olson et al. 1993)

ShrEdit was another example of an early system built to support collaborative writing. As illustrated in Figure 1, ShrEdit had a function that allowed users to follow other writers or have exactly the same view of the others. The user could also open multiple windows so that they could work on one section, and watch what the others were doing in another one so that they could perform both write and review activities. As for the concurrency control issue (one issue within the Document Control Method), ShrEdit supported simultaneous editing at the keystroke level, like Google Docs today. Also, like Google Docs, one writer could be within one character of the other; the only thing forbidden was that one couldn't add or delete where the other's cursor or selection was. Because ShrEdit was initially designed to support collocated collaboration, and example of which is shown in Figure 2.2, there was no special communication channel inside ShrEdit.

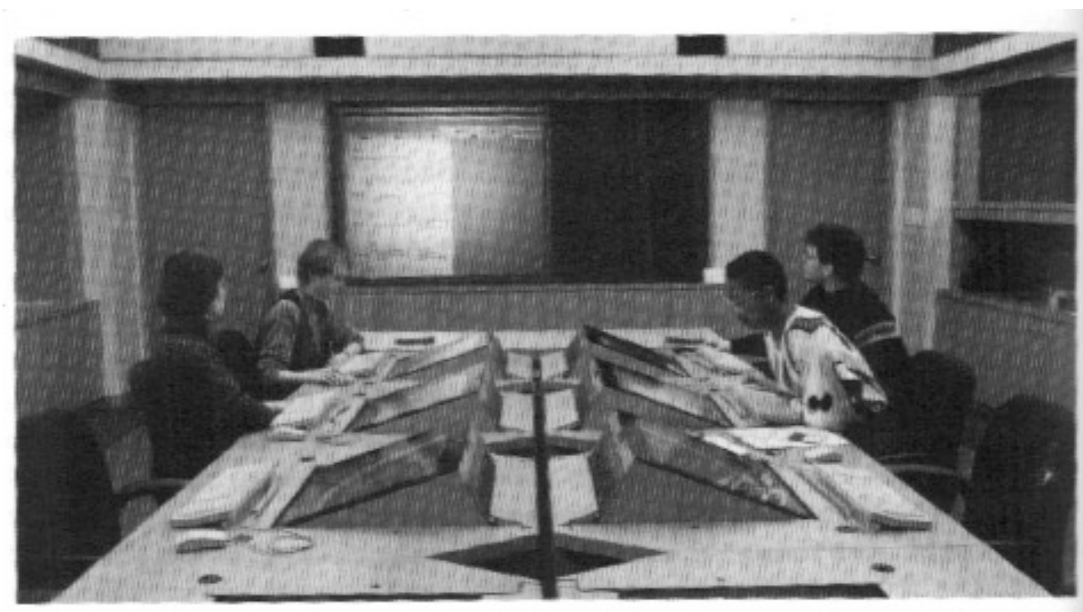


Figure 2.2: The Hardware Set-Up of ShrEdit Work Environment, Each Team Member Works on Separate Desktop Machines Connected Via Ethernet

Posner and Baecker (1992) reviewed these existing experimental systems. Based on their taxonomy, Posner and Baecker proposed 13 specific design requirements for systems to meet. They demonstrated the use of their design implications by analyzing 6 existing systems against these requirements (including ShrEdit (McGuffin and Olson 1992), SASSE, and some others as shown in Table 2.2), all research prototypes.

In Table 2.2, if the system was explicitly designed to support a requirement, it would be indicated with a double plus. If the system was able to handle that requirement, it would be indicated with a single plus. If there is a minus, it means the system could not handle it. All systems have some minuses. For example, Posner and Baecker (1992) considered that ShrEdit (McGuffin and Olson 1992) could support both asynchronous and synchronous editing, but could not support the explicit role assignment (it does not make users to be explicitly assigned as writer, editor and reviewer).

Table 2.2: Posner and Baecker (1992) Evaluated Some Experimental Systems that Support Collaborative Writing Using Their Framework

Requirements			Aspects	GROVE	PREP	Quilt	ShrEdit	SASE	SASSE
Individual writing									
	Basic word-processing		++	-	++	-	++	+	++
	Seamlessness with other media		++	-	++	++	+	+	++
Collaborative writing									
	Preserve identities		-	++	+	++	++	++	++
	Enhance communication		+	-	-	-	+	-	++
	Enhance collaborator awareness								
		Focused collaboration	++	++	-	-	+	++	++
		Peripheral awareness	-	+	-	-	-	+	++
	Annotations		-	++	++	++	-	-	+
	Undo		-		+	+	-	-	-
	Session control		+	++	-	++	+	-	++
Roles									
	Explicit roles		-	+	++	++	-	-	-
Activities									
	Variety of activities								
		Brainstorming	-	++	++	+	++	+	++
		Researching	-	-	-	++	-	-	-
		Planning(outline)	-	++	+	+	-	-	++
		Planning(process)	-	-	+	-	-	-	-
		Writing	++	-	++	+	++	++	++
		Editing	++	-	++	+	++	++	++
		Reviewing	-	-	++	+	-	-	++
	Transitions between activities		+	-	++	++	-	-	++

Requirements			Aspects	GROVE	PREP	Quilt	ShrEdit	SASE	SASSE
Document control methods									
	Several access methods		-	++	++	++	-	-	-
	Separate document segments		++	-	+	++	-	-	-
	Version and change control		-	-	+	-	-	-	++
Writing strategies									
	One or several writers		++	++	++	++	++	++	++
	Synchronous writing		++	++	-	-	++	++	++
	Asynchronous writing		+	+	++	++	-	-	++

2.1.1.3 Early User Studies

Pioneers in HCI evaluated a number of these early prototypes in laboratory settings with life-like but artificial tasks to understand how people think of and use a computer system in collaborative writing. For example, Olson et al. (1993) designed an experiment to compare how groups wrote together with the old tools (i.e., paper, pencil, and whiteboard), and with ShrEdit. They found that the groups writing with ShrEdit generated fewer but better design ideas. Therefore, the study suggested that collaborative writing tools did not need to have explicit role assignment; instead, tools could be a "shared workspace" where people would adapt to the tool and fluidly develop their own new work styles.

Researchers from Posner and Baecker's research group also ran an experimental study of two groups of four sixth-grade students to evaluate their synchronous collaborative writing tool, SASSE (Mitchell et al. 1995). They focused on the adoption of technology in an educational setting. The researchers found that even though the students who participated in the experiment had never written with others or used the tool before, they managed to use the synchronous editing feature and finish the writing task. These participants also developed collaboration awareness, ownership, and control strategies to adapt the new feature during the process. Results suggested that even the most inexperienced people could learn how to write together synchronously with SASSE.

Tammaro et al. (1997) evaluated a collaborative writing tool, Instant Update, used by people for real work. Instant Update supported multiple authors to view a single document. The system held a master copy of the document. Once a user opened the document, it created a local copy of the document; it synchronized back to the master copy when the user saved the changes. The system also captured meta-information such as who changed the document and when, and sent notifications once the document was changed. The study was designed so that that every time a group of participants created a document in Instant Update, they would notify a researcher and add the researcher as a co-author. In this way the researcher could watch closely how this group of co-authors edited the document. Researchers found that after three months of adoption, the participants refined their use of the tool, and changed from using the tool to write every document to using the tool to write only some types of documents. For example, the participants preferred to use the tool to write documents that had a consistent format and were produced on a regular basis (e.g., weekly activity reports), but not to write documents that required a complex work flow or those in which group members might join and leave. Echoing Grudin's essay about why CSCW systems fail (1998), they suggested that a collaborative writing tool must benefit everyone (e.g., someone might need to spend extra effort to coordinate with the team); it must support both individuals and teams; and it must be flexible.

2.1.2 Collaborative Writing Research in the Early 2000s

2.1.2.1 Commercially available systems and the use in the wild

The computer systems designed for collaborative writing in the 1990s were experimental, but the findings were stunning and guided the design of commercially available collaborative writing tools in following years. In the 2000s, researchers were interested in designing new features (e.g., commenting) and evaluating how people use them in the commercial tools (Storch 2005).

Kim and Eklundh (2001) studied people's collaborative writing practices with the existing commercial systems in 2001. They interviewed 11 academics with collaborative writing experience at that time, focusing on people's reviewing behaviors (one of the six activities that Posner and Baecker proposed). Overall, they found that participants reported they did not use any specialized collaborative writing tool. Instead, three personal word processors (i.e., Word, Latex, and FrameMaker), were commonly used. Regarding the reviewing behavior, participants reported that they rarely wrote in synchronously; the synchronous editing happened if they took turns at the keyboard during face-to-face meetings, or they could write in parallel on two documents at the same time and then paste into a single one. Researchers also found that participants preferred not to change others' words, but rather to suggest changes in a very general way. And surprisingly, none of the participants had used the commenting functions; they often wrote comments in an accompanying email or in the document itself with special colors or fonts. Participants manually kept multiple revisions of a document in case they needed to reuse deleted parts.

In general, participants found the existing tools were sufficient to support their collaborative writing.

Noel and Robert (2003) reviewed Posner and Baecker (1992) and applied the taxonomy to study how people were writing collaboratively in 2003. They were surprised to find that people were not using any web-based tools that were designed specifically to support collaborative writing (e.g., MRGS and Wiki Wiki Web); they still liked to write with personal word processors, such as Microsoft Word. The majority of users only wrote asynchronously, handing off the document from one to the other (Noel and Robert 2003; 2004). The reason, they conjectured, might be because the previous tools were built upon an understanding of individual writing paradigms. So users found it easier to write asynchronously. They believed that there was a gap between the existing research from the previous decade and the present writing practices; they suggested that instead of developing a new system to support collaborative writing, system designers should integrate the features that support collaborative writing into existing personal word processors, such as adding version control to Microsoft Word.

In summary, the empirical work up to this point found that people could produce as good quality documents using word processors that supported collaboration as they did using pen and paper. Even first-time users could manage to learn how to use the new features (e.g., synchronous editing) and develop new ways of working around that new capability. This early finding contrasts with other studies that found that in the wild, people were not using the tools designed for collaboration; people still preferred to use personal word processors and exchanged documents using email. In short, they could learn to use the tools, but, if given the choice, chose not to. The features supporting collaboration were not sufficiently beneficial to offset the cost of learning and using them.

2.1.2.2 Distributed collaborative writing

Thanks to the emergence of the Internet, remote collaboration became a popular research topic (Olson and Olson 2013). Studies were done to compare remote collaborative work to collocated collaborative work. Some specific topics of collaboration, such as communication, collaboration awareness, and synchronous versus asynchronous working mode, were examined.

Cerratto (1999) designed an experiment to compare the effectiveness of collaborative writing between two distributed groups of 8 students in a 15-day period: one that used Word together with email, and the other that used Aspects, a collaborative writing system that allowed synchronous editing and a chat function. They found that due to inexperience with the synchronous editing mode, the Aspects group took more time to finish the report task and produced work of lower quality. One reason might be that the synchronous way of collaboration requires more coordination effort. Giving people a tool does not necessarily lead to better collaboration. Also, student groups had difficulty adapting the tool into their old way of writing, so they had to develop new norms and strategies of writing together with Aspects (e.g., they had to spend extra effort in exchanging information about what the other was working on; and they had to archive and maintain their discussions to assure a common understanding and to remind them "who is writing what and where").

Cerratto and Rodriguez (2002) designed a follow-up experiment to study remote versus collocated collaboration asking co-authors to collaboratively write academic reports under two experimental conditions: in one condition the participants sat together using Word, while in the other the participants collaborated remotely using Aspects. These researchers found that introducing Aspects to people's collaborative writing practices caused serious failures in both the document output and the collaboration process. This was because it required more coordination effort, and people in the remote group could not exchange as much information to coordinate as the collocated group could. Therefore, they suggested that only certain types of collaboration might benefit from using Aspects, including collaborations that require minimal exchange of information. However, another earlier study suggested that distributed teams who write collaboratively could adapt to the limitations from the technology (e.g., the communication channels) to some extent (Galegher and Kraut 1994). The picture was not simple.

Lowry and Nunamaker designed a study to evaluate an experimental web-based collaborative writing tool, Callaboratus (Lowry and Nunamaker 2003). The Callboratus system had a chat function and supported synchronous writing from users in different rooms. They found that when compared to the group writing with Word, the Callaboratus group produced higher quality and longer documents. The researchers attributed this increase to the enhanced features that support coordination, collaboration awareness, and the planning of activities.

2.1.2.3 An extended framework

Lowry et al. revisited the research on collaborative writing using the newly-emerged, Internet-based, distributed tools from the 2000s (Lowry et al. 2004). Their primary goal was to provide a taxonomy to unite researchers and practitioners from multiple disciplines (e.g., computer science, social science, and humanities) who were studying collaborative writing. They extended and modified Posner and Baecker's framework (Posner and Baecker 1992). In Posner and Baecker's framework, the concept of synchronicity and distance were embedded in the categories of document control method (e.g., centralized or shared) and writing strategies (e.g., single writer or joint writing). Lowry et al. (2004) suggested that the framework should also include work modes, as "when and where the group will do its writing, in terms of same of different place and same or different times."

2.1.3 Collaborative Writing Research in the Past Decade

2.1.3.1 Cloud computing and web-based text editors

Thanks to the emergence of Cloud Computing technology, meaning much more computation was being done in the cloud rather than on the desktop with results communicated afar, web-based tools have started to play an important role in the market. These tools can support and archive co-authors' writing, editing, commenting, and communication in real-time. Researchers thus began to revisit the topic of collaborative writing. Brodahl et al. (2011) surveyed college students about their perceptions of collaborative writing using web-based technologies (e.g., Google Docs and EtherPad). They found that only 13.9% of their 166 participants were motivated to use the tools for collaborative writing, and 70.5% of them noted that they were confused because the tools were not working as they expected. This result is similar to the finding from another study, where participants reported that they were often confused about the Cloud Computing technologies (Voida et al. 2013).

Some other researchers reported case studies of how they used web-based word processors. One example is Boellstorff et al. (2013) who reported a case study in which four professors used Google Docs to write an entire book. They started writing with Word, sending drafts via email because they were used to writing in this manner. However, they switched to Google Docs because they found two limitations of the working style with Word and e-mail: in asynchronous editing, only one author could work on the document at a time; and when the team was editing together during remote meetings, each of them would print a copy of the document and make the same changes on their respective copies to maintain a common understanding. Other than a few face-to-face meetings, they relied on email and Skype to exchange ideas and resolve issues.

When they moved to Google Docs, they developed new ways of writing together, which significantly increased their efficiency in both synchronous and asynchronous editing sessions. For example, these authors used the commenting feature as a voting mechanism in asynchronous editing: once an author changed the text, (s)he would leave a comment; the three other collaborators needed to reply to that comment and vote on the changes. In synchronous editing during discussions, normally one co-author verbally proposed changes, a second one would type out these changes, followed by a third one correcting typos. They referred to Google Docs as a virtual world, which greatly facilitated collaborative writing.

2.1.3.2 Features of collaborative writing: directly editing, synchronous editing, and group dynamics

Some research focused on a few specific aspects of collaborative writing, such as direct editing versus commenting, or synchronous editing versus asynchronous editing, to see how these aspects interacted with group dynamics.

Researchers have studied the particular user behavior of collaboratively editing with Google Docs. From an interview study with 31 academic participants (both students and staff), Birnholtz and Ibara (2012) found that directly editing others' work had a negative impact on how they felt about each other. These pairs of strangers did not like the implication that if someone changed their text, the new text was better than their own. Consequently, people reported that they would think very carefully about how to make and explain changes. For example, participants commonly refrained from directly editing others' work, or they left explanation comments after making changes. These researchers suggested that system designers should design features that support the group dynamic, such as a communication channel like chat, or to show changes only to some team members and not to others according to the specific roles of each member. That is, in a research team with both senior and junior researchers, a senior researcher might not need to see the grammatical changes made by another senior, but only the high level comments. This contrasts with all the researchers preferring to see all the changes made by a junior researcher to ensure the quality of such changes. It is a matter of trust.

In a follow-up to the interview study, Birnholtz and Ibara ran a laboratory study in which two people worked together to write a document (Birnholtz and Ibara 2012). They focused on how co-authors communicate while they are writing in Google Docs, and whether this communication impacts their social relationship, which was measured by a social attraction questionnaire (Birnholtz et al. 2013). They also quantified the direct editing by the number of changes and hypothesized that the direct editing would negatively impact the social relationship. The results showed that communication helps to maintain people's social relationships in synchronous writing, but harms social relationships in asynchronous writings. One explanation was that asynchronous writing did not require as much communication as synchronous writing, so users might expect the other to contribute into the content instead of just talking. The number of edits also has a negative impact on people's social relationships in asynchronous editing. Therefore, they suggested that Google Docs should use "<Name> suggests <changes>" instead of showing the changes directly, which is actually reflected in a feature introduced in Google Docs in 2015.

This finding echoes the one from Blau and Caspi (2009), which examined the influence of collaboration on perceived ownership and perceived outcome quality. These researchers ran an experiment with 118 students randomly assigned into 2-person groups under 1 of 5 conditions. In each condition, the Google Docs document sharing strategies were different. For example, a student may only look at the other's work and give suggestions, but cannot edit it; or they may directly edit the other's work. They showed that college students prefer suggesting changes rather than direct editing. Students thought collaboration could improve the quality of writing overall. But, in particular, students believed other students made the document quality worse because others were not experts and they did not trust their peers.

2.1.3.3 Computer-supported collaborative learning

Educational researchers have long been interested in using collaborative writing technology to support students' learning. In particular, many studies examined how to use these technologies to help students improve their writing skills (Higgins et al. 1992; Keys 1994; Roskams 1999). Researchers compared the outcome differences between individual and collaborative writing, where they found that the use of blog-based or wiki-based systems, where students write together, helps students achieve greater improvement in their writing (Arslan and Şahin-Kızıl 2010; Strobl 2014; Mak and Coniam 2008). Various independent systems, such as peer-review or writing evaluation programs, were built to capitalize on the advantages of being connected to other people on the web. These technologies often provide peer review/feedback features to enhance the meta-cognitive and reflective process, which is known to be important for becoming a good writer (Cho and Schunn 2007; Calvo et al. 2011).

Yim et al. (2014) found that cloud-based platforms that offer simultaneous writing (e.g., Google Docs) can encourage middle-school students to engage with the kinds of writing practices typically occurring in academic or career settings. Using the cloud-based technology, students wrote and revised more frequently than they would have in a typical literacy exercise (Yim et al. 2014). These researchers confirmed that embedding Google Docs into a class was a novel teaching approach for teachers as well, who then exploited its simultaneous access and editing features in order to develop new instructional practices (e.g., color-coding the grammar errors and collaboratively analyzing learner's errors).

Collaborative writing systems might have greater potential in education beyond the context of teaching English writing or in a classroom setting. It might become a handy instructional tool in Massive Open Online Courses (MOOCs). While researchers were studying MOOC students' motivation and behaviors to understand the reasons behind high dropout rates, they found the lack of collaboration features to be important. Some of their participants were using Google Docs to collaborate with their remote classmates because the MOOC platforms lacked that functionality (Zheng et al. 2015). This finding suggests that it could be helpful for MOOC platforms to incorporate features that support collaborative writing, helping students experience more interactive learning and comprehend the material in a more collaborative way.

2.1.3.4 Collaborative writing research outside academia

A handful of studies have examined collaborative writing in populations beyond academia. For example, Google had an internal study to understand how Google Docs was being used (Sun et al. 2014). The authors built a visualization tool to uncover the pattern of different types of writing activities in Google Docs and to reveal how documents are created collaboratively and how often they write synchronously and remotely. They also conducted analyses on log data and found that employees were increasingly writing collaboratively: in 2011, 30% of the new employees shared their documents and 55% of them looked at others' shared documents; in 2013, 50% of the new employees shared their documents and 85% looked at others' shared documents. These results illustrated an altered story as what was described 20 years ago, or even 10 years ago. Back then, researchers found that users did not like the specialized tool to support collaborative writing, but rather preferred using their personal word processors and the users also rarely wrote synchronously even when synchronous writing was possible (Posner and Baecker 1992; Noel and Robert 2003). These differences suggest that it is necessary to re-examine collaborative writing practices and to refresh our understanding of it.

These studies enriched our understandings of the present writing collaborations, but we lack a big picture of how actual users are writing collaboratively in general. In particular, we are interested in:

- What tools do co-authors use, and what do they do in today's collaborative writing? Why do they have different behaviors?

- Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?
- What practices of collaborative writing might be related to the quality of the documents?
- How can we improve the design of the systems to better support collaborative writing?

2.2 Information Visualization and Visual Analytics

Most of the previous studies on collaborative writing were based on interviews, experiments, observations and shadowing. Interviews can explore what people think they do in collaborative writing. Despite their sophisticated designs, experiments are often isolated from the real world context, where participants have much shorter time and are more focused on the task. Observing and shadowing can gather people's behavioral data and inform an understanding of what people actually do in the real world, but they are time consuming and therefore hard to scale up. An additional research approach is needed that can help us interpret people's behaviors and styles of coordination in the real world, using the existing data traces people generate while they are working. Most of today's word processing systems capture certain types of editing traces of users, but these trace data are too detailed to be interpreted by humans. We need a computer system to help with our research.

Information Visualization and using visualization to analyze data has been a research approach for many centuries, ever since the mathematicians used lines and bar charts to represent numbers and trends. In the modern computer science field, visualizations are often used to explore a large dataset and to generate overviews. In the following sections, I will review some of the visualization systems that were built to study collaboration. As you can see, once the visualization hides certain details of the data, it can reveal certain patterns of work that would be hard to see from other analyses of the data.

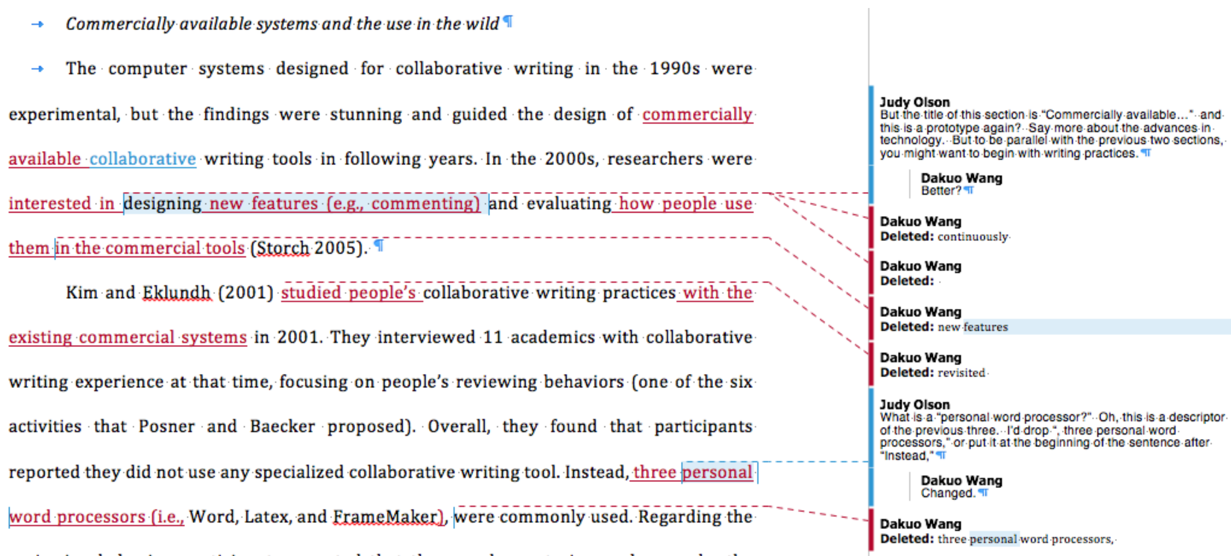
2.2.1 Ways of Showing History of the Document's Creation

Co-authors may benefit from a rich view of activity over time to see who has been working in which part of the document, how various parts relate, etc., just as co-developers of software have expressed a need for (Ball and Eick 1996; Lanza 2001). A good visualization allows users to perceive information in context according to their needs. Good visualizations have been shown to be more powerful than text-based commentary (Froehlich and Dourish 2004). In this case, by seeing a bigger picture, authors can better infer each other's intentions, more easily reach common ground, and produce higher quality outcomes (Cross 1990; Dourish and Bellotti 1992; Michailidis and Rada 1996; Noel and Robert 2004; Viegas et al. 2004). Instructors of writing would also likely benefit from a bigger picture of the student's writing process. And, finally, researchers have much to learn about collaborative writing especially now that modern word processors and other authoring tools allow simultaneous writing.

2.2.1.1 Word

There is a long history of providing various views to reveal the history of a document's creation. In a flurry of work on collaborative writing in the 1990s, many explored ways to show the recent history (Rada 1996), and today both Word and Google Docs offer views of recent changes. The development of algorithms that calculate the differences between two documents support tracking changes (Miller and Myers 1985;

Myers 1986; Hunt and Szymanski 1997; Fraser 2012). As shown in Figure 2.3, Word uses color to denote individuals' contributions, with additions in the text itself and deletions and comments in a side column. These edits stack together and remain until someone accepts them.


Commercially available systems and the use in the wild

The computer systems designed for collaborative writing in the 1990s were experimental, but the findings were stunning and guided the design of commercially available collaborative writing tools in following years. In the 2000s, researchers were interested in designing new features (e.g., commenting) and evaluating how people use them in the commercial tools (Storch 2005).

Kim and Eklundh (2001) studied people's collaborative writing practices with the existing commercial systems in 2001. They interviewed 11 academics with collaborative writing experience at that time, focusing on people's reviewing behaviors (one of the six activities that Posner and Baecker proposed). Overall, they found that participants reported they did not use any specialized collaborative writing tool. Instead, three personal word processors (i.e., Word, Latex, and FrameMaker), were commonly used. Regarding the

Judy Olson
But the title of this section is "Commercially available..." and this is a prototype again? Say more about the advances in technology. But to be parallel with the previous two sections, you might want to begin with writing practices.

Dakuo Wang
Better?

Dakuo Wang
Deleted: continuously

Dakuo Wang
Deleted:

Dakuo Wang
Deleted: new features

Dakuo Wang
Deleted: revisited

Judy Olson
What is a "personal word processor?" Oh, this is a descriptor of the previous three. I'd drop ", three personal word processors," or put it at the beginning of the sentence after "Instead,"

Dakuo Wang
Changed.

Dakuo Wang
Deleted: three personal word processors,

Figure 2.3: Tracking Changes in Word

2.2.1.2 Google Docs

Google Docs has a different underlying architecture in which changes are tracked and saved in revisions. These revisions then can be shown by selecting the "revision history" side panel and noting the color of the author who made the changes. In Google Docs, all changes are automatically made, although authors have the ability to revert to an earlier version (the entire version, not one at a time) if they disapprove of a change.

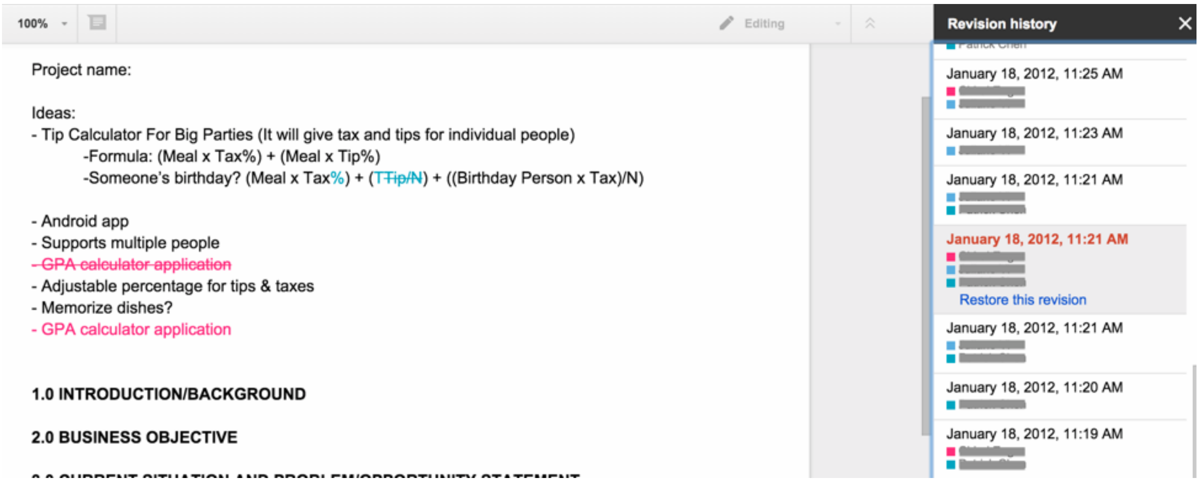


Figure 2.4: Authorship of Changes as Shown in Google Docs Revision History.

2.2.2 HistoryFlow Reveals Patterns of Collaboration in Wikipedia

There have been a few earlier efforts to visualize text written by multiple authors. One that inspired our work is HistoryFlow, built to explore the co-authorship patterns in Wikipedia (Viegas et al. 2004). HistoryFlow is a tool to visualize how a Wikipedia page is created and edited over time. It uses columns to indicate revisions of a document and different sized sections to represent the size of the changed content and color to indicate authorship, all in relative position in the document. For example, Figure 5A shows the four revisions using columns, and colored rectangles to represent different segments of words written by co-authors. Figure 5B shows the move of document's sections using light-colored links. In other words, it shows who did what, how much, where in the document, and when. Whereas Figures 5A and B show the order of the changes, Figure 5C shows the revisions scaled by time.

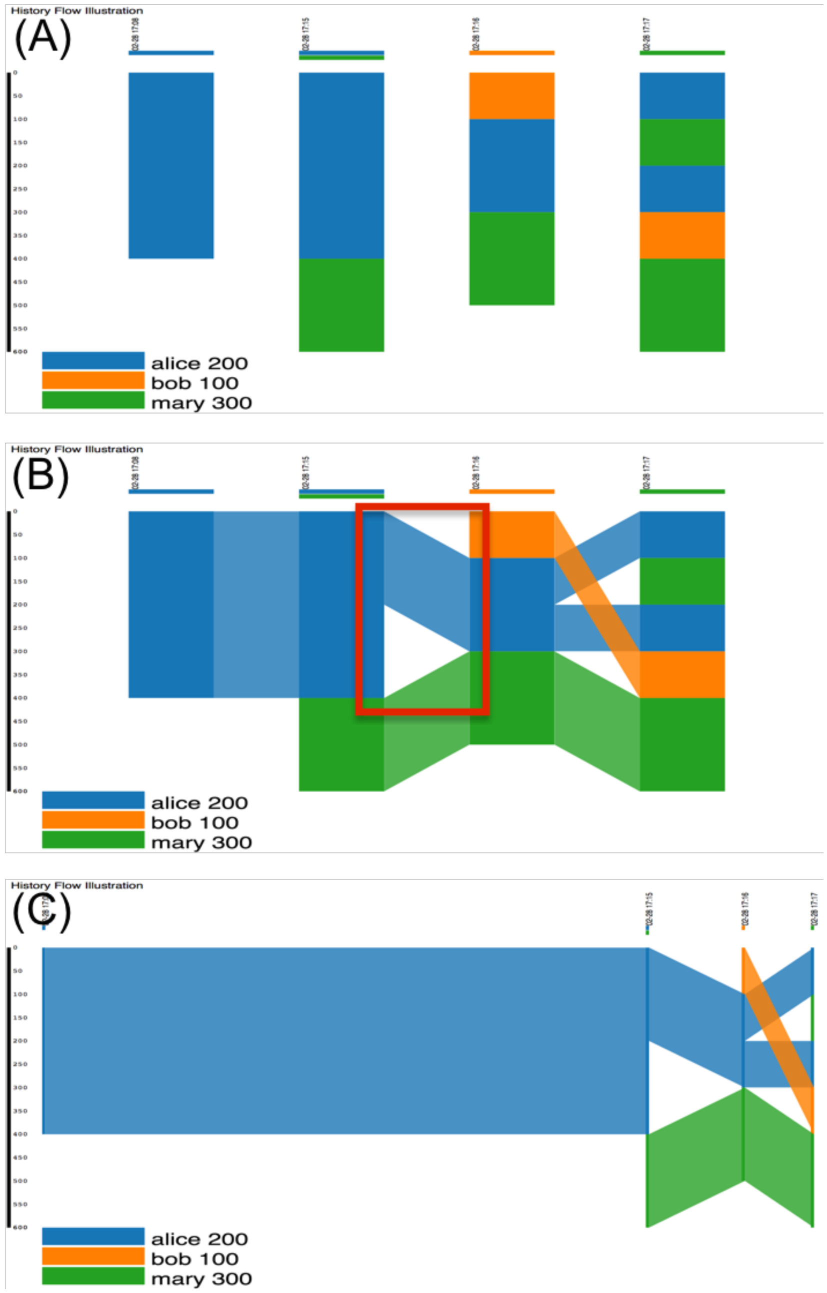


Figure 2.5: Representation of the *HistoryFlow* Rules Using D3.js (Bostock et al. 2011). (A) indicates how much is written or deleted in different revision columns, (B) shows the mapping of changes or stability over time, and (C) shows this same view scaled by time.

In the collaboration scenario illustrated in Figure 2.5, Alice (the blue) created the document and added a chunk of text in the first revision. In the second revision, Mary (the green) came in and added more words at the end of the document, while Alice's work remained. In the third revision, Bob (the orange) came in, deleted a part of Alice's original work and added some words to the beginning (as illustrated in the highlighted box in Figure 5B). In the final revision, Mary contributed some work in the middle of Alice's work, which divided the latter into two parts, and also moved Bob's work from beginning to the middle.

Figure 2.6 illustrates one of the collaborative writing patterns in Wikipedia that was identified as the negotiation pattern (Viegas et al. 2004). This pattern is revealed by the HistoryFlow visualization where we can see a clear zigzag arrangement in a few revisions and then it stabilized. The visualization suggests that multiple authors had a disagreement over the Wikipedia page content adding and deleting the same passage a number of times. The Wikipedia community has noticed this phenomenon, calling it an "edit war". Without this visualization tool, researchers would have had to spend much more effort in identifying this collaboration pattern.

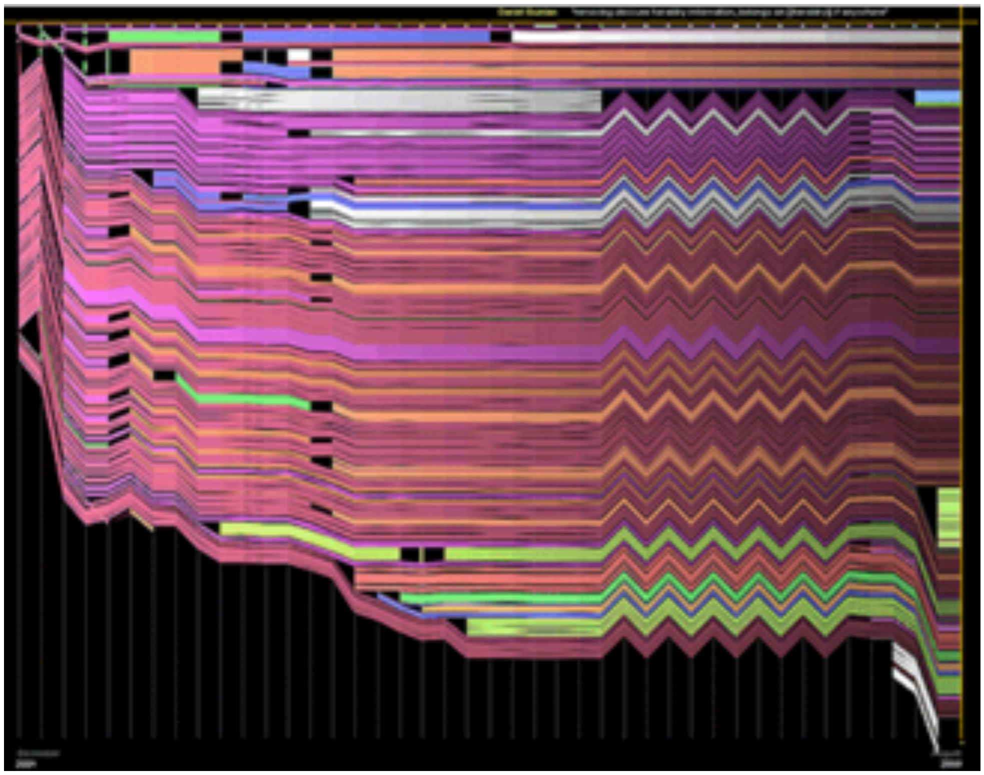


Figure 2.6: The HistoryFlow of the Wikipedia Entry for "Chocolate" Showing Amount Entered by Different Authors and then a Zigzag Pattern of an Edit War (Viegas et al. 2004).

In addition to revealing collaboration patterns, the history flow visualization is also useful in identifying authorship and evaluating contribution evenness (Viegas et al. 2007). Wikipedia aims to create a neutral point of view so it does not want the entire page written by only one editor, because a single-authored entry may represent a personal bias. The color-coded rows can be used to reveal the authorship of the document and to see whether one author (color) dominates the document. When using the visualization to analyze the coordination pages in Wikipedia (i.e., Talk pages, which is also in the wiki structure), the history flow visualization also yielded patterns of group coordination, policy, and processes (Viegas et al. 2007).

Diaz and Puente extend the original HistoryFlow visualization into corporate settings (Diaz and Puente 2010), as Wiki is widely used in companies to promote collective intelligence (Holtzblatt et al. 2010). They created visualizations for an enterprise wiki system and found that, when compared to Wikipedia, the enterprise wiki tends to be much smaller and each page has fewer revisions. In addition, the contributors in the wiki system are employees of the company and often have connections between each other. Therefore, the system is also used to reveal the contributors' relationships and their connections through a common subject (i.e., Page) so that a Social Network Analysis (SNA) graph can be generated.

We believe that the HistoryFlow display of who did what over time is useful in the more tightly collaborative setting of co-authoring a document. However, HistoryFlow has its own limitations. The system is a proprietary IBM product and only worked with Wikipedia revision data. People outside of IBM cannot access it; researchers cannot build on it. Because it only worked with Wikipedia revision data, where the edits were always made asynchronously, the system did not consider how to visualize the concurrent editing done by multiple authors. Therefore, it would be useful to extend the HistoryFlow to visualize co-authors' activity as well as their simultaneous work. The visualization then can show a bigger picture of what is being changed and where these changes are in the document.

2.2.3 Revision Map to Study Collaboration on Google Docs

Another related visualization looks at differences between successive versions of a text document, displaying the history as a revision map, shown in Figure 2.7 (Southavilay et al. 2013), part of the iWrite suite of tools to support writing. Unlike other computer systems built to support collaborative writing (O'Rourke et al. 2011; Shermis et al. 2010), the revision map system and its tool suite focus on the writing process instead of the final product, mainly for pedagogical purposes (Calvo et al. 2011).

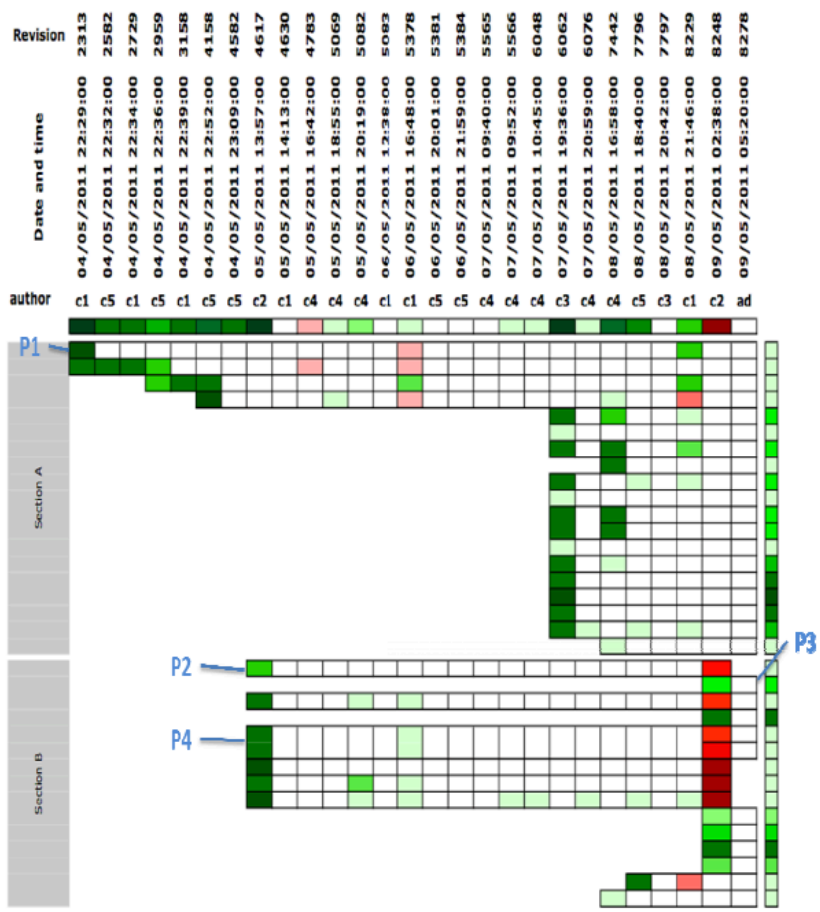


Figure 2.7: Revision Map Visualization

iWrite is based on Google Docs using machine learning and information visualization techniques to provide language learners automated feedback. The system is used to analyze the students' writing collaborations and generates topic-based collaboration networks, which can show who wrote on the same topics with whom during their writing tasks.

In Figure 2.7 The unit of analysis is a paragraph. Color indicates the number of word changes in a paragraph. For example, in Figure 2.7 the final document has two sections (Section A and B) indicated by the gray bars along the left side. Each cell represents a paragraph aligned with the section in which it is located. Green indicates that there are more additions than deletions in that revision, whereas red indicates more deletions than additions. The horizontal axis represents time going from left to the right. The authors are indicated with a code above the revision columns (in this case C1 through C5), which in turn are time stamped.

The revision map visualization system inspired us less by its visualization and more by its system architecture design. The researchers built up the visualization system overlay on Google Docs by examining its revisions and metadata archive. Similar to our goal, revision map aims to display the histories of Google Docs rather than the software engineering code files, described next.

2.2.4 Various Visualization Tools in Software Engineering

A related set of visualizations has emerged in software engineering, in large part because most software systems are developed by many different programmers (Curtis et al. 1988; Dabbish et al. 2012). Seesoft was the first to create visualizations of line-oriented software code data (Eick et al. 1992). As shown in Figure 2.8, the visualization uses columns to represent files in a project and thin rows to represent lines of codes. The height of the column represents how large each file is, and the color of the thin rows indicates the age of the code (e.g., red rows are the most recently changed lines of code, the blue ones are the oldest). These visualizations reveal programming details, such as who wrote each line and when it was written, revealed with a mouse-hover over the line. The authors believe that this abstracted representation allows the users to gain insights into the whole system more easily and at the same time, a finer-grained level upon detailed examination. Project managers and developers who used Seesoft confirmed its usefulness in balancing the team's workload, alerting developers to potential bugs and identifying existing errors (Eick et al. 1992).

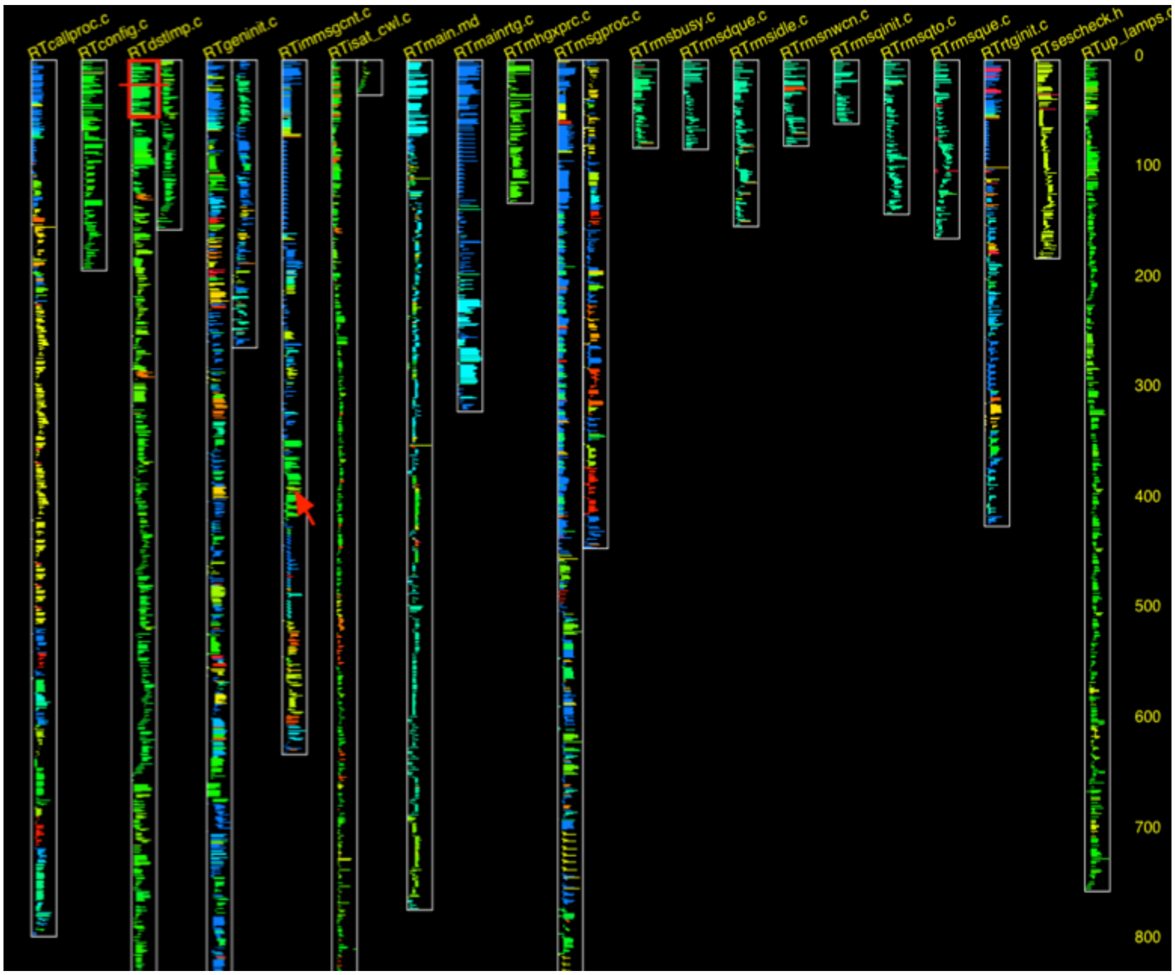


Figure 2.8: Seesoft Visualization

Augur, shown in Figure 2.9, extends Seesoft's line-oriented visualization to show software development activities together with the code (Froehlich and Dourish 2004). The line-oriented visualization has three columns: one thin column on the left represents different authors, another represents activities (e.g., whether the entry is a comment or a method definition, etc.) using various colors, and the wide column shows the actual code, color-coded to show, again, how recently it was written. The Augur system also provides concurrent access (the developers can see the visualization while in the development process), interoperability (it can support different source code repository systems) and is online (any user with Internet access can use it).

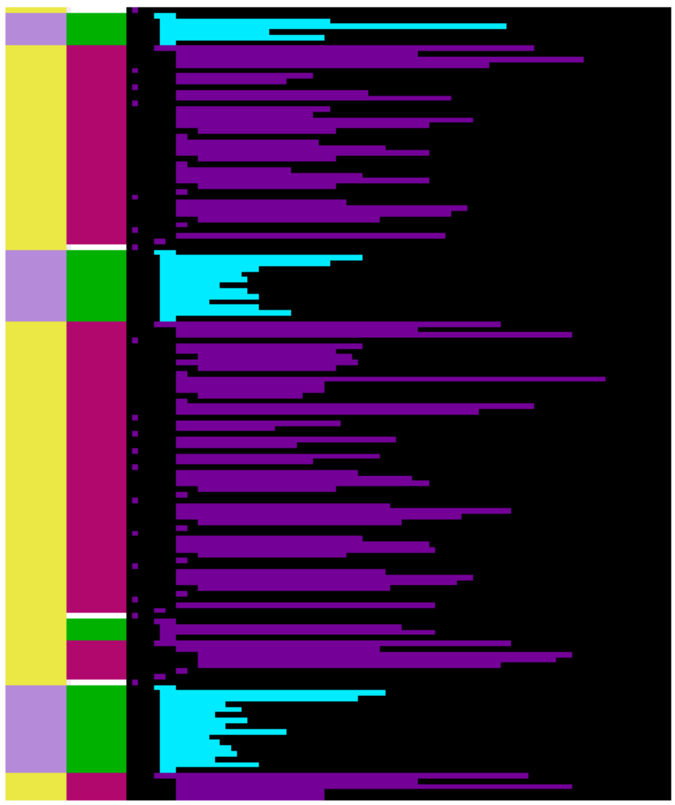


Figure 2.9: Augur Visualization

In contrast, CVSscan uses code repository data to visualize code's evolution, shown in Figure 2.10 (Voinea et al. 2005). CVSscan shows either a line-oriented or file-based visualization. In the line-oriented view, CVSscan presents each revision of a single code file as a colored column and uses the horizontal axis to indicate time. The line-based mode clearly indicates the line modified by additions (light blue), modified by deletions (red), modified by editing (yellow) and constant (green) of each line of code. The system has been shown to be very useful in helping developers understand software repository histories and helping them maintain the software (Voinea et al. 2005).

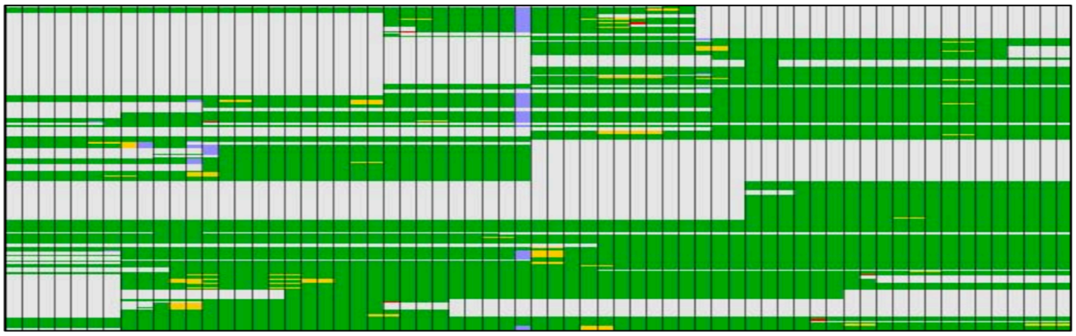


Figure 2.10: CVSscan

There are other visualizations focusing on different aspects of a software project's evolution. For example, Lanza uses the evolution matrix to characterize a code file's history at the class level (Lanza 2001). In Figure 2.11, each rectangle represents a class. The vertical dimension is used to represents a file's revisions and the horizontal dimension is used to represent time from left to right. From this visualization, it can be easily seen which class is created or deleted in which revision, and during which time period there is a lot work done. They validated the usefulness of the visualization using a few projects in the lab, showing that the evolution matrix visualization provides intuitive results about the object-oriented project's evolution, even though it is only to the class-level.

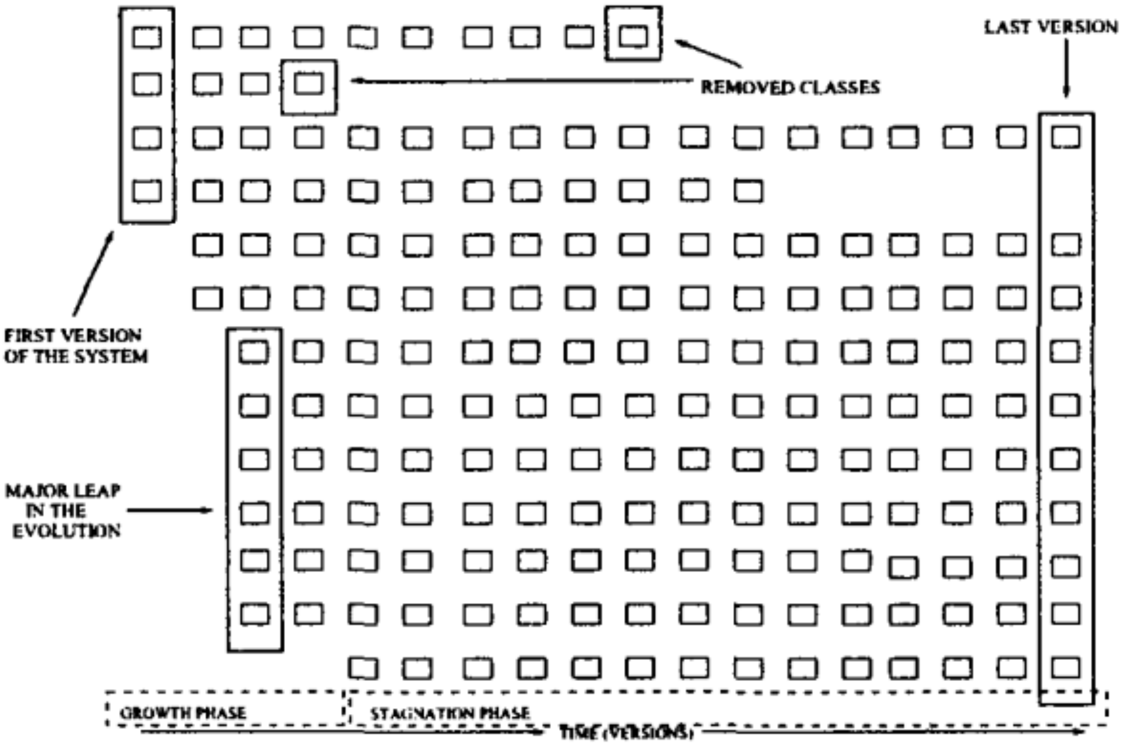


Figure 2.11: The Evolution Matrix Visualization

Van Rysselberghe and Demeyer (2004) use a dot-plot to depict the active moments during a project's development, used to recognize relevant changes. They had no need for detailed information so that they limited it to the level of file changes. In Figure 2.12, files' names are listed below the chart and the y-axis is used to represent time. When a file is changed at a certain time point, they put a dot. They used the visualization to run a few large software projects (e.g., the Tomcat server project) and found it useful. For example, they used it to identify unstable files that changed frequently, like AminatedString.java in this example, which might indicate a bad design.

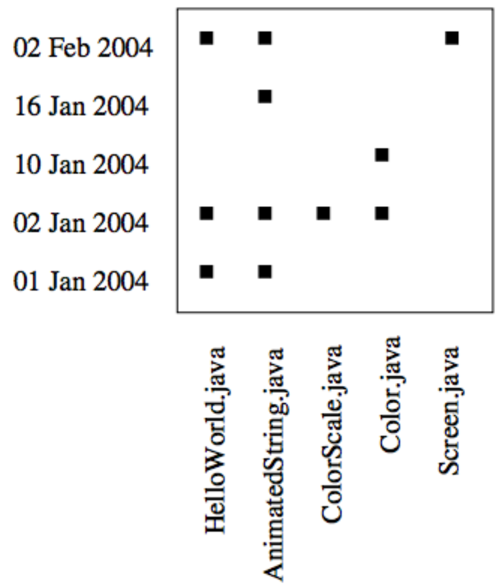


Figure 2.12: The Dot-Plot Visualization in Van Rysselberghe and Demeyer (2004)

Girba et al. (2005) designed the Ownership Map visualization to link the changes in code and the author who made the change, so they could understand how developers interacted when and where, shown in Figure 2.13. Their system, Chronia, relies on the CVS log data and assumes files are connected if they are committed in the same period. The system assigns ownerships to the line level, noting that the person who edited a line the most recently "owns" the line, and the person who has the most line ownership in a file owns the file. In Figure 2.13 example, the vertical direction lists many files represented by colored lines. The horizontal direction represents time. The dots on the line represent users' edits and commits. By applying this visualization to several projects in the real world (e.g., Tomcat), they were able to identify certain behavioral patterns (e.g., R5 in Figure 2.13, a "monologue pattern" which means a period when all files share the same ownership). Chronia is limited in that it works only on CVS log data and it cannot reveal file renaming or moves in its present state.

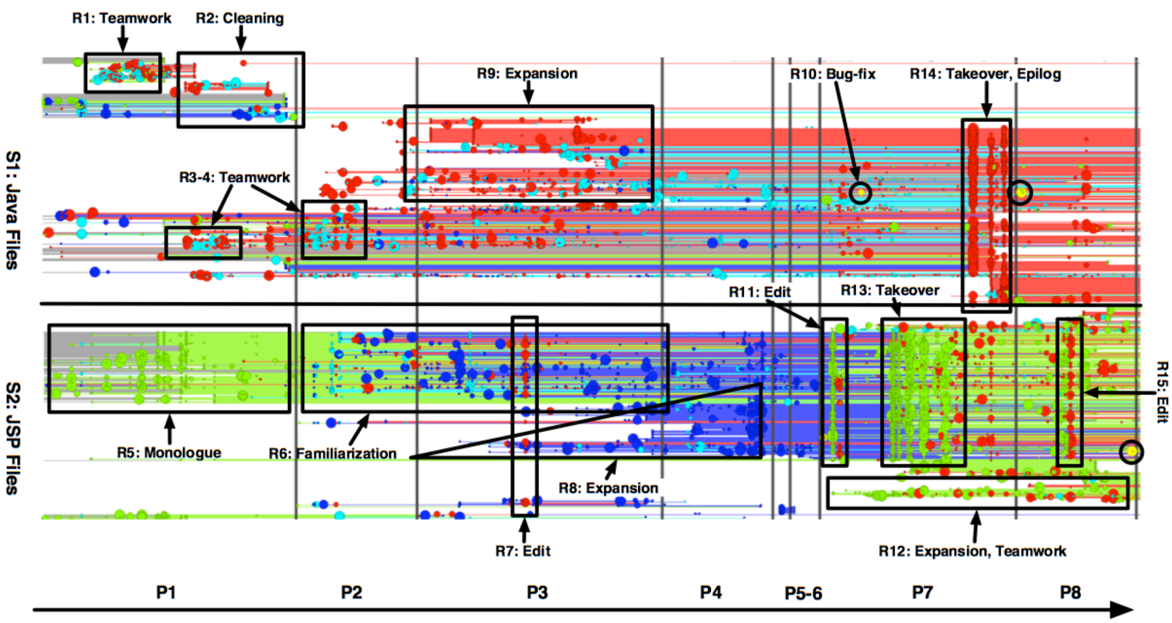


Figure 2.13: The Ownership Map Visualization

Figure 2.14 and Figure 2.15 are two recent visualization examples that visualize the evolution of a project repository hosted in Git and in Eclipse's plug-in revision control systems respectively (Elsen 2013; Servant and Jones 2013). VisGi in Figure 2.14 uses the sunburst tree layout to depict the project folders architecture. The depth of a file's directory is by distance from the center to the edge (e.g., "/root/directory/file.txt"). The first circle in the center represents the root directory of the project ("/root" in the previous example). The second circle to the center represents the second layer of directories ("/directory"), and so on. The files are at the edge ("/file.txt"). The two slider-bars at the bottom allow users to select different timestamps and different group notes. The layout can also be used to visualize the change (delta) between two branches of the project. For example, a group developed a branch with "/root/directory/directory1/file1.txt" and the other group developed a branch with "/root/directory/directory2/file2.txt". As shown in Figure 2.14, two branches are overlapped and the blue sections indicate the creation of folders (such as "/directory1") and files (such as "/file1.txt") while the red represents the deletion (such as "/directory2/file2.txt"). The researchers pointed to the need for further work, for example, a way to represent file content and authorship.

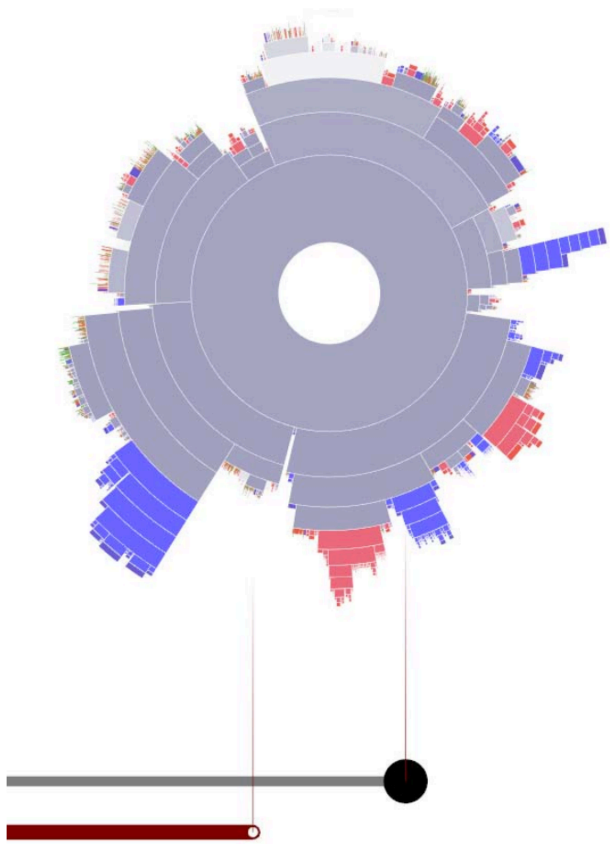


Figure 2.14. VisGi visualization

The Chronos system shown in Figure 2.15 presents different versions of code (at the bottom) along with a gray horizontal bar as timeline (at the top). In the scenarios in Figure 2.15, the user wants to know who wrote a section of code and who edited it recently. Two adjacent revision slices are rendered, while in the real system, it could reveal all the revision slices so it could be very long. This visualization showed a selected section code's historical change events in different revisions of the project's evolution below the time it was generated, which is intended to support the developers' recognition of authorship patterns (Servant and Jones 2012). This design is based on the observation that sometimes programmers want to find collaborators to help with understanding a particular part of code. The right person to ask is the one who recently edited the code or the one who wrote it in the first place. The authors of Chronos further conducted an evaluation experiment within a developer team, in which the developers spent less time, examined less information but solved the software-maintenance task more correctly (Servant and Jones 2012).

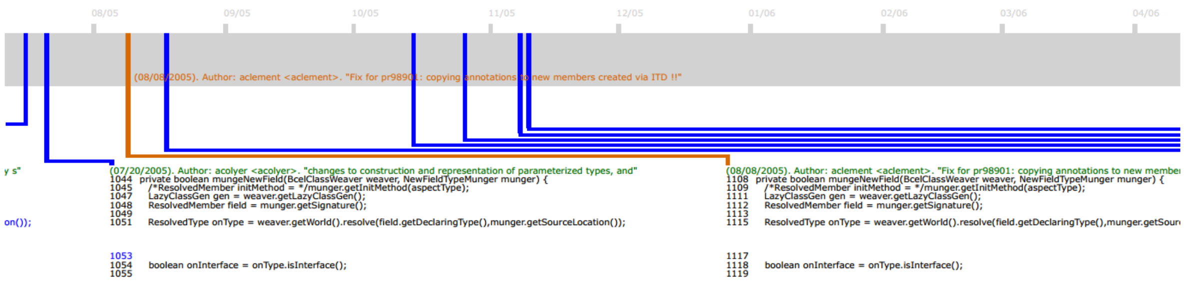


Figure 2.15: An Example of Chronos Visualization

As we can see, all these systems have similarities. Most of them use one orientation (vertical or horizontal) to represent time and use the other one to represent the size of the file or the number of classes. Some of them use color to represent the authors, others use color to represent different activities or code structures. A few systems provide granularity at the class level or the file level, but most of the systems used the line-based approach. Some systems pay more attention to accessibility and interoperability issues, and try to explicitly address the collaboration awareness issues while designing the system.

However, none of the reviewed visualizations display simultaneous editing likely because the systems that people were collaborating through did not allow synchronous work. What are the new patterns of collaboration now made possible by these new systems?

In addition, many of the above-mentioned visualizations present too much information to the users. It is difficult for users to apprehend the most important information, if the visualization is not well designed. Users have limited cognition and attention, so we need to highlight the most important information to make the visualizations easier for users to interpret. Information visualization can be particularly powerful in revealing an overview of the data, presenting the patterns and trends. However, some of the aforementioned systems provided too much detailed and distracting information, failing to present a high-level abstraction to reveal the patterns within the visualization.

These earlier visualizations as well as visualization design principles (Tufte and Graves-Morris 1983; Ware 2012) inspired us to develop a new document visualization system, DocuViz, to study how users write together asynchronously and synchronously. Therefore, we add another question into our research questions:

- How can we build a useful information visualization tool to help with the research of collaborative writing? Is visual analytics method a promising way to study collaborative writing, and potentially useful for co-authors as well?

2.3 Research Questions

In summary, this dissertation focuses on six research questions that are inspired by the previous literature:

- RQ1: What tools do co-authors use and what do they do in today's collaborative writing?
- RQ2: Why co-authors choose to use certain tools over the other tools, or ways of working together over the other ways of working together?

- RQ3: What practices of collaborative writing might be related to the quality of the documents?
- RQ4: Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?
- RQ5: How can we improve the design of the systems to better support collaborative writing?
- RQ6: How can we build a useful information visualization tool to help with the research of collaborative writing? Is visual analytics method a promising way to study collaborative writing?

Later in the dissertation, Chapter 3 will report an interview study that addresses RQ1, RQ2, RQ4, and RQ5. Chapter 4 presents the visualization system that addresses RQ6. Chapter 6 covers a mixed method study that addresses RQ1, RQ3, RQ4, RQ5, and RQ6.

CHAPTER 3. STUDY I: EXPLORING USERS' PERCEPTIONS IN TODAY'S COLLABORATIVE WRITING

3.1 Introduction

The goal of this study is to better understand people's perceptions and practices of collaborative writing with the help of commercially available technologies (e.g., using Word and Google Docs), and to explore design implications to improve these tools. Many researchers and designers have been exploring this question for 30 years, but people's technological readiness keeps changing and the technologies also change. People, even young children, are much more comfortable with computer systems today than they were decades ago. Technologies today are more sophisticated than they used to be. The synchronous editing capability at the keystroke level only existed in a few experimental systems like ShrEdit (McGuffin and Olson 1992) 30 years ago. Now, Google Docs and many other online editors allow synchronous editing, and the general public uses it. We may therefore expect new practices. But old habits die hard. We may see people use these new capabilities but in the old ways.

In order to better understand coauthors' collaborative writing practices and perceptions, we interviewed 30 people about topics including: what tools and features they use, when do they choose to write together with others, how they use these tools, and how they think of the process. We used a semi-structured interview script, as shown in Appendix A. From this study, we enrich the understanding on how people write together, propose design implications for collaborative writing technologies, and suggest future research directions.

3.2 Research Questions

First, we were interested in the features and accompanying practices that people are using in today's collaborative writing. In particular, we focus on the synchronous editing feature and the commenting feature, as well as the practices around them because these features are pervasive and appear in multiple systems.

RQ1: Which tools/features do co-authors use and what do they do in today's collaborative writing?

Second, we were interested in exploring why people chose to use certain features and certain ways of working. In particular, we are interested in two practices: Now that people have the feature and the capability to write synchronously, why do they sometimes choose not to do so? People can leave comments or make changes directly to the content. Why do they prefer commenting over direct editing, or vise versa?

RQ2: Why co-authors choose to use certain tools over the other tools, or ways of working together over the other ways of working together? We use synchronous editing and direct commenting as two examples.

RQ4: Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?

RQ5: How can we improve the design of the systems to better support collaborative writing?

3.3 Research Methods

In the current study, we conducted semi-structured interviews with 30 people, asking what they write together, how they write together, what tools and features they use, and most importantly, why they use such features and write in certain ways. We used snowball-sampling (Biernacki and Waldorf 1981) to recruit participants. We interviewed a total of five college students and seven graduate students, six professors, one lawyer, one accountant, three researchers and four engineers from IT companies, and three consultants with MBA degrees. All interviewees were located in the United States; eleven participants were interviewed in person, and nineteen participants were remotely interviewed by video conferencing via Skype or Google Hangout. Audio recordings were collected for all interviews with interviewees' consent and then transcribed.

While people from varying disciplines use the word "collaborative" differently, we are adopting the definition that Dillon proposed in 1993: any document production activities that involve more than one person is collaborative writing (Dillon 1993).

Guided by Posner and Baecker's framework, we iteratively developed the coding scheme to categorize the tools/features that people use, their collaboration practices, and why they choose to use them or not to use them (Table 3.1).

Table 3.1: Coding Categories.

Category	Sub-category
Tools	Web-based Editors (e.g., Google Docs)
	Personal Word Processor (e.g., Word)
	Other Editors (e.g., VI)
	Systems that support collaborative writing (e.g., Dropbox and Email)
Features	Synchronous access and editing
	Commenting and suggesting changes
	Collaboration awareness features (e.g., color cursor and tracking changes)
	Communication
	Other neat features (e.g., search keywords in screenshots)
Practices	Writing synchronously or asynchronously
	Commenting or directly editing
	Writing collocated or remotely
	Communication
	Role assignment and contribution evaluation
Reasons	Power Dynamics in collaborative writing
	Awareness of responsibility and contribution
	Writing Privacy
	Peer pressure and protocol

3.4 Results

3.4.1 Overview

Our interviewees reported that they are writing collaboratively now more than before. With the pervasiveness of writing together and the large scale of collaboration, collaborative writing has become even more complex. We first briefly report which tools/features and practices that people are using in collaborative writing. Then we use two practices (synchronous editing and direct editing) to illustrate the complexity of today's collaborative writing.

3.4.1.1 More Frequent, More pervasive, and Larger Scale

Compared with previous studies about collaborative writing (Posner and Baecker 1992; Kim and Eklundh 2001), our study found that participants reported that they are writing collaboratively now more than before. All 30 participants in our study reported that they were frequently involved in collaborative writing activities (at least once a week, if not daily).

Participants reported that they collaboratively wrote various types of documents and in different scenarios. All participants mentioned work-related documents, and over one-third of participants reported that they also collaboratively wrote documents for personal purposes. This is new, as previous literature reported only work-related or education-related writing collaboration. Work-related documents mentioned included group reports, scholarly publications, and meeting minutes. Personal documents mentioned included documents such as travel itineraries, monthly expense summaries, and invitations for weddings and parties. Not surprisingly, participants' professions dictated the different kinds of documents they wrote together: engineers in IT companies write documentation together, and college students often write class assignments in groups.

Collaborations have also been conducted on a larger scale. When compared to previous studies where most collaboration had only two co-authors (Beck 1993; Birnholtz and Ibara 2012), the participants in this study reported that they often write with more collaborators than they used to. For example, college students said they are required to work in groups with 3 or 4 others to finish class assignments; in a scenario where students voluntarily form study groups to prepare for quizzes, they may collaboratively edit a document with dozens of other students. The engineers in IT companies said they often created documents and shared them with the whole company; thousands of employees could read and comment on them (although editing may not be allowed).

3.4.1.2 Collaborative Writing Tools/Features and Practices

Participants considered various systems as tools to support collaborative writing. For example, Microsoft Word and Google Docs were the most commonly mentioned systems being used in today's collaborative writing. All participants were familiar with them and had used them. But participants also described a few other systems as supporting collaborative writing. These systems can often be categorized as text editors (e.g., LaTex and VI), communication systems (e.g., online messaging), and shared space systems (e.g., Dropbox) or project management systems (e.g., Git).

Participants reported many features that they used to support collaboration. The function that allows users to keep track of changes was one of the most commonly described features (i.e., "tracking changes" in Word and "suggestion mode" in Google Docs). Participants often referred to the commenting function and the tracking changes feature as one, because the changes and the comments were both displayed in similar pop-out text boxes.

Some participants greatly valued the ability to edit synchronously that is provided by some web-based editors.

> *"In most occasions whenever working online, we use Google Docs. It's accessible. We like the collaboration ability and the synchronous collaboration."*

Often the tools and features dictate the practices. For example, participants usually used Word to edit files separately, and then exchanged them with email or shared storage tools (e.g., Dropbox, OneDrive and Google Drive). When using Google Docs, they were more likely to write synchronously.

> *"We would just edit the file at the same time [in the meeting]; and then everybody went back home, or went back to offices, and they still contributed to the file."*

In summary, people today commonly write collaboratively for both work-related and personal purposes. There are many commercially available tools and people are familiar with their features and use them in their collaborative writing. Often, people's choices of tools/features correspond to their choices of practices.

Whether to use comments to suggest changes or to directly edit others' words is a complicated choice for writing collaborators, and many previous studies have explored this question (Birnholtz and Ibara 2012). We noticed the same issue reported by our participants. We explore interviewees' reasoning for why they choose to write synchronously versus asynchronously, and why they choose to edit directly versus comment by the side. We categorize participants' reported rationales into four sections (in sections 3.4.2 to 3.4.5): Power Dynamics in Collaborative Writing, Awareness for

Responsibility and Contribution, Writing Privacy, and Social Norms, Policy, and Network Effects.

3.4.2 Power Dynamics in Collaborative Writing

The first reason for why people have different preferences for synchronous versus asynchronous work is related to power dynamics. Much previous literature (e.g. Lowry et al. 2004; Posner and Baecker 1992) discussed writing roles (e.g., writer and editor) in collaborative writing, whereas our participants reported that they and their collaborators have different roles in their company or in school. For example, students write with professors, or programmers write together with designers in a company. Various roles and the corresponding rights and expectations (Forsyth 2009), called power dynamics, can influence the behaviors in the collaboration.

3.4.2.1 Hierarchy in writing teams

In many writing scenarios, a writing team would *"have a main person who is in charge [of or] who will make comments about how to make this all one kind of document."* In some other scenarios, the team does not have a hierarchy. However, one of the participants believed that a democratic view of writing collaboration would actually cause problems.

> *"When people pretend that there's not a leader or there's not a hierarchy, that's when some trouble starts. People would be thinking, everyone's great and everything is fair and democratic. Well, that's actually never true, especially when you're dealing with [relationships between] faculty and Ph.D. students."*
>
> *"It's not the technology that makes it worse, it's just the lack of leadership … in terms of why we need to have a leader [to make decisions], you can't just be the person with an idea and everyone else has to like your idea, they aren't your puppies, right?"*

3.4.2.2 Using the access control feature to reflect the hierarchy

Some web-based systems (e.g., Google Docs and Microsoft OneNote) allow users to assign various access permissions to different collaborators, such as edit, suggest, comment, or read only. People use these different access permissions to impose the power hierarchy in teams. For example, for a system design document in IT companies, the core engineer team will have permission to write and edit the document, while the designers may only have permission to read and comment, and the rest of the company may only have permission to read the document. This is an example of how a team uses the existing document control feature to reflect the power hierarchy in this collaboration.

Participants found this access control feature quite useful: by restricting the editing permission to the core members, it can prevent unexpected changes from irrelevant people, and limits the decision-making power to only the core team. Meanwhile, sharing read permission with the whole company encourages knowledge sharing.

3.4.2.3 The unspoken leader

Even if there is no explicit power hierarchy in some writing scenarios, several participants believed there is an "unspoken leader" in the writing team.

> *"So I believe the unspoken leader or the one who has the kind of authority in the document ... is usually the one who initially created [the document]. ... I think this is kind of the implicit hierarchy that comes into that document."*

> *"In the team usually there's someone who talks more than others, and even though we don't assign a leader ... we assume ... that the person who talks the most is the person structured like a leader."*

3.4.2.4 Social status and expertise

Difference in social status and expertise are often the source of the power dynamics.

Participants reported that their choice of editing directly versus commenting indirectly was related to the social status of the collaborator. For example, participants reported that they would not want to change their advisors' (or managers') words. But they were more likely to edit their friends' and students' words. On the other hand, the professor participants said they felt quite comfortable directly changing their students' writing.

The student and advisor case may also be a case reflecting differences in expertise. For example, the professor reported that he used only the commenting function when suggesting changes to a senior colleague because he believed the colleague could address those grammar errors or typos. But he would directly edit his students' work. Similarly, the IT engineers reported that they would not allow user-interface designers to touch their technical designs just like they would not change the designers' work.

3.4.2.5 Conflict and control

The power dynamic is also related to control of the document and ability to resolve conflicts. With the power of being a leader, a participant said he had a better chance to express his voice in the final draft.

> *"I will often volunteer [to be the leader] because I want to make sure my opinions or my ideas are in there, so I will volunteer to take it. Like on this paper, I have some ideas. I want to make sure they are in there. I want control."*

If there is a conflict within a team, knowing who the leader is is important and helpful for resolving the conflict.

> *"They asked me to write something that I didn't think should be included in there. So there was a little back and forth about that. I lost [to them]."*

3.4.3 Awareness for Responsibility and Contribution

People choose not to write synchronously or edit directly in text sometimes because they have concerns that these behaviors might be blurring individuals' responsibility and contributions. Many previous studies have addressed the importance of creating awareness in collaborative writing (Dourish and Bellotti 1992). In this study, we found that group awareness, especially a different form of awareness about responsibilities and contributions, is crucial for successful collaboration.

Today's text editors, particularly most web-based ones such as Google Docs and Shared LaTex, can support synchronous editing much better than systems in earlier years (Kim and Eklundh 2001). Writing synchronously requires enhanced and more fine-grained awareness in the moment. To support the awareness of what others are writing, Google Docs uses color-coded cursors in the document to indicate collaborators' real-time writing. Other tools like Microsoft OneNote use colors to lock and highlight the paragraph that is being edited by other users.

However, in addition to providing awareness of others' writing progress, it is also important to have an awareness of each member's responsibility and acknowledging their contributions, which is detailed in the following subsections.

3.4.3.1 Acknowledging individual contribution

Participants believed it is important to be able to provide awareness of an individual's contribution so that the individuals can get appropriate rewards. For example, one participant said:

> *"It's for the purposes of academic evaluation so that a person could be rewarded with the grade that matches his efforts. It also helps with the team dynamics so that you can identify who delivered what they promised, and who did not."*

Identifying an individual's contribution is also important for the teams to recall past edits.

> *"It's just easier for us to know who writes what so we can talk about it on the next day, like 'Okay, I see your paragraph written over here. It's written by you, so tell me more about it.'"*

3.4.3.2 Clarifying responsibility

Users wanted features that clarify each collaborator's responsibility and keep track of the accomplishment of their assigned work over time. In our interviews, participants from various professions (e.g., consultants, engineers and the lawyer) reported that they used project management systems in their companies to plan a project, assign tasks to different team members, and track the progress. These systems were usually paired with offline editors (e.g., Word). Team members might be assigned the writing, editing, proofreading, or validating tasks. The system records each person's "check-in" (e.g., uploading a document) and "check-out" (e.g., downloading a document) activities, as well as the writing, editing, and reviewing process. Therefore, the companies know whom to blame if anything goes wrong.

Some participants said they also found the revision history feature of Google Docs useful for clarifying responsibilities, which they infer from who writes or edits a section. The revision history feature shows text differences between adjacent versions of a document. In particular, participants used the revision history feature to keep track of what others had changed.

> *"The revision history is very, very good as well. We want to have a sense of who is collaborating, [and] who is actually working on the project, 'Cause usually a team has like five or six people. It's a lot of people in the team. And we don't want to have one guy or just two or three people do the most work and then the others not do anything."*

In some working situations, a clarification of responsibility is a must. One of our participants, who is a lawyer, mentioned that synchronous writing is forbidden in her working place since an incorrectly written legal document can have severe consequences. In this case, the law firm had to make it explicit that the employees cannot use the synchronous editing feature.

> *"… [writing simultaneously] will cause complications and other complex issues. For example, you will not be quite sure who is responsible for what changes or revisions. And that will involve issues. … [So we] have this very mature system to make sure that people know who made the mistakes or caused the problems, if there's anything wrong."*

3.4.3.3 Appropriated features to create awareness of responsibility and contribution

In many commonly used text editors, there is no feature to support the awareness of contribution and responsibility. However, we found that many participants devised creative approaches to mark people's contribution in the writing. For example, participants often change text fonts and colors to manually embed authorship information in the text. Many participants reported that this method is very useful for supporting collaboration. In one case told by a participant, after a discussion among team members at the beginning of collaboration, they decided that each of them should use a different background color to represent each individual's contribution and responsibility. In order to remember the rule, they sometimes also wrote a coding scheme at the beginning of the text. After they finished writing and revision, they deleted the colors from the final document.

3.4.4 Writing Privacy

While the current editing tools have powerful features to support collaborative writing at a fine-grained level in real time, we found that some participants refused to use the synchronous features for other reasons. The concept of "*private space*" and "*writing is private*" was mentioned many times.

> *“You’re watching other people writing and you know yourself to be watched by the other people … I lost the pleasure of writing … Writing should be a private activity.”*

One reason that some participants do not use synchronous editing features is because they worried that their detailed typing behaviors (e.g., insert and delete the same word) might be interpreted by others as struggling with the thought process. Being watched or possibly judged by their collaborators would make them uncomfortable.

> *“I don’t want people to see my thought process, because when [I write], I type and then delete and then insert again … so I think it will be better for me just to go to another text document and then type … When I see that it is good [enough], I will copy and paste it [back into the document that is being synchronously edited].”*

Participants also believed that they might be distracted when they saw what others were typing and they might distract others as well.

> *“The simultaneous writing is awesome; however, the lack of simultaneous writing in Word is also awesome. So it’s like sometimes you want to write together, and then sometimes it’s distracting.”*

However, distracting is not necessarily a bad thing. Sometimes people wanted to be distracted by others’ writing, often because their writing is closely related to others’ input and by seeing others’ writing, they can coordinate their thoughts.

> *“I’m writing an introduction and I see someone working in a couple paragraphs later. I start looking at what they’re writing to converge on the same point.”*

The concern for privacy is less severe in some types of writing tasks. For writing tasks such as taking meeting minutes, setting up outlines, and assigning responsibilities in a meeting, participants perceived that the synchronous editing was very useful and they had no issues in writing synchronously with others.

> *“I'll edit documents simultaneously, but those documents are primarily committee documents. Like I’m on a faculty-search committee, then we write a description of the position together [during the meeting].”*

3.4.5 Social Norms, Policy, and Network Effects

The last category of reasons for why participants decided to use or not to use certain tools or practices is unsurprisingly social norms, institutional policy, and network effects.

3.4.5.1 Social Norms

Some participants' teams have a shared agreement that directly editing others' work is not polite. They believe each writing piece should be regarded as a personal intellectual property, even within collaborative writing. It would therefore be rude to directly change "*a writing piece that belongs to somebody else*." These people would also feel angry if other co-authors directly changed their writing.

> *"Well, that [editing others' work] seems really not polite. You never edit someone else's work, except if you are the supervisor of this group. [Laughs]"*

Instead of directly editing, people would prefer to leave a comment or initiate a discussion in order to suggest the changes in a way that shows their respect for another's work. For example, two participants mentioned that:

> *"Usually I know that whatever that person wrote was for a reason. You know, it's not something I would just take away. Because I know they're all very smart, and [they have] their reasons to add that section. So I would never just kind of delete anything without actually suggesting a change first."*

> *"In Google Docs, specifically the adding suggestion feature was very good. It allowed us to kindly provide feedback or edit each other's work without their permission."*

3.4.5.2 Institutional policy

Taking a closer look into industry, it becomes clear that the choice of writing tools is often dictated by company policies. For example, participants reported that those who work for Google are not allowed to use Microsoft products unless they get special permission, whereas participants of Microsoft are not allowed to use Google's apps. Both of these companies have their own writing editors, and they are in competition with each other. Other IT companies that do not have a competing writing product still may dictate which tool to use, in order to keep their tech-support simple or to keep their data secure. For example, participants reported that the Dropbox company used Word and shared Word documents on internal servers. Participants from Facebook also used Word and Quip because the company does not want to store information on Google's server.

A few participants also mentioned cost as another factor for why they prefer some free tools (e.g., Google Docs) over others (e.g., Word). Participants said:

"I don't have Microsoft Word installed in my computer because it is not free."

The choice of whether to directly edit others' words or simply suggest changes seems a complicated one for writing collaborators, and a previous study has explored this question (Birnholtz and Ibara 2012). They found that collaborators perceived that these behaviors would have different impacts on social relationships within the team. This perception influences collaborators' behaviors. We found that the difference in participants' professions and institutions may also influence whether they prefer editing directly or leaving comments.

Participants working in companies were extremely cautious about changing others' work. They thought, "*others are also smart people and they have their reasons to put that word there*" and "*we should respect others' work*".

Student and faculty interviewees were generally open to direct editing, but they would prefer that others leave an explanatory comment together with the change. One participant said:

"If it's a paper written by a colleague, like another professor, then typically I'll turn on the track change for sure, and sometimes I change something and I would feel it more necessary to add a comment to explain why I changed it."

3.4.5.3 Network Effects and Predefined Perceptions

Another reason why people prefer certain tools or practices over other tools or practices concerns network effects. The tools and practices that one's colleagues and friends all use is preferred over others tools and practices. It is part of the effort to build common ground within a group collaboration.

"I'm not a big fan of Word … [I'm using it] just because most of my collaborators use Word."

Word recently released an online editor that allows users to write their Word documents in a browser, and Google Docs developed an offline mode that allows users to continually edit the document even if Internet is disconnected. However, none of our participants had used these new features. Participants tended to have predefined perceptions, i.e., "*Word is for asynchronous writing and Google Docs is for synchronous writing*." Their friends and colleagues are all using each tool in a specific way, and they thus believe the tool is best for that way of working. It is unlikely that they would switch to another tool even if the second one provided functions similar to the first one.

3.5 Implications

Overall, collaborative writing is increasingly common in everyday life. There are an increasing number of tools and features that support collaboration, and as a result, collaborative writing practices are becoming more complex. We found that participants had different perceptions and behavioral preferences of collaborative writing. Based on these findings, we propose the following three design suggestions.

3.5.1 Supporting Collaboration beyond a Flat Structure

Often embedded in collaborative writing is a power dynamic and team, which some existing design features support. For example, Google Docs allows users to assign different levels of access to different people. Our participants reported that they were using this feature to reflect the power dynamic: only the core members had the editing access, whereas other members of a team only had the viewing and/or commenting access.

In addition to the access control feature, there are other features that could be implemented to reflect power dynamics. A previous study (Birnholtz and Ibara 2012) found that direct editing might be more efficient, but using comments to suggest changes could help with maintaining a good social relationship between collaborators.

In line with this finding, we suggest that when displaying the direct changes, the system should reveal different information based on the stated relationship between the editor and the viewer. People often do not need to see the detailed changes made by their supervisor or an expert because they trust (or are required to trust) this expertise or authority. But people often want to see the detailed changes from a junior team member in order to ensure the quality of those changes. It would thus be useful to give co-authors the option to hide changes made by one co-author while highlighting some changes made by another.

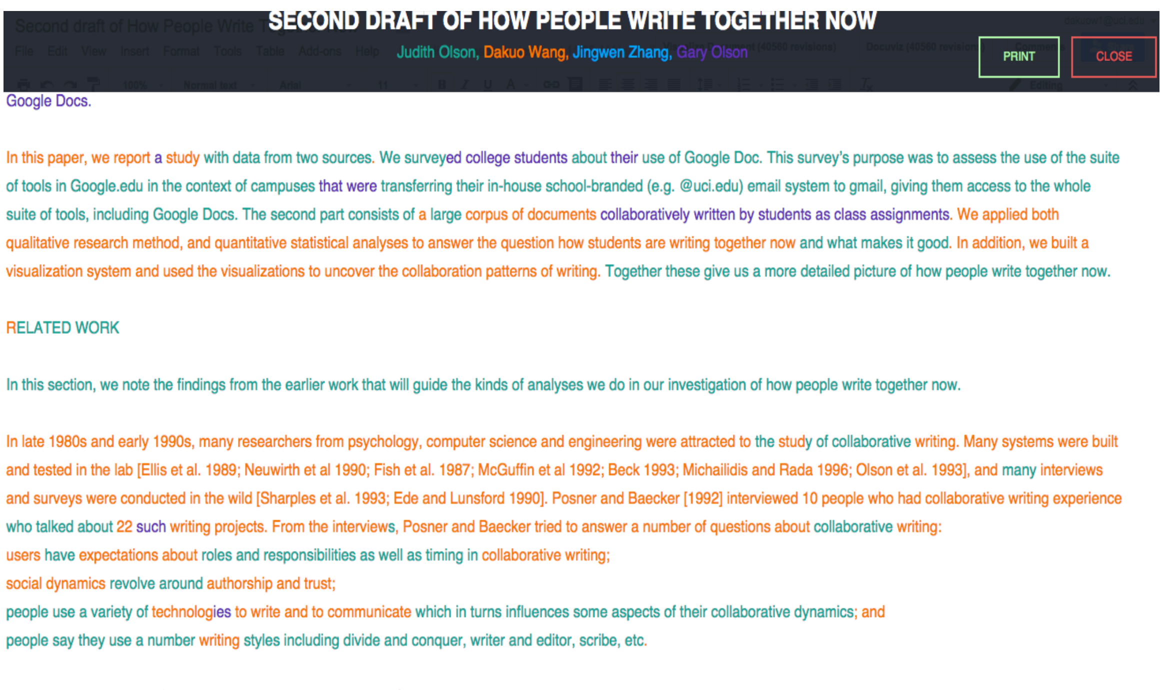
We can design the tracking changes feature to be even more intelligent, leveraging social relationship information. Many workplaces have an organization hierarchy that labels the relationship between colleagues, some public social media sites (e.g., LinkedIn) also have that information. It would not be hard for today's collaborative writing systems (e.g., Google Docs and Word) to harvest this information and to infer the social relationships between co-authors. If a collaborative writing system can detect and calculate the closeness between two collaborators, it can customize the ways of displaying changes made by one to the other. Or, more simply, the system could ask for the user's preference of whose edits to show and which ones can be automatically accepted, skirting the possibilities of incorrect inferences from other sources. The system thus can remember the user's choices. Eventually, everyone may use the same tool (e.g., Google Docs or Word), but everyone's interface would be different.

3.5.2 Supporting Awareness of Individual Responsibility and Contribution

The new features of synchronous editing enable users to work in new ways, but the old-fashioned way of asynchronous editing is still preferred by some users and by those in certain occupations. For example, the consultants and lawyer participants preferred to use Word and to exchange documents via email so they could keep everything in order and keep all behaviors traceable. Participants from educational settings or engineer teams also required the ability to identify each individual's responsibilities and contributions.

Thus, we propose a system design that preserves and presents the information about individuals' responsibilities and contributions. Knowing who wrote a passage will reveal whom one might want to talk to in order to agree on a significant change. Knowing that a particular non-committed co-author had written very little could trigger a discussion of commitment level.

We have implemented a publicly available prototype (AuthorViz) in this direction. AuthorViz (Figure 3.1) is designed to help with the authorship attribution problem in the final draft of a document. We packaged this system as a Chrome browser plugin instead of standalone systems in order to engage a broader user population. AuthorViz provides a view of the overall authorship attribution of a co-authored document. Authorship attribution has been a lasting research topic in many fields, including HCI, Natural Language Processing, and Computational Linguistics. Most of studies so far have to artificially craft documents with a combined authorship as corpus for analyses. For example, researchers often select a few paragraphs from author A's work and some others from author B's work, combine these paragraphs together to craft an artificial document, and then run the algorithm to extract linguistic signatures to identify the authorship for each paragraph. Finding a natural corpus with co-authored documents has been challenging, and labeling the authorship information for this corpus is even harder. With the help of AuthorViz, researchers can easily label paragraphs' authorship for a co-authored document, and potentially use any co-authored Docs document as their research corpus.


SECOND DRAFT OF HOW PEOPLE WRITE TOGETHER NOW

Judith Olson, Dakuo Wang, Jingwen Zhang, Gary Olson

PRINT CLOSE

Google Docs.

In this paper, we report a study with data from two sources. We surveyed college students about their use of Google Doc. This survey's purpose was to assess the use of the suite of tools in Google.edu in the context of campuses that were transferring their in-house school-branded (e.g. @uci.edu) email system to gmail, giving them access to the whole suite of tools, including Google Docs. The second part consists of a large corpus of documents collaboratively written by students as class assignments. We applied both qualitative research method, and quantitative statistical analyses to answer the question how students are writing together now and what makes it good. In addition, we built a visualization system and used the visualizations to uncover the collaboration patterns of writing. Together these give us a more detailed picture of how people write together now.

RELATED WORK

In this section, we note the findings from the earlier work that will guide the kinds of analyses we do in our investigation of how people write together now.

In late 1980s and early 1990s, many researchers from psychology, computer science and engineering were attracted to the study of collaborative writing. Many systems were built and tested in the lab [Ellis et al. 1989; Neuwirth et al 1990; Fish et al. 1987; McGuffin et al 1992; Beck 1993; Michailidis and Rada 1996; Olson et al. 1993], and many interviews and surveys were conducted in the wild [Sharples et al. 1993; Ede and Lunsford 1990]. Posner and Baecker [1992] interviewed 10 people who had collaborative writing experience who talked about 22 such writing projects. From the interviews, Posner and Baecker tried to answer a number of questions about collaborative writing:
users have expectations about roles and responsibilities as well as timing in collaborative writing;
social dynamics revolve around authorship and trust;
people use a variety of technologies to write and to communicate which in turns influences some aspects of their collaborative dynamics; and
people say they use a number writing styles including divide and conquer, writer and editor, scribe, etc.

They constructed a set of terms to describe the major aspect of collaborative writing, including roles, activities, document control, and writing strategy, shown in Table 1.

Figure 3.1: An Example of AuthorViz Visualization (different colors represent different authorship in the final draft).

We may also learn from other existing designs. The Babble system developed for synchronous computer-mediated communication systems by Erickson et al. could also work for the synchronous collaborative writing context (Erickson et al. 1999). They designed a visualization (Figure 3.2) to reflect how active each person is in a text-based conversation. When a person is more active (or adds a lot of content to the document in our scenario), his/her dot will move toward the center of the circle. If a person is browsing other webpages or using other software, his/her dot will move outside the circle.

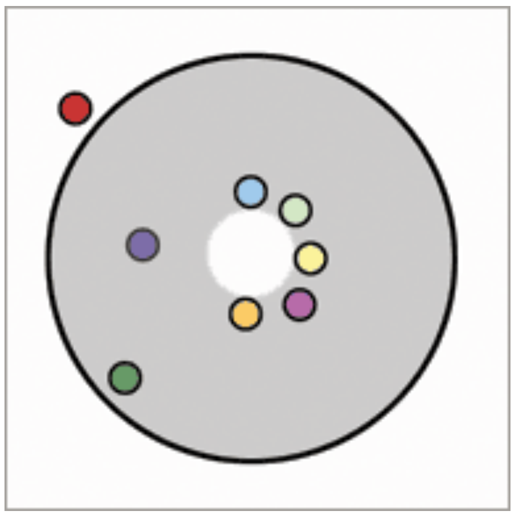


Figure 3.2: The Visualization Used to Represent the Activeness of Participants in Babble (Erickson et al. 1999).

3.5.3 Balancing Awareness of Collaboration and Privacy of Writing

Participants had different attitudes about synchronous editing. Most participants found it to be a useful feature, but some participants found it distracting and stressful to watch (and be watched by) others while writing. A few participants had to develop work-around strategies to avoid synchronous editing, which included typing in a separate document and then copying and pasting the paragraph back to the synchronous editing document. This indicates that users might also need a private writing place in addition to the synchronous writing session where they can generate ideas and articulate the words without interruption. ShrEdit, a tool developed in the 1990s, explicitly supports a private writing session in addition to synchronous and asynchronous public editing (McGuffin and Olson, 1992). And while a user is working in this private window, the fact that the person is actively writing should be displayed in a way that informs collaborators that the user is not being lazy or away from the keyboard.

3.6 Limitations and Conclusion

Although our sample is not representative of a broader user population and we have no intention of claiming any generalizable conclusion, this study can generate in-depth insights into how people are writing together now and why they choose to write in certain ways at the current time, 2016. The findings might be different in 3 or 5 years, as people get more familiar with the tools and collaboration practices.

The contexts and kinds of collaborative writing are enormous, and we had to start somewhere. We acknowledge that people's practices and perceptions could be different in different scenarios. As we mentioned earlier, Boellstorff et al. reported a case study where they wrote a book in Google Docs (Boellstorff et al. 2013). Their experience is certainly different from the experiences reported by our engineer participants, but some of the phenomena that they reported overlap with our interviews. For example, one challenge noted by both them and us concerned how to handle and accept the changes made by others. They needed an awareness of who was responsible for the change, and whether the third collaborator accepted it or not. They devised new features that use the commenting feature to vote for a change.

This work also informs future research directions. We have analyzed practices that evolved and adapted to the synchronous and asynchronous editing modes. This dichotomy is in the dimension of time-distance. We are also interested in the factor of distance and its effect on a writing collaboration. Although we do not have data, some of our participants mentioned that they were not collocated while they were collaborating. This suggests that future word processors could embed video and audio communication channels, and capture and store people's conversation as part of the document.

In conclusion, we have presented an interview study that focuses on people's practices and perceptions about collaborative writing with today's technology and context. Our results suggest that people from various occupations are writing together more frequently, more pervasively, and more with complexity. With the help of various technologies, people can write together in different ways. In particular, we were interested in two behaviors: whether participants wrote synchronously or asynchronously, and whether they preferred direct editing or suggesting changes. We found a number of factors (Power Dynamics, Awareness of Responsibility and Contribution, Writing Privacy, and Social Norms, Policy and Network Effects) that affected how they wrote together. We conclude by suggesting that system designers should design collaborative writing systems that reflect the power dynamics in teams, provide visual representations of team members' responsibilities and contributions, and balance an awareness to collaboration with the privacy of writing.

CHAPTER 4. STUDY II: DOCUVIZ: BUILDING VISUAL ANALYTICS TOOLS TO SUPPORT COLLABORATIVE WRITING RESEARCH

4.1 Introduction

Knowing that people report that they sometimes work synchronously and now write in new ways, our next goal was to investigate people's actual behaviors in collaborative writing. We are interested in the details of their collaboration, and thus needed to build tools to help us analyze the traces they leave when writing. One key tool is a visualization of their behaviors. None of the visualizations reviewed in Chapter 2 show simultaneous editing, likely because the systems that people were analyzing did not allow synchronous work. However, since the 1990s in research software (Ellis and Gibbs 1989; McGuffin and Olson 1992; Rada 1996) and now commercially authors can write simultaneously. During the synchronous work sessions, the co-authors can see where each other's insertion points are and the emerging text or changes, almost instantaneously. What are the new patterns of collaboration now made possible by these new systems?

These earlier visualizations inspired us to develop a new document visualization. We offer a new tool, DocuViz, that displays the entire revision history of Google Docs, showing more than the one-step-at–a-time view now shown in Docs' revision history and Word's tracking changes.

The research question here is:

RQ6: How can we build a useful information visualization tool to help with the research of collaborative writing? Is visual analytics method a promising way to study collaborative writing?

In what follows, we first give an overview of DocuViz, and describe its architecture and the user interface, allowing the reader to imagine the system in use. We then present a number of implementation challenges and our solutions. We end with a number of cases in which the tool has the potential to be useful: To authors themselves to see recent "seismic activity" (sections of text that had been heavily edited in a short period of time), indicating where in particular a co-author might want to pay attention, to instructors to see who has contributed what and which changes were made to comments from them, and to researchers interested in the new patterns of collaboration made possible by simultaneous editing capabilities.

4.2 System Overview

DocuViz is a general-purpose, interactive visualization system for the revision histories of Google Docs, shown in Figure 4.1. Like HistoryFlow, DocuViz shows who did what when. Each column represents the document at that moment (called a slice, technically a piece of the revision history), with authorship of the segments of text noted in color. The height of the bar represents amount of text; successive columns represent time moving left to right. The sections between columns help the eye track the placement of text over time plus the additions and deletions. Additions are right facing openings; deletions are right facing contractions. Moves are blocks of identical text that have been repositioned. They are shown with a crossing bar between slices. The little bar at the top of the columns shows by color who was present in that slice of time, one of which is shown at Figure 4.1. We consider someone who is present but inactive to be collaborating at the moment. They could be reading to edit, conversing with other authors present, etc.

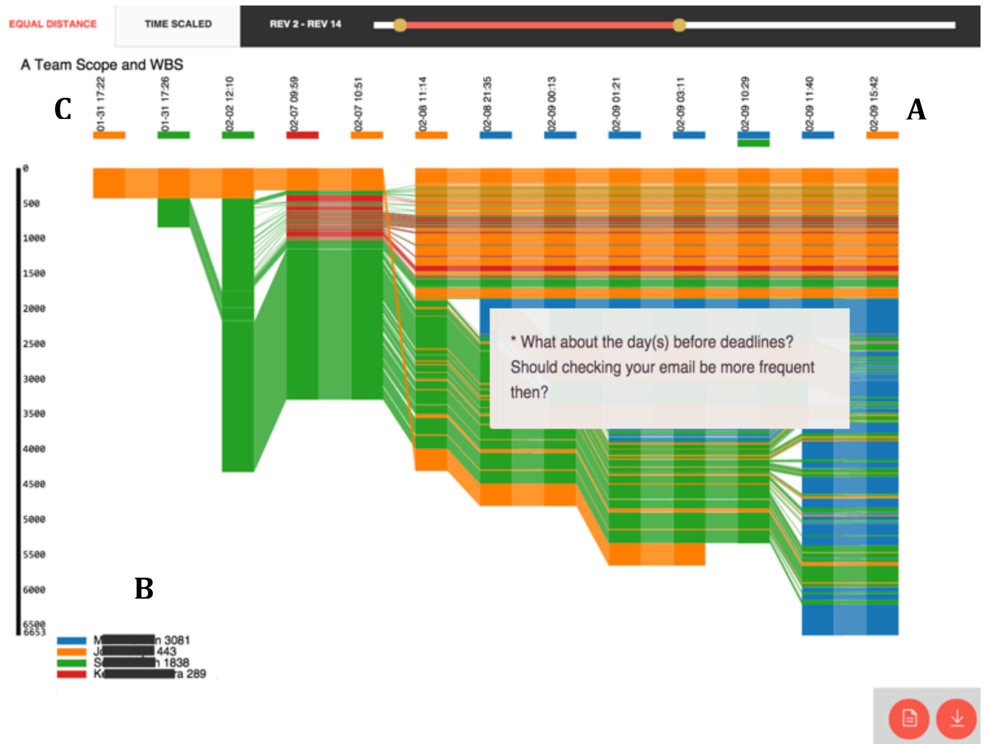


Figure 4.1: The User View of DocuViz.

The colored bars at the bottom left in Figure 4.1 show a compilation of the number of characters in the final document that were produced by each of the authors. The two tabs at the top of Figure 4.1 allow two views, one where the columns are equidistant, shown in Figure 4.1, and one where they are linear in time, shown in Figure 4.2. In Figure 4.1, one can better see the move of orange text and a burst of activity near the end. Hovering over the bars will show the text in that segment, a feature that turns out to be very helpful in analysis.

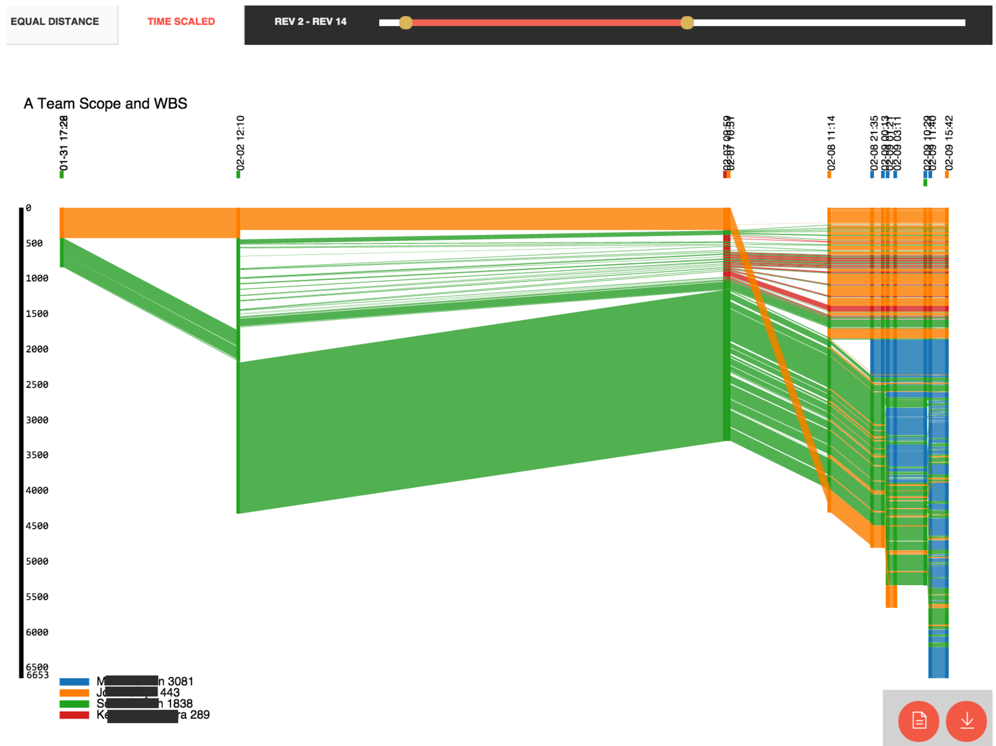


Figure 4.2: The Same Document as in Figure 4.1 but Shown Linear in Time.

4.3 System Architecture

The system's architecture is simple and straightforward, shown in Figure 4.3. After the user logs on and allows DocuViz to access their Google Docs, the system retrieves the user-selected document's revision history data from the Google Docs server using the Google Drive API. The system then computes an intermediate differentiating (diff) result between each pair of two adjacent revisions using the Myers diff algorithm (Myers 1986). The system then takes all the diff results and calculates a single data file following the visualization rules and saves it as a JSON (JavaScript Object Notation) file. A final visualization is rendered on the user's browser using the JSON data file. The system's user-end visualization and interacting functions are implemented in D3 (Bostock et al. 2011) and JQuery JavaScript libraries. Although the system now works only with Google Docs data, all sub-systems are packaged so that it can easily be upgraded to accommodate other document formats, such as MS Word files, as shown in the upper right of Figure 4.3.

DocuViz is free and available to the public. It can be accessed at: *docuviz.ics.uci.edu*

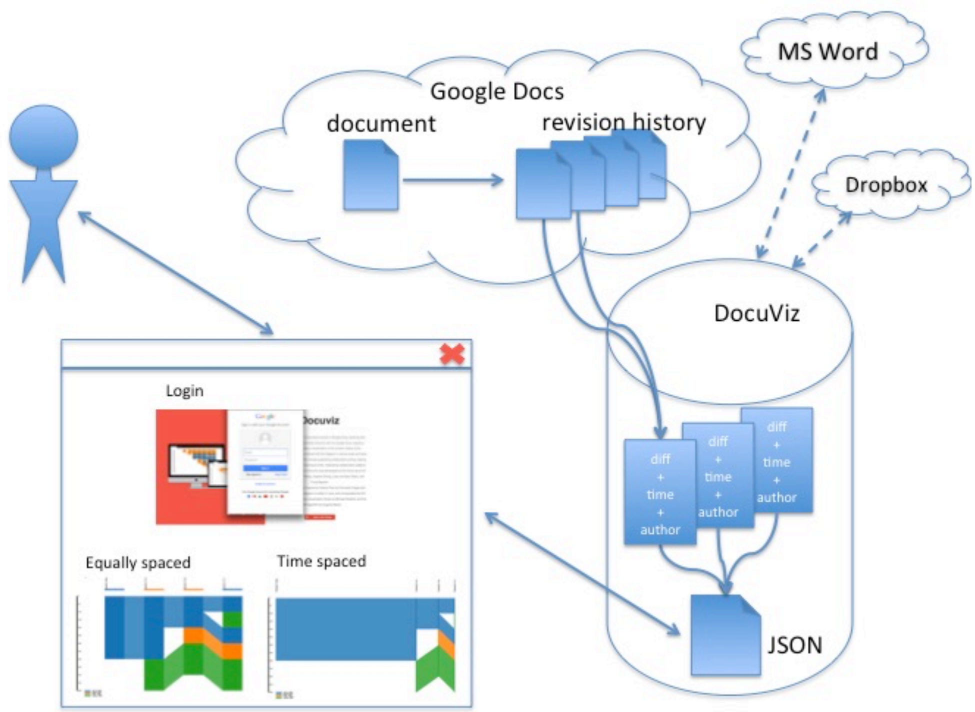


Figure 4.3: DocuViz Architecture

4.4 User Interface

The user interface is simple. After granting access to Google Docs and selecting one document to visualize, the rendering like that in Figure 4.1 is shown. Because one may not want to view and calculate participation on the entire history of the document, but rather on a smaller more focused period of time, the interface has a slider bar at the top to allow the user to select the range of possible slices to display. We used this, for example, to analyze student documents up to the moment they are turned in for a grade, even though in some cases, these documents were viewed and changed a number of times after that point.

4.5 Implementation Challenges

4.5.1 Attributing Authorship to Individuals

The first challenge was that in the API, the activities in each slice are attributed to only one author (the last) even though the revision history indicates more than one active participant. If we want to attribute actual authorship to the proper individuals, instead of getting the data from the revision histories and their associated API we either have to re-architect our system to fit the data stream that actually creates the visual depiction of the revision history (not available in the current API) or we have to allow users to hand annotate those sessions. For the time being we chose the second alternative and designed an easy-to-use function to allow users to label the authorship. We have a technical solution that will allow us to implement the first option in DocuViz 2.0.

4.5.2 Simultaneous Work

The second challenge is to define simultaneous work. In our analyses, some of which is reported below, we considered two authors to be working simultaneously if their activities were within 7 minutes of each other. We believe this is a reasonable window, given that people report having long conversations about what to include in the document and then periods of intense activity. If someone has the document open while they converse, they are considered part of the simultaneous work session.

4.5.3 Moves

The third major challenge we faced was to decide the difference between the deletion and addition of similar text and an actual move. Two issues arise: How big is a change before it is considered a move, and do we give credit to the original author or to the one who moved it (for structural clarity, for example). Unfortunately, our data stream is only text based and we use diffs without the commands "cut" and "paste" indicated, which would have made this a lot easier.

Previous research in file comparison has produced promising algorithms to detect differences between two files and moves (Hunt and Szymanski 1997; Miller and Myers 1985; Myers 1986). We chose the Myers algorithm for speed, but it does not automatically find identical pieces of text that might signal a move (Myers 1986). This is a tradeoff. The Myers algorithm is significantly more efficient (the algorithm complexity is O(ND)) and at a finer-grain level (characters) than the alternatives, but unfortunately lacks this capability. So based on a well-established program library of Myers algorithm (Fraser 2012), we implemented our own move-detection function that for every deletion of 20 or more characters, we look in the next slice for an addition of that size and exact content. If it matches, it is designated a move. If, however, the person who moves the text then edits it significantly, it is not considered a move.

4.5.4 What Is Not Displayed

In the current API from Google Docs, comments are appended to the end of the text, without indication as to what text they were attached to or the structure of comment-reply-resolve. Furthermore, some of the changes co-authors make have to do with formatting and/or adding figures and graphics to the document. These do not appear in the API at all. In our analyses, these changes are noted when we examine the individual revision histories, not when we look at the visualizations. Future work will investigate whether these kinds of changes are noted in the data stream behind the API, and if so, we will architect DocuViz 2.0 with those indicated as well.

As mentioned above, we caution people against over-interpreting our calculation of participation. Ours is a simple count of how many of the document's final characters were entered by each author. We recognize that actual contributions may not be reflected in this character count. One contributor's key conceptualization, represented in only a few words, may be the most valuable part of the document. Another author may be conversing with the co-authors while one or more of them scribes the ideas.

Having reviewed the architecture, user interface, and challenges, we turn now to showing several cases in which DocuViz has been used in valuable ways.

4.6 What Can This Tool Be Used For?

We can see DocuViz being useful for three kinds of people: Authors themselves, instructors or tutors who evaluate and help the work of others, and researchers.

4.6.1 Authors Themselves

As noted in the introduction, co-authors need to be aware of what others are doing. We believe that the one-step view in MS Word Tracking Changes and Google Docs Revision Histories are helpful but impoverished. These display the latest changes made. This is often sufficient if the work is coordinated asynchronously, that there are clear handoffs with known responsibility of who is "in charge" now. But it is more difficult to track when there are rapid changes made in close succession or even simultaneous; in Word, the tracking changes stack up into a horrible mess and in Google Docs, it requires going back through a number of revision slices to know what changes are being made. Furthermore, there are patterns of interest that are not visible in the one-step view, like frequent changes in a section, contentious activity we might call "seismic."

In Figure 4.4, we show the DocuViz of a part of the co-authoring efforts of the Olsons in a chapter in *Working Together Apart* (Olson and Olson 2013). In this excerpt, beginning August 18, one author (orange) cut a very large section out of the second half of the chapter and began writing another take on it. Early afternoon on Aug 29, the original author (blue) deleted this new beginning and began anew. After a number of off-line conversations, the two authors agreed on what the deficiencies were in the deleted text and how to approach the section. The old section was then pasted back in and immediately shortened to reflect this conversation. Had DocuViz been available, this change would have been recognized much sooner.

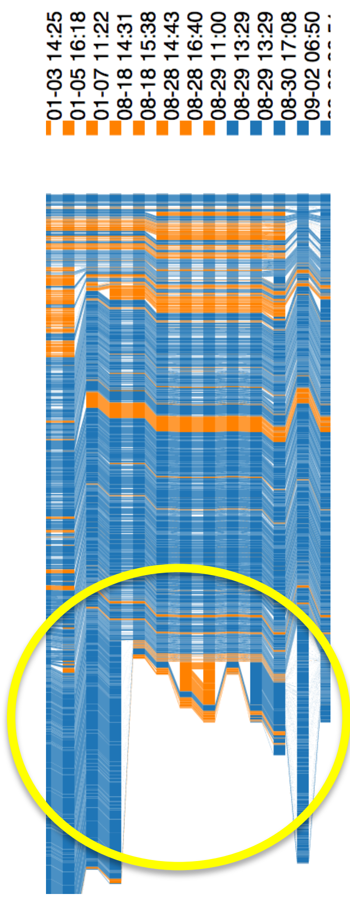


Figure 4.4: A Particularly Contentious Collaborative Episode.

In some student team papers we analyzed as part of the study described in Chapter 5, we have seen portions with "seismic activity" as well, where all authors are editing the same area in a short period of time. This contrasts with pieces of text that remain stable over time, suggesting perhaps that people have read and agreed on those. Seeing where the "seismic" text is can be useful for people to go see "what the fuss is all about." We could imagine an extension that would alert in semi-real-time where seismic text was happening. In Figure 4.5, there appears to be some seismic activity in the sections in the red circle, comparing to the stable texts in the green circles. Upon closer examination (by hovering over that section in the live DocuViz), this particular piece of text had to do with expectations of each other coming on time to meetings, and more importantly, what the punishments would entail.

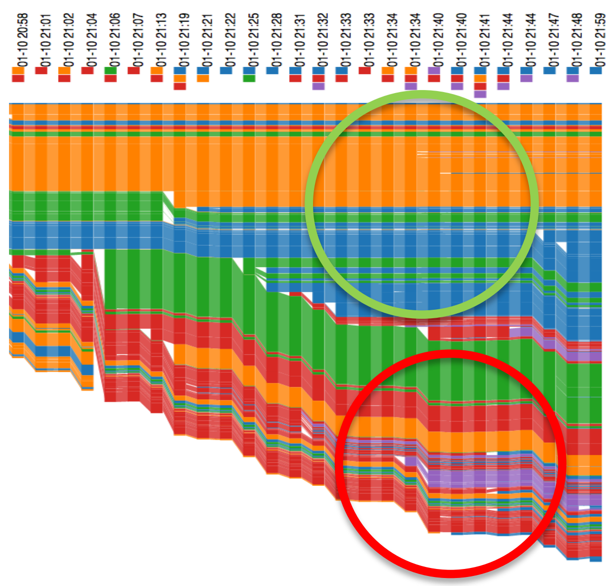


Figure 4.5: DocuViz that Contrasts Stable Texts at the Top (in the Green Circle) with Those More Seismic Near the End (in the Red Circle).

In another recent use of DocuViz, three instructors of writing at the City University of New York (CUNY) used the visualization to reflect on their own collaborations. In Figure

4.6, they visualized the growing set of course notes they kept on how to teach the courses they co-taught. They noted immediately that the new material was inserted at the top of the notes, with the older sections being pushed down to the bottom, out of sight without scrolling. One section was somewhat seismic, and the preface before the seismic sections enjoyed a lot of same-author editing. One author, blue in this case, was the major “owner” or leader in this document but the three instructors contribute key parts.

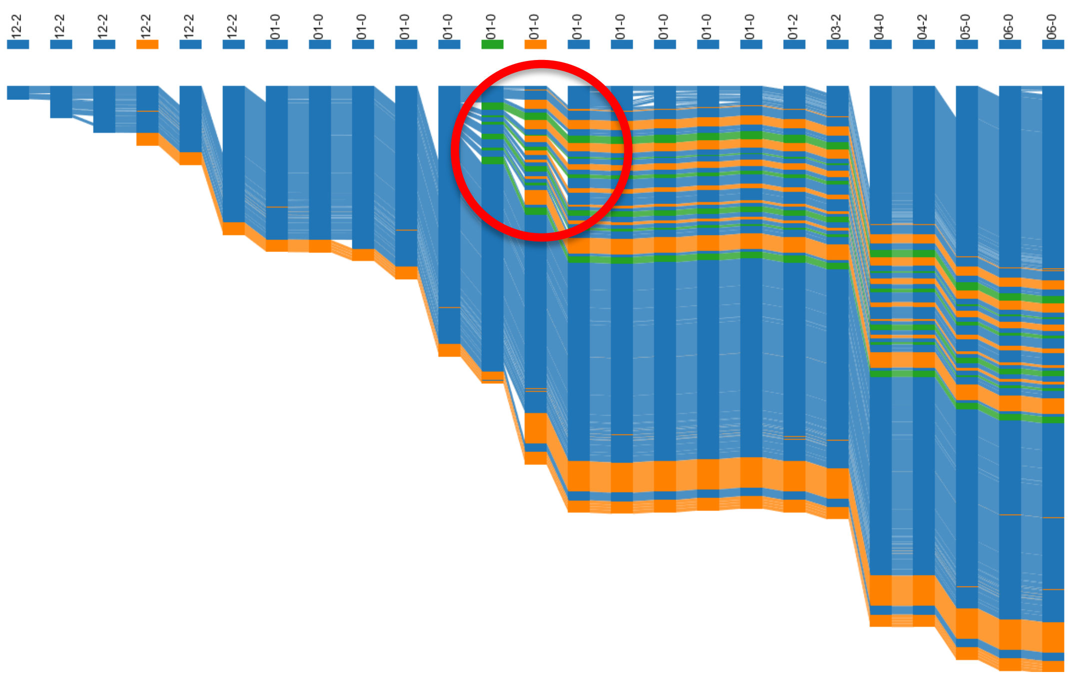


Figure 4.6. DocuViz of Growing Notes for a Co-Taught Class in which the New Material “Pushes Down” the Old. Seismic Activity is Indicated in the Red Circle.

4.6.2 Instructors or Tutors

The most immediate piece of information instructors might be interested is the simple calculation at the bottom of the visualization that shows how much of the final version was contributed by each author. Figure 4.7 shows an example, annotated with pseudonyms.

Valerie Mank	134
Zamud Bahoo	871
Donald Kinde	1186
Julia Maraschi	383

Figure 4.7: The Report of How Many Characters Each Contributed to the Final Document. Names Here Are Pseudonyms.

As mentioned above, two things might be missing from this count that could misinform the inference of how much each person contributed. The first is that people can be present and conversing, while others write what they say, a style called “scribe” (Posner and Baecker 1992). The other is that people sometimes copy the work of others from another working document and paste it into the “final.” This paste loses the attribution of original authorship and assigns it to the one who pastes.

The three instructors whose own work is shown in Figure 4.6 also used DocuViz to see how a student responded to comments on a draft. Figure 4.8 shows the single authored document in its draft and final version. The instructor’s comments (not shown) were telling the student author to include more references to the literature in the essay. On seeing the revision shown in DocuViz, the instructor could immediately see the quantity of the revision and where the additions and edits were. By hovering over the appropriate sections, the author could read the contents and assess whether the response was adequate.

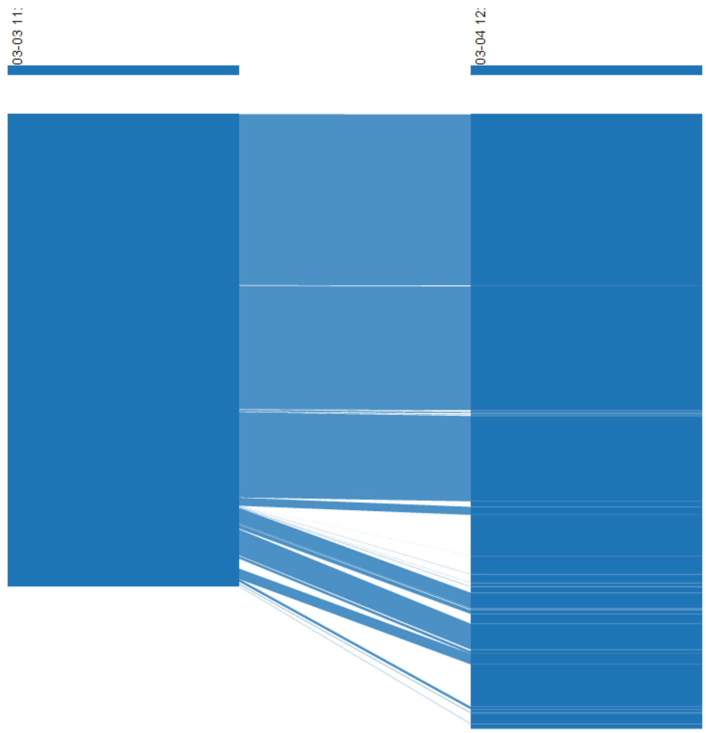


Figure 4.8: A Simple Edit of an Essay by One Student Where the Locations of the Edits Were Immediately Visible, both in terms of quantity and, by hovering, seeing the actual contents.

Because these instructors found DocuViz useful, they introduced the system to their students and it turns out *"… many [students] found the maps to give them useful information about how they wrote together - they made the invisible visible ….*"

4.6.3 Researchers

Our main goal in producing DocuViz was for research—to investigate the patterns of collaborative creation of documents and how they correlate with quality, using standard procedures for assessment (Storch 2005). We examined a corpus of 96 documents produced by undergraduates in a Project Management class. Because students often used the capability of being able to work simultaneously, we are interested in, among other things, how often and how they work in this mode. The detailed results are presented in Chapter 5.

4.7 Limitations and Conclusion

As mentioned earlier, DocuViz is built using the Google Docs API. This limits our ability to visualize simultaneous work, the placement and "conversation" that appears in formal comments and the contributions of formatting and figures. These limitations are the result of the inconsistency between the data stream stored in Google's database and the data that they provide to the public developers through their API services. Because of this, we are building a DocuViz version 2.0 that is capable of bypassing the API, accessing the actual data stream. In this way, all the previous mentioned challenges will be addressed.

In sum, DocuViz is a tool that allows people to see a useful visualization of revision histories of Google Docs. The richer, longer-term view shows places of seismic activity where authors may want to have more focused discussion to come to agreement about a particular issue, to note large reorganizations of ideas and be sure to be in concordance, and explore others' novel approaches to creating documents. As of the date of writing, our web site has been accessed by hundreds of unique IP addresses, and DocuViz has been applied to thousands of documents other than ours.

CHAPTER 5. STUDY III: HOW PEOPLE WRITE TOGETHER NOW: A CASE STUDY WITH COLLEGE STUDENTS' CLASS ASSIGNMENTS

5.1 Introduction

This chapter presents a study that examined the data traces of collaborative writing behavior in student teams' use of Google Docs. We applied both qualitative research methods and quantitative statistical analyses to answer the question of how students are writing together now and what makes their writing good. In addition, we demonstrated the use of DocuViz and its visualizations to uncover the collaboration patterns of writing. Together, these begin to give us a more detailed picture of how such people write together now.

5.2 Research Questions

Previous studies enriched our understandings of present-day writing collaborations, but we still need a big picture of how actual users are writing collaboratively today. Is there anything new now that people can access documents online and actually write at the same time? We predict that "old habits die hard," so that the new capabilities might not produce different styles of work. That is, we might see "divide and conquer" and hand-off styles of work just as we did when people were limited in earlier word-processors. We expect to see the same stages of activities, seeing drafting, reviewing, and revising, but questions remain as to whether people, when comfortable with each other, will actually edit each other's work when they have not been given the explicit role of editor. Most importantly, can we discover which of these roles, control methods, activities, writing strategies and work modes leads to high quality work?

In summary, this study addressed the following research questions:

RQ1: What tools do co-authors use and what do they do in today's collaborative writing?

RQ3: What practices of collaborative writing might be related to the quality of the documents?

RQ4: Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?

RQ5: How can we improve the design of the systems to better support collaborative writing?

RQ6: How can we build a useful information visualization tool to help with the research of collaborative writing? Is visual analytics method a promising way to study collaborative writing?

5.3 Research Method

5.3.1 Data Corpus

The data corpus in this study is a collection of 96 Google Docs from three successive years (2011, 2012, and 2013) of undergrad students taking a Project Management class at UC Irvine prior to a year-long capstone course where they designed and implemented a system for a real client.

In the 32 teams, most (78%) of the teams had 4 students in them; the rest had 5. They created their documents in whatever manner they wished, and then when they decided that it was ready to be submitted, they moved it to a folder that the instructor and teaching assistant had access to, with both read and write permission. Because some students did not follow instructions and either made their documents into PDFs or used

Microsoft Word and merely dragged the final document into the folder to be graded, we do not have all the revision histories for all teams for all assignments. The total number of usable documents was 96, with the distribution over years shown in Table 5.1.

Table 5.1: The Number of Documents in Corpus for Each Type of Assignment for Each Year.

	Communication Covenant	Scope and WBS	Business Case	Cost, Risk, Quality
2011	8	4	6	--
2012	9	9	10	10
2013	11	11	8	10

The assignments were four standard documents used in project management (www.pmdocuments.com; and in Schewalbe 2015):

- Communication covenant,
- Business case,
- Scope statement and work breakdown structure,
- Risk, quality, and cost document.

In 2011, the risk, quality and cost document was not assigned, so for that class, we have only the first three kinds of documents.

5.3.2 Analysis of Documents

Our raw data are the documents and their revision histories, showing the timestamp of each stored revision, which we call a slice, and the authors in that slice.

Guided by previous literature, we generated a list of measures to depict the writing collaboration. A summary of the measures can be found in Table 5.2. Most of the quantitative measures, like the length of the document, are straightforward as is the time duration (elapsed time) that a team worked on a document, and how close to the due time (time before due) when they finished the editing. However, the following measures require some explanation.

We use the number of characters in the final document that were authored by each member as a measure of participation. For example, if Alice entered 1000 characters, 500 of them were then deleted (by herself or by others), we attribute the remaining 500 characters as Alice's contribution. We recognize that this is only one kind of contribution. Although interesting and informative, it is not the only way one might contribute to a co-authored document (Posner and Baecker, 1992). In particular, one author might be the one entering text (a "scribe") while someone else dictates or discusses the points. Our measure does not capture anything having to do with the un-typed conversations about the work, only those that are entered. Interestingly, there were a number of occasions, which we describe later, in which the conversation happened either in the formal commenting feature or in the body of the text itself.

When measuring the balance in the participation, we first calculated the individual's participation, described above. We used imbalance in participation as the variance of those proportions. If everyone in a four-persons team wrote the exact same number of characters, the imbalance would be 0.00. If one person wrote the whole document, the imbalance would be 0.25. Variance of number of characters each person wrote in the final document is preferred over a Gini coefficient because variance does not change with the size of the team. Gini coefficients do. Another measure, Blau's index, is for categorical data. Coefficient of variation overweighs asymmetry when resources are scarce; in our case time and length of document are unlimited (Harrison and Klein, 2007).

Much of our deep analysis comes from the DocuViz visualizations that we made of the revision histories (Wang et al, 2015). In the live visualization, when the mouse hovers over a portion of a slice it shows the actual text in a pop-up window. Often this view triggered more questions and our further examination of the actual revision histories of the content to see exactly what was added, moved or deleted in context.

The visualizations give clues as to the collaboration style, but most of the qualitative coding involved closer examination of the revision contents one by one.

We noted if there was a clear *leader*. The formal definition of leadership is "a process of social influence in which a person can enlist the aid and support of others in accomplishment of a common task" (Chemers, 2014). The simple definition is "someone is a first or principal performer of a group" (Merriam-Webster online dictionary). In our case, we looked at the beginning few slices of the document to see if someone took the initiative in creating the document, enacting one of the designated collaboration patterns (e.g. creating an outline and assigning people to sections), as well as often cleaning up the final submissions. This leadership is more than just creating and naming the document with others then just putting material in without a clear plan.

The most complicated coding was the *styles of work*, the style in which the students coordinated the collaboration and developed the document. Many began with an outline, a copy of the assignment description, writing from scratch, and/or pasting in an example and editing to match their situation. Some teams made explicit the assignment of responsibility for certain sections to certain people, and some began with informal discussions about where to meet or who would do what. Documents could be coded as having several work patterns, such as an outline and assignment of responsibility. We will discuss more about the type of work patterns in Section 5.4.4.

For *leadership* and *styles of work*, codes were generated first by crafting our definition, three of us coding the same documents, comparing codes, refining our definitions, etc. until we came close to agreement, using Krippendorff's alpha. We then divided the corpus and coded our portions. We used Krippendorff's alpha because there were three coders, a situation that the more commonly used Cohen's Kappa does not cover. On a random sample of 7 documents our average Krippendorff's alpha was 0.88, a high level of agreement (Hayes and Krippendorf, 2007).

We also noted from the DocuViz visualizations whether *editing* was done on something someone else wrote. And, by examining the revisions themselves, we noted whether people *commented* within the document using the commenting feature or they inserted their comments into text.

In measuring *simultaneous work*, we examined the timestamps of the slices with two or more authors present and considered those with a gap of 7 min or less to be in the same session. All participants in that block of time are considered to be working simultaneously. This is a somewhat arbitrary cutoff, but one that appears reasonable. While others (e.g., Sun et al, 2014) have used 15 min cutoffs for defining simultaneous work, we thought it too long to have face validity. Consequently, we examined the distribution of all inter-slice times 15 minutes or less, and found that 90% of those were 7 minutes or less. Seven minutes of no recorded activity seems to be a reasonable, face-valid time. By adopting this cut-off, we will omit some sessions where they were talking or even writing on a whiteboard or paper, perhaps, but that is at the cost of over-including some where the participants were really taking a significant break. From this we can calculate the number of *solo-authored sessions*, the number of *simultaneous sessions* and their *lengths*, ending with a calculation of *the total amount of simultaneous work.* We can also count the *number of authors* in the simultaneous sessions.

Here we use Figure 5.1 to illustrate how we calculate some of the measures. In the document in Figure 5.1, there are 5 *authors* (represented by different color) who write 16 *slices*. The document started at Jan 04, 14:39, and ended at Jan 05, 23:32. So the *elapsed time* is 1,973 minutes. From the class syllabus, we know the assignment was given at Jan 4, 13:50 and the due time for this document is Jan 6, 23:59. So we can calculate the *time before due* as 1,468 minutes. As we described, we measure the *simultaneous work* by examining the timestamps, grouping those *slices* with a gap of 7 minutes or less into a *session*. If there is more than one author in the *session*, we count it as a *simultaneous session*, otherwise we count it as a *solo-authored session*. For instance, in Figure 5.1, the 3 slices at the beginning are counted as 3 solo-authored sessions. The 4th to 6th slices are combined into a session (the gaps are 1 minute and 2 minute respectively), which has 2 authors (orange and red), so that it is a simultaneous session. The duration of this simultaneous session is 3 minutes (from Jan 04, 18:08 to Jan 04, 18:11). In addition to this session, there is another simultaneous session from Jan 04, 22:50 to Jan 04, 22:57 that has 2 authors (green and purple), with a duration of 7 minutes. In summary, in Figure 5.1, there are 11 *single-authored sessions*, and 2 *simultaneous sessions*. The *maximum number of co-authors* is 2 authors working in the same session. The *longest simultaneous session duration* is 7 minutes.

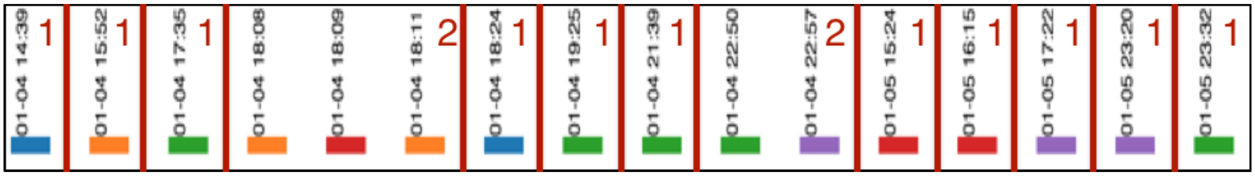


Figure 5.1: The Timestamps and the Authors Legend to Illustrate How We Calculate Some of the Measures. Red Lines Indicate Sessions, Red Numbers Indicate the Number of Authors in Each Session.

5.3.3 How We Assessed Document Quality

Because all students were writing from the same instructions, we had the unique opportunity to measure quality and to see what behaviors correlate with it. We re-graded all the documents. We asked three former teaching assistants (all graduate students in computer science) of the course to construct a rubric for each assignment. The rubrics are in Appendix C. in These rubrics evaluated the documents on completeness, clarity, and format. Nineteen documents were randomly selected and independently evaluated by the three coders. After the first round, they examined their differences, clarified the rubrics, and rescored the same documents independently. The final Krippendorf's Alpha score was 0.87. Given this high agreement, they then divided the remaining 77 documents and graded them according to the rubrics.

Because some of the independent variables are nested (e.g., teams repeat assignments and are nested within years), and some variables were continuous and some others were categorical (which we then coded into binary dummy variables), we chose the *hierarchical linear modeling* to run the analyses (Field, 2009). This analysis used IBM SPSS Statistics version 23. We ran analyses on each of the independent variables that may have an effect on each of the three dependent variables respectively, always controlling for *year, assignment type*, and using *team* as a repeated measure. The four dependent variables included: *Quality* of the final document, the *elapsed time* from the start to the end of a document, how *close to the assignment deadline* when they finished, and *document length*. As recommended by many researchers, we built up multilevel models starting with a "basic" model and then adding in variables, so that we can compare the fit of the models (Raudenbush and Bryk 2002). In the following section we only report the variables that had a statistically significant effect. The details of these models and how we selected variables in the ultimate model appear in the Appendix B. A summary table of all the independent variables and dependent variables we investigated is shown in Table 5.2.

Table 5.2: A Summary of the Independent and Dependent Variables Organized by the Categories in Posner and Baecker.

Control variables	Year
	Assignment
Repeated measure	Team
Independent variables	
Roles:	Number of authors
	Number of slackers
	Balance of participation
	Evidence of Leadership
Document Control:	N.A. (as all had shared control)
Activities:	Having a plan
	Editing (editing self or editing each other's work)
	Commenting (either in text or with formal commenting)
	Writing a longer document
Writing Strategies:	Styles of work
Work modes:	Number of solo authored sessions
	Number of simultaneous sessions
	Duration of the longest simultaneous session
	Total time working simultaneously
	Maximum number of authors in simultaneous session
Dependent variables	Quality of the document
	Length of elapsed time from start to finish
	How close to the deadline it was finished
	Document length

We ran the analyses on the 96 documents from the 32 teams of student-authors. Our analysis covers all three years but takes into account that in 2011 there was missing data for one of the assignments.

5.4 Results

The results section begins with some basic quantitative data on the documents that students wrote. We then organize the remaining results using the framework proposed by Posner and Baecker (1992) and then extended by Lowry et al. (2004).

5.4.1 Basic Data

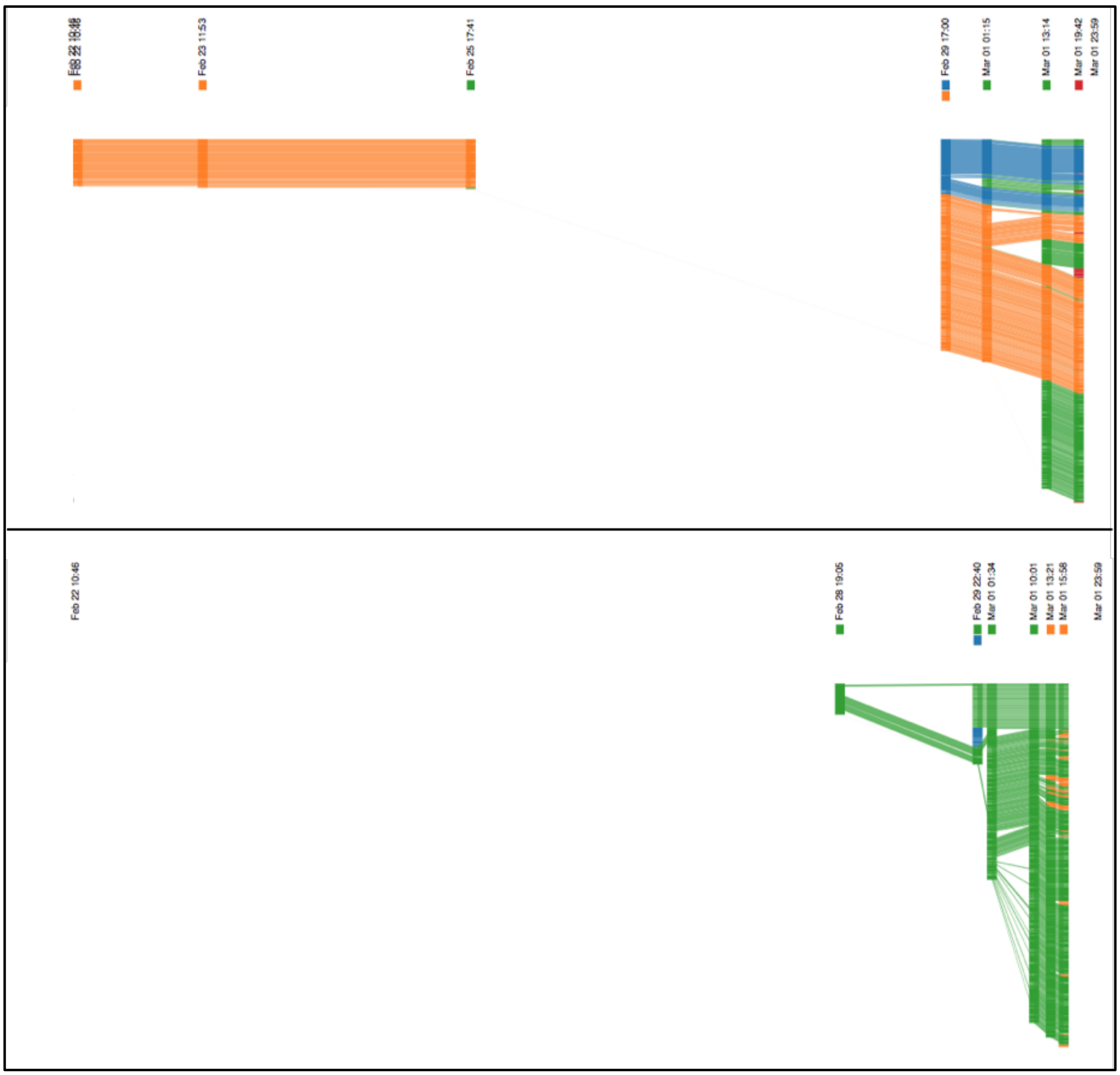
Document Length

As expected, the student documents for different assignments were of different lengths. The Communication Covenant was on average short, only 594 words, about one page long if single-spaced. The Scope and Work Breakdown Structure assignment was on average 1,346 words, a bit more than two pages. The Business Case similarly was 1,531 words, 2 ½ pages long. The Cost, Risk and Quality document was on average 967 words or 1.6 pages. Knowing this, we controlled for assignment type in doing the regressions on quality and in doing so found that longer documents (controlled for type) often score higher in quality (Beta = .00096, $p < .05$).

Time

The mean elapsed time from the document's first appearance and the due date is 76.8 hours or 3 ¼ days. The median is a lot shorter, 40 hours, 1.7 days, suggesting that there is a long tail to the distribution. Indeed, the range went from 1.01 hours to 16.13 days. Also, we found that the mean elapsed time from the last revision until the deadline is 17.6 hours, with a range from 1 minute to 3.32 days.

The timeline view of the development of the documents in DocuViz, put onto common timescales representing the start date of the assignment (the day it was discussed in class) and the due date, shows us some interesting patterns. As is shown in Figure 5.2A and 5.2B, two representative documents from the collection show when in allotted time period the work happened. Figure 5.2A shows one team member opening the document on the start date and pasting in the assignment description, which is later removed to “clean up” the final document for grading. It also shows a major burst of activity the day before it is due. Figure 5.2B shows a major group effort a full day before the assignment is due.



Figures 5.2A and 5.2B: Showing the Activity Spread Out on a Timeline from When the Assignment Began to When It Was Due.

5.4.2 Aspects of Collaborative Writing

We follow the organization of aspects of collaborative writing presented in Table 2.1:

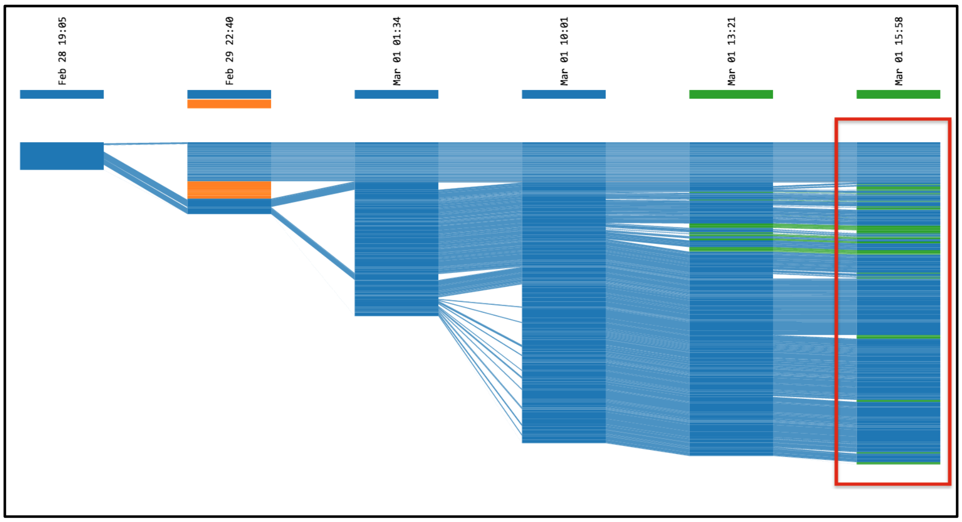
- Roles
- Document Control Methods
- Activities
- Writing Strategies
- Work Modes

5.4.2.1 Roles

Posner and Baecker and Lowry et al. enumerate a number of roles, including writer, consultant, editor, reviewer, scribe and facilitator. Since we have no record of their conversations about the writing, we are unable to judge anything outside of that which leaves traces of actions. We do not, therefore, know if there was someone dictating while another wrote (the Scribe mode), whether one was merely a consultant, or whether there was a facilitator present. We can, however, detect who was a writer and whether participation was balanced, and annotate the existence of leadership from examining the first few slices.

How many were writers? Of the 96 documents, 74 (77%) showed full participation; all members of the team participated in the writing of the document. Seventeen show evidence of one missing team member (which we called slackers) and 5 documents have two slackers.

How even was the participation? To review, if there are four team members and one person writes the whole document, the imbalance would be 0.25. If everyone participated exactly equally the imbalance would be 0.00. For the 96 documents in this corpus, the mean of measure of imbalance is 0.05, the median 0.04, with a range from 0.001 to 0.25, showing the full range of values. Most of the participants contributed fairly evenly. Figure 5.3A and Figure 5.3B illustrate the extremes using DocuViz visualizations, from one with uneven participation in Figure 5.3A, and even participation in Figure 5.3B.



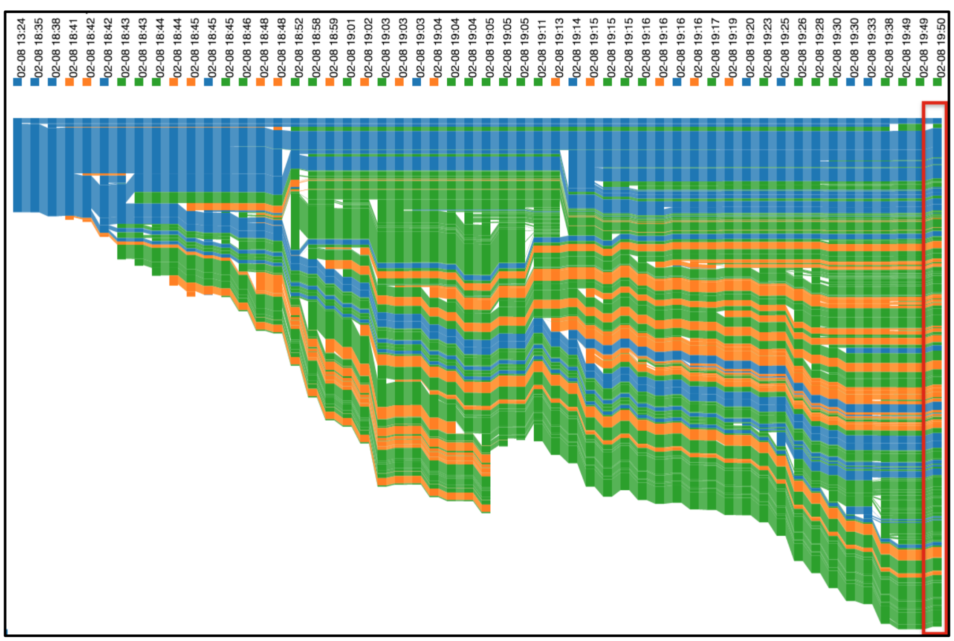


Figure 5.3A: An Uneven Participation in the Final Draft. Figure 5.3B: A More Even Participation in the Final Draft.

In the hierarchical linear regression model, balanced participation was strongly associated with higher quality work (Beta = 44.38, p<01).

Was there evidence of leadership? In 81% of the documents there was clear leadership. Out of the 16 teams for whom we had all the documents, in only two teams was the same person the leader for all their documents. For one team, a different person took leadership for each document. When there were leaders, the leader contributed the most characters in the final document only 50% of the time. Leadership does not necessarily mean being the major writer.

Later, in the hierarchical linear regression model, the presence of a leader was associated with higher quality documents (Beta = 8.70, p<.01).

5.4.2.2 Control Methods

Posner and Baecker's taxonomy separates Control Methods into ones that are Centralized (where there is only one author who has access to the document), Relay (formally one person at a time with others physically unable to edit while that person is in control), Independent (where people work on individual parts of the document and maintain control of that part throughout), and Shared (with all people having access to the whole document all the time). Although there are work situations in which the first three are appropriate, fairly equal-status student teams, all teams had Shared control.

5.4.2.3 Activities

In the more complete Lowry et al. taxonomy, Activities include Brainstorming, Converging on a Plan, Outlining, Drafting, Reviewing, Revising, and Copy editing, with supporting activities of researching, socializing, communicating, negotiating, coordinating, monitoring, rewarding, punishing and recording. Since we have no verbal record to accompany the trace activities inside the documents, we are unable to note brainstorming or the verbal activities in the supporting set. The teams in our dataset moved from stage to stage in fluid ways. However, in this section we will call upon evidence of their having specific plans and the mixture of edits and commenting in Reviewing and Revising the document.

Figure 5.4 shows an instance of explicit project management inside the document. Note that the assignments and notes grew in the beginning of the document, and then were deleted before the final time to turn in the document.

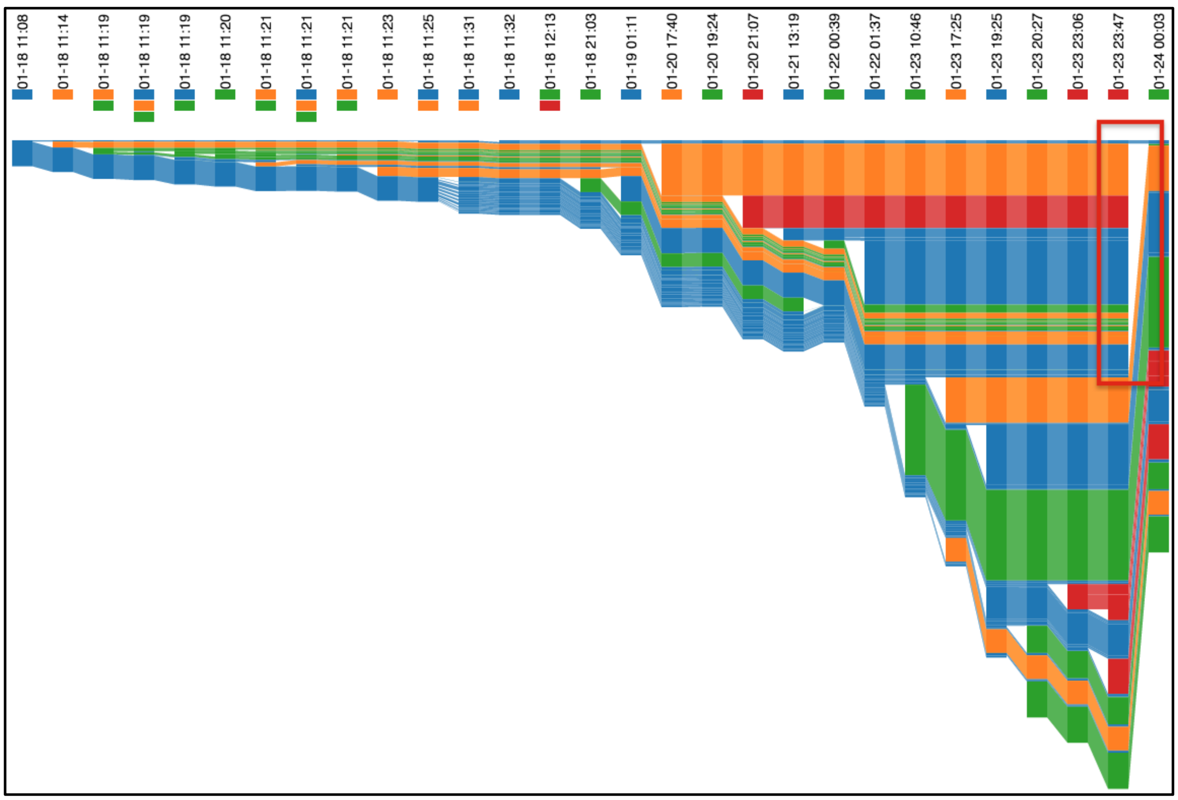


Figure 5.4: Explicit Project Management and Discussion at the Top of the Document Then Deleted at the Last Session Before Turning in the Final Version, as Shown in the Red Box.

Figure 5.5 shows an example of what an explicit project management text looked like. It includes an outline and the attachment of people's names next to them, written in one simultaneous session by two authors.

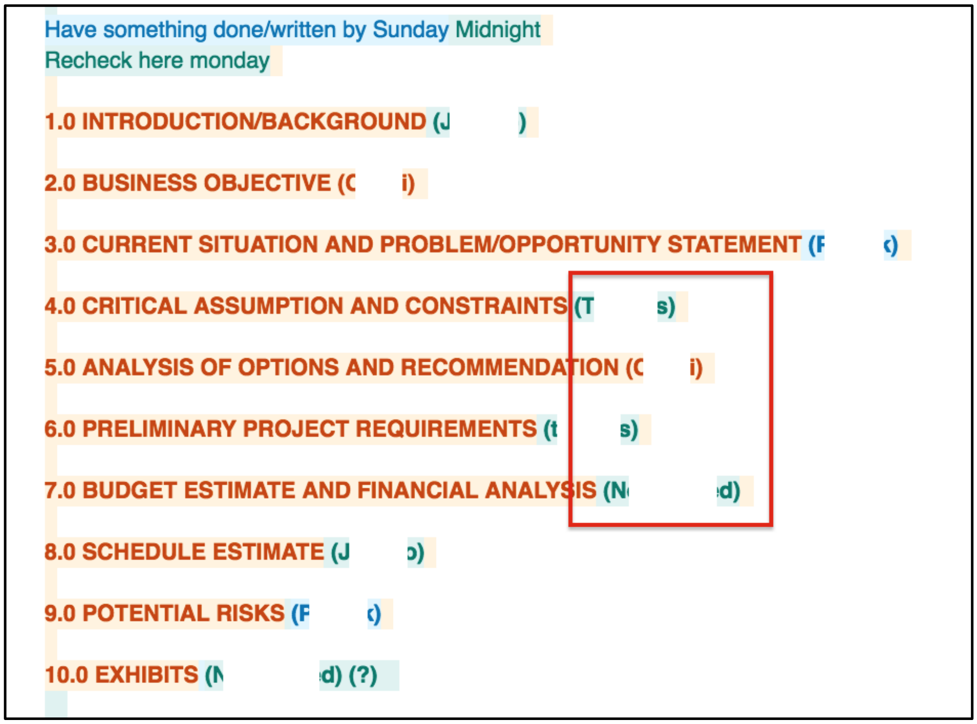


Figure 5.5: Explicit Project Management in the Document, where Each Team Member Marks Their Name After Each Section, as Shown in the Red Box. Blanked Out for Anonymity Purpose.

People were frequently adding material, though not always editing the material. Surprisingly, 3% of the documents exhibited no editing whatsoever. In these cases, people wrote adding to what was written before, but never changing anything. In 7% of the documents, people only edited their own contributions, 9% only others' writings, but a full 80% edited both theirs and others' writings.

In Figure 5.9 in the later section on styles, there are examples of parts in which there is no editing (the orange at the top) and some editing (the green at the bottom). Figures 5.2 and 5.3 shows a more regular pattern of people editing each other's work. In the hierarchical regression analysis, the more they edit each other's text the sooner they finish (Beta = -685.20, p<.01). It was not significantly associated with higher quality.

Collaborative writing obviously entails conversations. We believe the long simultaneous sessions included either face-to-face conversations, audio conferences, or chat. But for asynchronous work, the participants conversed either through the formal commenting system or within the document itself. In 57% of the documents there was no commenting of either sort, and only 16% of the documents showed evidence of authors using the formal built-in commenting feature. 37% of the documents showed commenting within the text, often adding color-coding or even comment codes (e.g. //*, *//) to bound their comments, to signal their intention that it will be deleted in the final version. Figures 5.6 and 5.7 illustrate both styles.

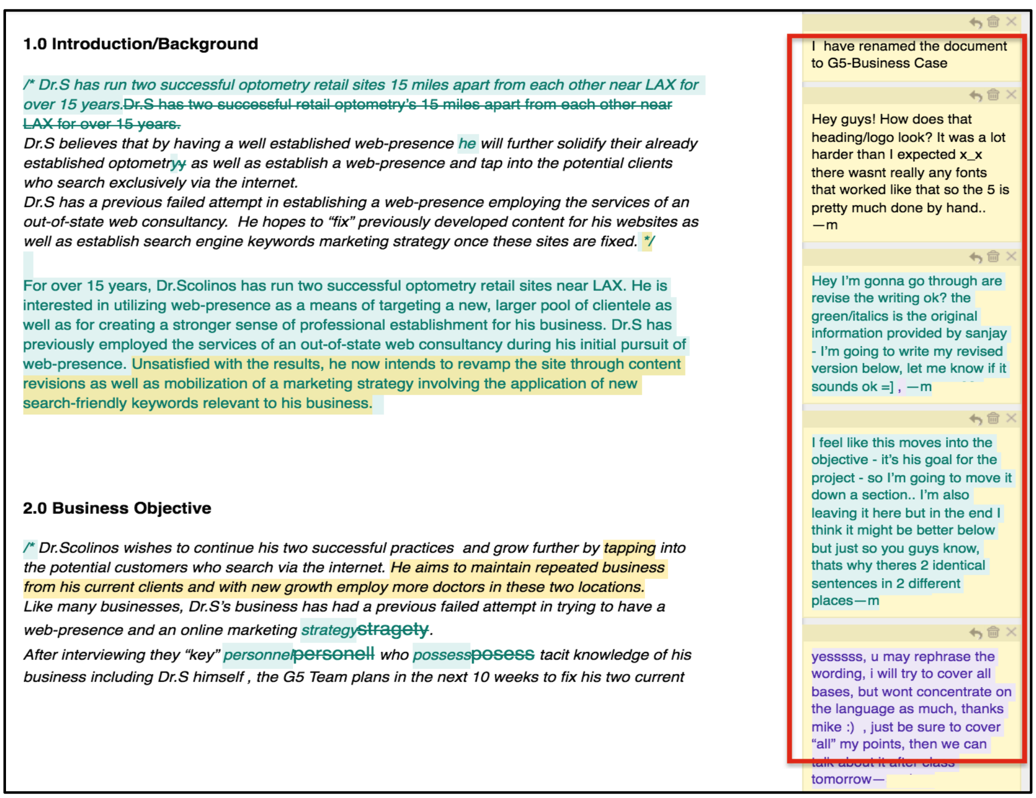
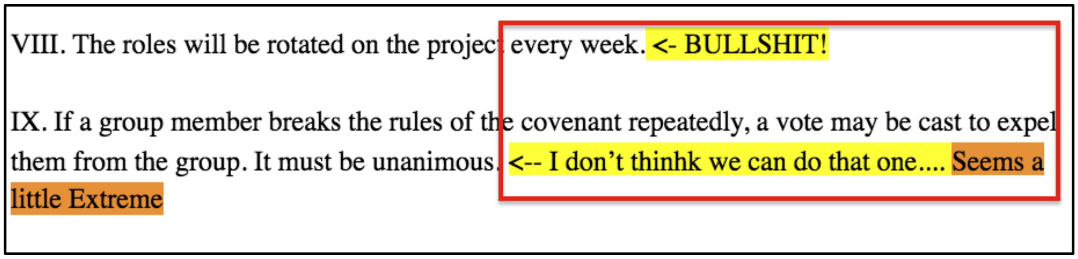


Figure 5.6: An Example of Using the Formal Built-In Commenting Feature in the Document, as Shown in the Red Box.


VIII. The roles will be rotated on the project every week. <- BULLSHIT!

IX. If a group member breaks the rules of the covenant repeatedly, a vote may be cast to expel them from the group. It must be unanimous. <-- I don't thinhk we can do that one.... Seems a little Extreme

Figure 5.7: An Example of Using the Informal In-Text Commenting, with Highlighting Added by the Participants to Call Attention to the New Material.

5.4.2.4 Strategies (Styles of Work)

Lowry et al augmented the Posner and Baecker's Writing Strategies to include Single Author, Scribe, Parallel Writing-horizontal division (divide and conquer), Parallel writing-vertical division (taking different roles), Reactive Writing (what Posner and Baecker called Joint Writing), Sequential Single Writing, and Mixed Mode. We see below the different styles of work that include outline (divide and conquer), and that there is a mixture of roles in writing and editing. We note that many of the work in our student corpus (29 out of 96) is Mixed Mode, which exhibit more than one styles of work.

We coded the styles of work as defined in Table 5.3 by looking at the visualizations and the actual content of the document revisions. These styles are illustrated in the following figures.

Table 5.3: Definitions of Styles of Work in the Content Analysis

Style	Description
From scratch	Someone begins to write the actual content of the document without preface.
Outline	Someone creates an outline which they collectively fill in.
Assignment	Someone pastes in the assignment description and due date to guide their work and to ensure they are complete when finished.
Example	Someone pastes in an example, such as another's business case or one found on the Internet, and then replaces sections with their own material.
Assign people	Someone explicitly assigns sections to team members, or people explicitly volunteer, either through text or in formal commenting.
Informal discussion	Collective informal discussion in the beginning such as planning what they're going to do, and building a common ground, before actually starting to write the content.

Figure 5.8 shows the *from scratch* style, where the team member, labeled as orange, puts in a chunk of text and others add to it, and finally edit it lightly.

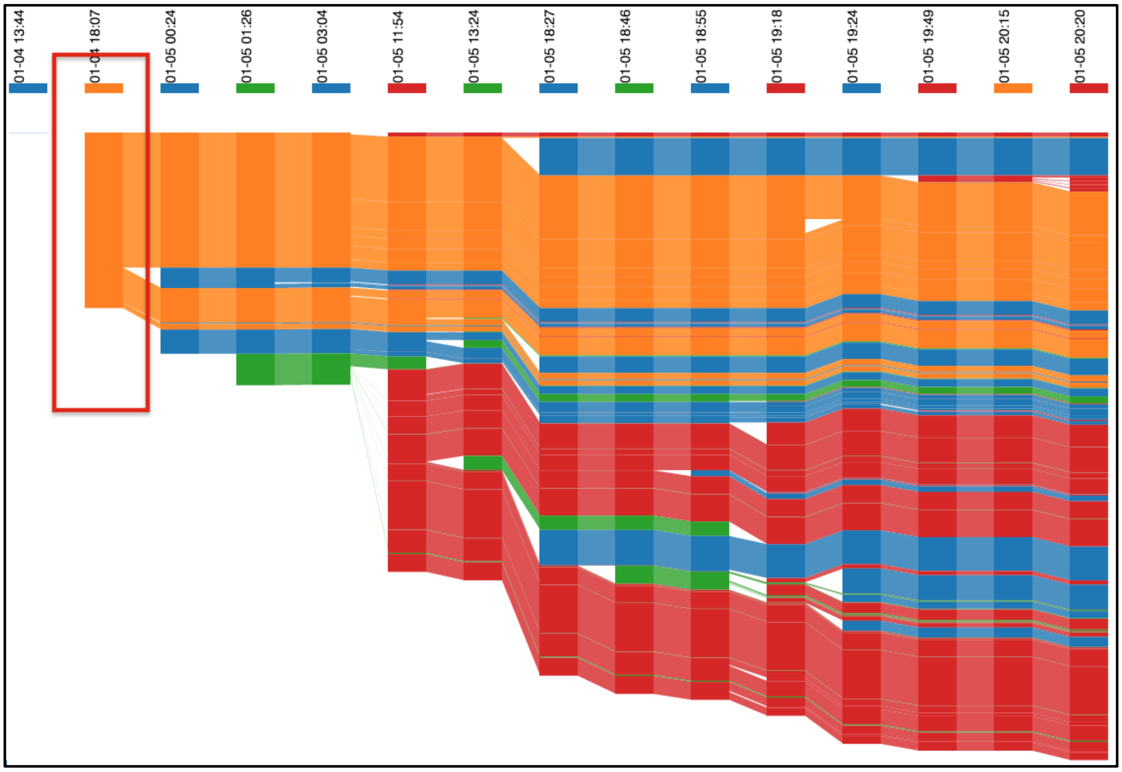


Figure 5.8: The *From-Scratch* Style.

Figure 5.9 shows that the leader (in blue) wrote a short chunk in the first slice, an *outline* of the document. Then all co-authors including the blue, the orange, the red and the green wrote separate sections of the document. It is very clear that there is a boundary between each section of the document, as you can see that there is a tiny blue line between different sections. Most of the co-authors did not edit each other's writing except the orange author edited some of the green's work and also edited blue's work at the last moment. This pattern was reported by the subjects interviewed by Posner and Baecker in 1992 (Posner and Baecker 1992) calling it Separate Writing (partitioning the document), but this is the first time that someone has revealed it from actual data.

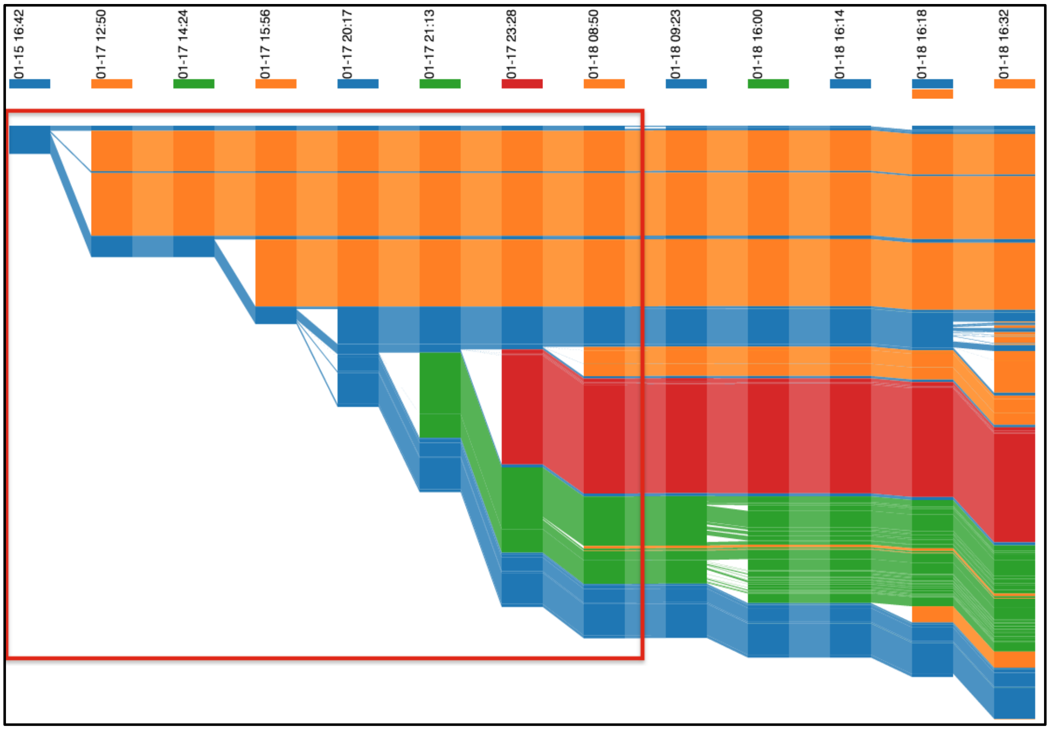


Figure 5.9: The *Outline* Style

Figure 5.10 illustrates an *assignment* style, where the literal assignment as posted in the class website is copied and pasted into the document (here by blue). It is later removed, as part of the process of cleaning up the document for final submission.

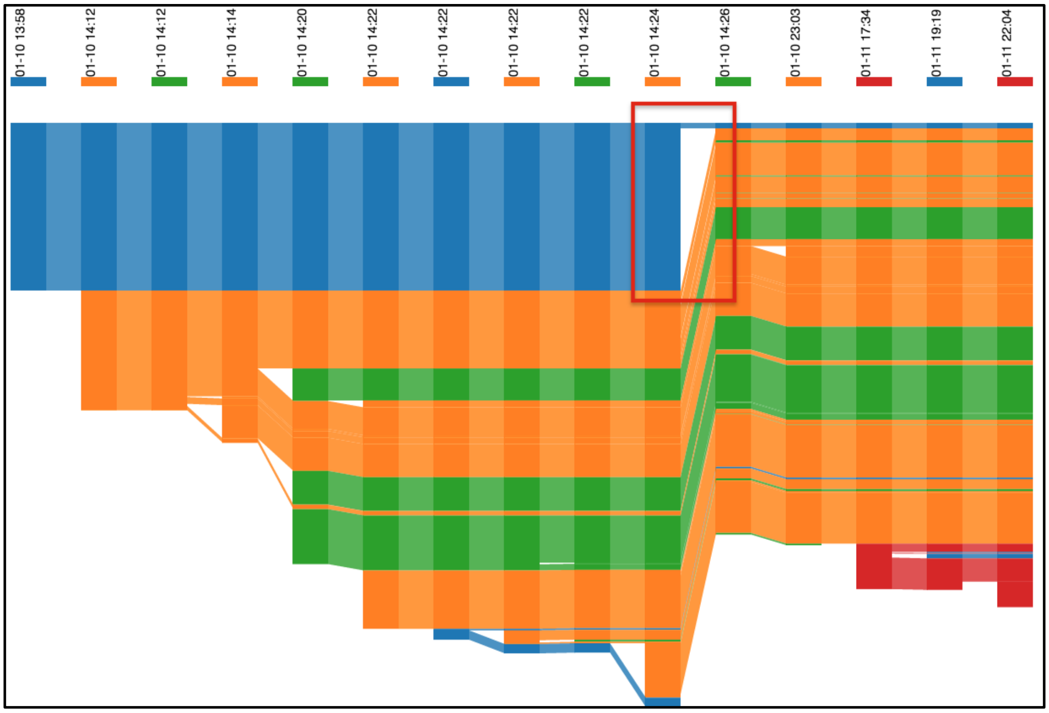


Figure 5.10: The Assignment Style.

As shown in Figure 5.11, this visualization illustrates a work style that students used in some of their assignments, which we called *example style*. Although we were surprised by this style of collaboration from students' class projects, upon reflection we believe it might be common in corporate life where a report is recurring, having the same format in general but different content, such as a monthly report. For this assignment the students were required to write a business case for their project. It appears that an easy way for students to write it is to find an existing business case as the example, paste it in and then modify it to fulfill their own case and the requirements of the class. That is why in this figure we can see the very long starting document, which then gets smaller with sections replaced with their own text. This style has not been discussed in previous literature, and is opposite to the first two styles, in which the document was almost continuously increasing.

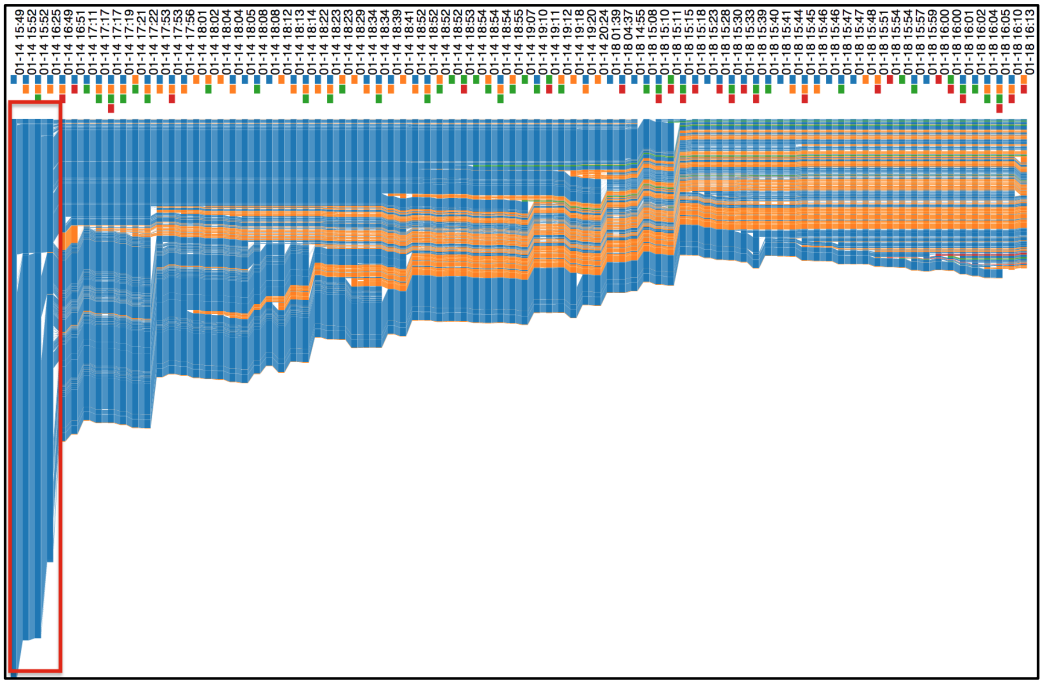


Figure 5.11: The *Example* Style

The last identified style that more than one group exhibited is what we call *informal discussion*, shown in Figure 5.12. Here the participants insert directions to each other and comply informally, not as structured as that in Figure 5.8. Instead of cleaning it up in one big deletion near the end, the notes were incorporated into final text with small edits.

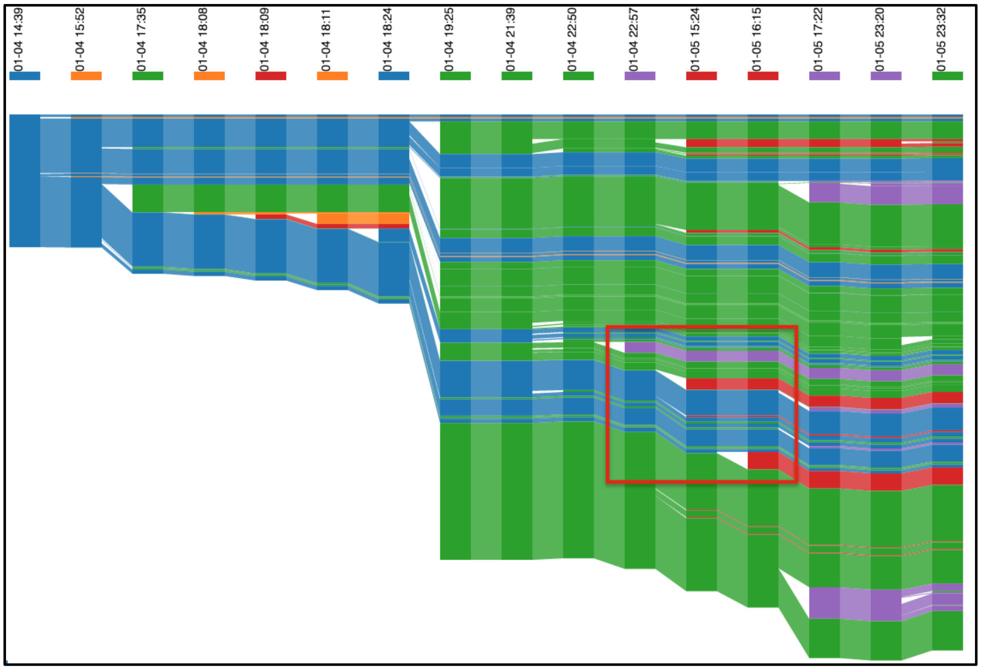


Figure 5.12: The *Informal-Discussion* Style*.*

One unique style emerged in our corpus, one we call *brainstorm and select the best of each*, shown in Figure 5.13. We can see four different authors (blue, green, orange and red) contribute almost identical amounts of information at a certain time point (Jan 30, 23:05). The length of the document then decreased sharply in the next revision. After looking into the content of the document, we saw that the four authors agreed that each of them would write a version of the whole assignment and then two authors (red and blue) collectively chose the best parts from each. As shown in the visualization, the authors represented by blue and the red have a major part of the final draft, whereas most of the work contributed by authors represented by green and the orange is abandoned. This may be driven by the quality of their work or the social dynamics within the group.

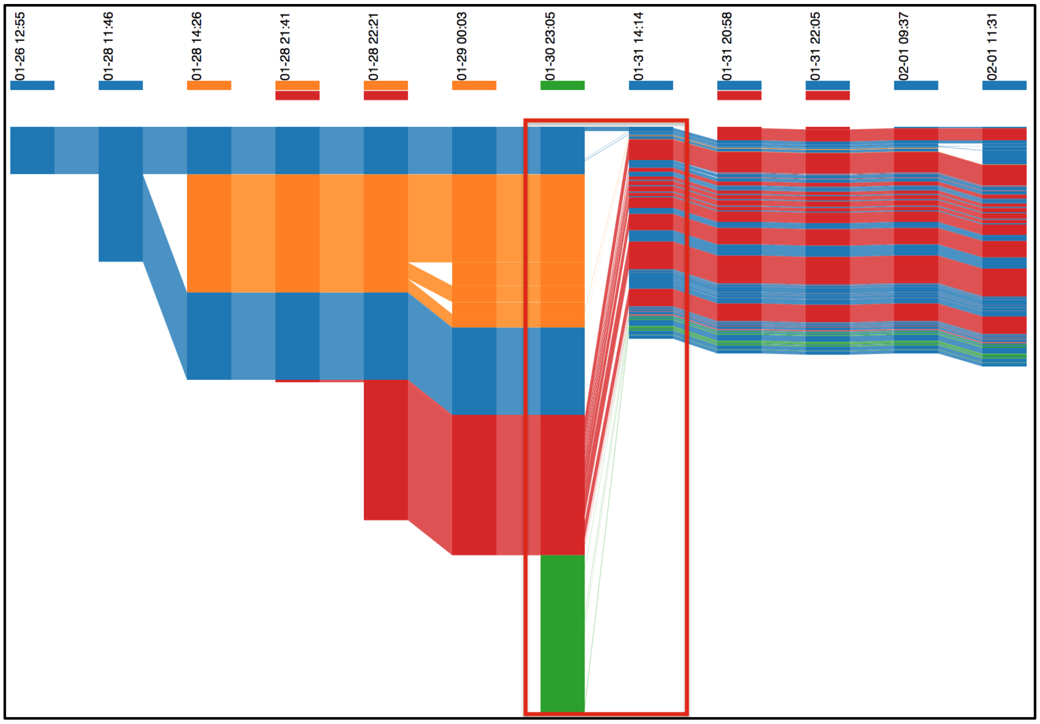


Figure 5.13: The *Brainstorm and Select the Best out of All* Style

Table 5.3 shows the definition of and Table 5.4 shows the distribution of styles in our corpus of 96 documents. Writing from scratch and starting with an outline were the two most common styles. Clearly patterns co-occur. Sixty-seven of our 96 documents exhibited only one pattern. We noted that when they started with an outline, it was accompanied by something else, either more text ("scratch"), inserting the text of the assignment, assigning people to sections, adding informal discussion, and in one case pasting in an example as well. It is logical that pasting in an example does not accompany writing from scratch, as both create large amounts of beginning text.

Table 5.4: Distribution of Styles of Work. A Document Can Exhibit More Than One.

Style	Number of documents that exhibited this	Number of documents for which this was the *only* style
From scratch	40	28
Outline	34	19
Assignment	27	14
Example	8	5
Assign people	12	1
Informal discussion	10	0

Because the teams produced multiple documents, we have an opportunity to see whether the team adopts the same work style over the documents. Interestingly, for all teams that had more than 2 documents for us to examine, none of them adopted the same work style across the documents. Perhaps this was because, as students, they were experimenting with different ways of working together in general and it was reflected in the documents, or the assignments themselves led groups to different styles.

We did find that the assignment type itself drove the adoption of different styles ($\mathcal{X}2$=39.51, $p<.001$). The Business Case was much less likely than other assignments to be done from scratch and much more likely to use an outline. The complicated last assignment which included discussion of cost, risk, and quality, was more likely to have the exact wording of the assignment pasted to help them be sure they had completed everything.

5.4.2.5 Simultaneous Work

Lowry et al. list Degree of Proximity and Degree of Synchronicity as two Work Modes. We do not know how many of the sessions were face-to-face versus remote, although many students commented that it was easier to work face-to-face and will do so in the future. Here we show Degree of Synchronicity as how much of the work is simultaneous.

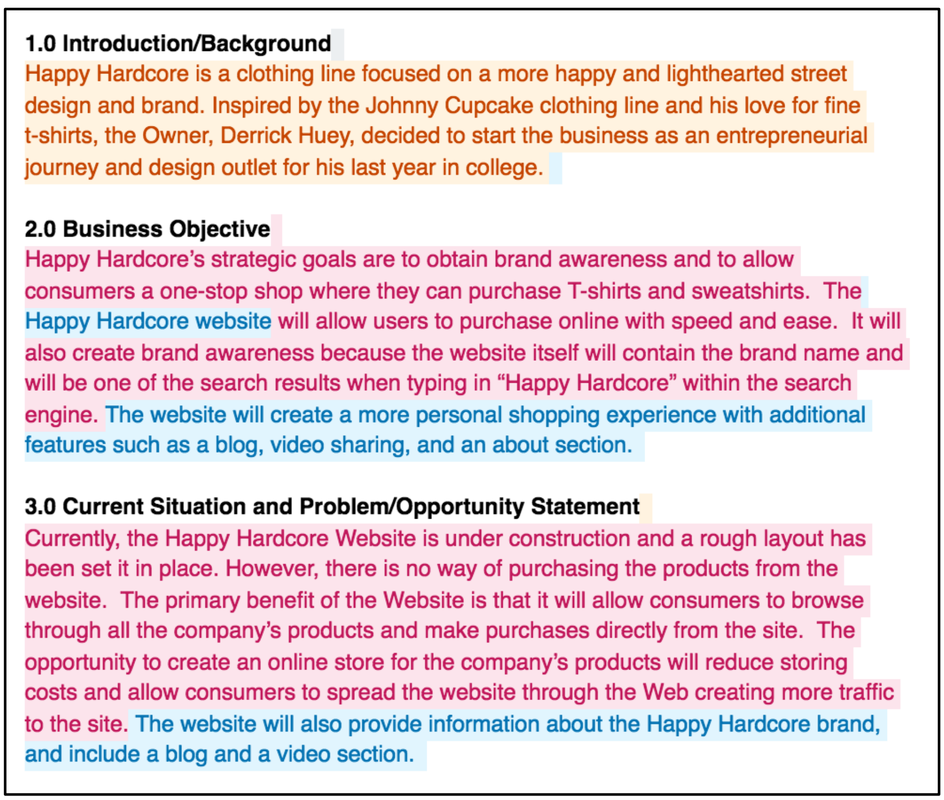
In the corpus of student documents that we have, all documents except five (95%) exhibited some simultaneous work. Three of those five were classic divide and conquer following an outline, a style that can easily be done in asynchronous mode. The other two were very unbalanced, with one person doing most of the work. At the other end of the spectrum, 3 documents showed all simultaneous sessions; the team members always worked with at least one other person present. Their longest single simultaneous sessions were 56, 35 and 46 minutes long, and none of them was done at the last minute.

On average, those people who worked simultaneously (95%) did so in a mean of 3.5 sessions, lasting 33 minutes total on each document with an average of 9.2 minutes per session. The team that had the most simultaneous work worked for 112 minutes. In all the documents, the longest single simultaneous session was 74 minutes.

Of course, the more traditional way of working (the only way to collaborate before simultaneous editing was possible) is to edit alone and then pass control to someone else on the team. Indeed, the median number of solo-authored sessions was 5, with a range from 0 to 18. But as mentioned above, only five documents were produced entirely in this mode.

In the hierarchical linear regression analysis, having more solo-authored sessions was associated with longer elapsed time from start to finish (Beta = 394.17, $p<.01$) and turning it in closer to the deadline (Beta = 77.69, $p<.01$). Having the longest simultaneous session being longer was associated with earlier turn-in (Beta = 9.80, $p<.01$). And, the more authors in the longest simultaneous session was associated with earlier turn-in (Beta = 394.41, $p<.01$).

Often simultaneous work involves people working on different parts of the document, enacting a divide-and-conquer strategy. However, we did see a number of cases where the simultaneous work is on the same section, in close proximity to each other. Figures 5.14 shows an example.



1.0 Introduction/Background

Happy Hardcore is a clothing line focused on a more happy and lighthearted street design and brand. Inspired by the Johnny Cupcake clothing line and his love for fine t-shirts, the Owner, Derrick Huey, decided to start the business as an entrepreneurial journey and design outlet for his last year in college.

2.0 Business Objective

Happy Hardcore's strategic goals are to obtain brand awareness and to allow consumers a one-stop shop where they can purchase T-shirts and sweatshirts. The Happy Hardcore website will allow users to purchase online with speed and ease. It will also create brand awareness because the website itself will contain the brand name and will be one of the search results when typing in "Happy Hardcore" within the search engine. The website will create a more personal shopping experience with additional features such as a blog, video sharing, and an about section.

3.0 Current Situation and Problem/Opportunity Statement

Currently, the Happy Hardcore Website is under construction and a rough layout has been set it in place. However, there is no way of purchasing the products from the website. The primary benefit of the Website is that it will allow consumers to browse through all the company's products and make purchases directly from the site. The opportunity to create an online store for the company's products will reduce storing costs and allow consumers to spread the website through the Web creating more traffic to the site. The website will also provide information about the Happy Hardcore brand, and include a blog and a video section.

Figure 5.14: An Example of Team Members (red and blue in the second paragraph) Working in Close Proximity.

5.4.3 Quality of Collaborative Writing

Of major interest in this work is the relationship between many of these measures that depict the writing collaboration and the resultant quality. The hierarchical linear regression showed that one control variable, the assignment type, had a significant effect on quality ($p<.01$). Later more detailed analyses showed that the Risk, Cost, and Quality assignment was on average lower in quality than the others. This might be because the assignment combined three standard reports in Project Management, and there were no clear examples to follow. Indeed, in all the patterns where an example was pasted in to begin their work, none of them were in the Risk, Cost, and Quality assignments. Most of those began by pasting in the assignment description, which was quite detailed.

Controlling for the differences the assignment type had on the grades, there were three variables that were directly related to quality: The length of the document (Beta = .001, $p<.05$), the presence of a leader (Beta = 9.87, $p<.01$) and balanced participation (Beta = 50.35, $p<.01$).

Controlling for the different assignments, which inherently called for documents of different lengths, the longer the final document, the higher the score (Beta = .001, $p<.05$). This is not a surprising result, in that the more thought that went into a project, its competitive analysis, etc. the more complete it was. This completeness likely required more words to express.

As noted earlier, the more balanced the participation, the higher the quality. This is likely from the fact that people bring different expertise into the project.

Also noted earlier, the presence of a leader was associated with higher quality work (Beta = 9.87, $p<.01$), as well as longer time from start to finish (Beta = 2245.26, $p<.05$) and ending closer to the deadline (Beta = 717.32, $p<.01$). In addition, it is the case that having more authors active increases the work time (Beta = 1499.51, $p<.05$), but also contributes to turning in the assignment earlier (Beta = 303.33, $p<.05$). Start early, end early, if you have everyone working.

Figure 5.15 puts all the links together, built up over the course of the results section. Simply put, longer documents exhibit higher quality, likely from being complete and more fleshed out. We also get higher quality with more balanced participation and leadership. But leadership comes at a cost: The work goes on longer and is finished later.

Interestingly, simultaneous work, with more authors participating and the session being longer leads to finishing earlier. The work is not necessarily higher quality, but it gets done with less last-minute stress.

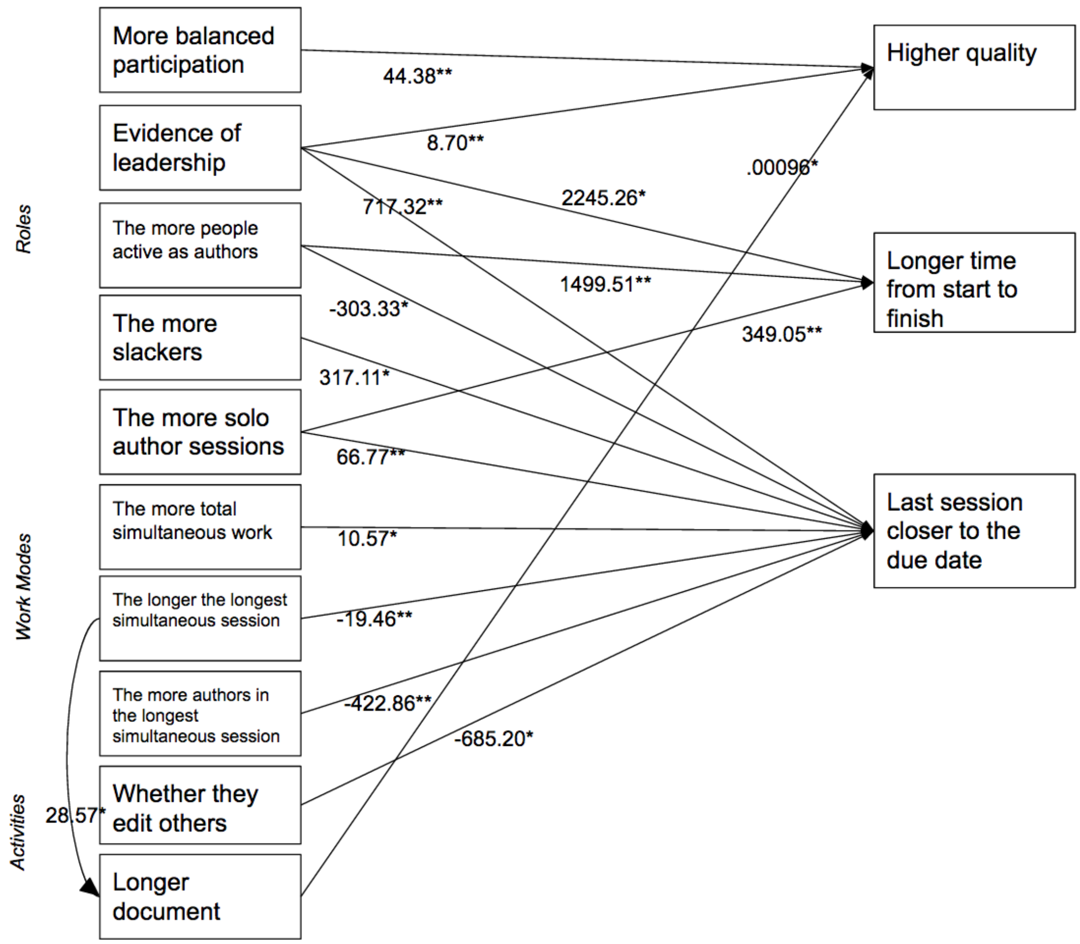


Figure 5.15: The Combined Relationships Between Aspects of Collaborative Work and Quality, Elapsed Time and Proximity to the Due Date.

5.5 Implications

Whereas previous analyses of collaborative writing were primarily based on people's reflections or in surveys, this work is based on trace analysis of what they actually did--from Revision Histories inside Google Docs. Our findings are important benchmarks for a theoretical account of how collaborative writing works today, though as we will point out in section 5.6, there is still a lot to learn before such an account can be constructed.

5.5.1 Summary of Empirical Findings

We find strong evidence for people writing simultaneously, as well as handoffs. Clearly, the ability to write and edit simultaneously is a distinct advantage. It is a style of working that allows the work to get done in meetings, rather than just talking about what needs to be done. Based on previous literature (e.g., Noel and Robert, 2003, 2004), we conjectured that students would be "stuck in their ways," and revert to a hand-off style of collaboration, not taking advantage of being able to work simultaneously. In contrast, we found large amounts of simultaneous work. Indeed, some of the teams only worked simultaneously, and then not as a scramble to meet the deadline. Only five documents showed no evidence of simultaneous work. In several simultaneous sessions, someone pasted in and then soon deleted a funny picture or symbol intended to be a fleeting bit of humor. These findings are in marked contrast to earlier work (e.g., Noel and Robert 2003, 2004; Blau and Caspi 2009), where participants reported they were not used to, or indeed not fond of, working simultaneously. This finding also extends the taxonomy of Posner and Baecker by showing that once writers are familiar and comfortable with working simultaneously, they do more than just writing activities (planning, brainstorming, writing, editing, revising). The also plan, socialize and entertain team members in the text, using the text space for more than just the parts of the final document.

Our results showed that in many groups, the students freely edited each other's entries, in some cases making major moves, deletions, and additions. This result supports the findings of Birnholtz and Ibara (2012) and Birnholtz et al (2013) that if co-authors know and trust each other, they are more likely to make changes directly rather than commenting on the text. In fact, we saw instances where students wrote comments in text instead of using the formal commenting because they were not aware of the existence of such a commenting function. It might be important to increase users' awareness of such functions, although we really did not see this lack of commenting getting in the way of successful editing.

The statistical analyses showed that more balanced participation was correlated with higher rated quality of the documents. We also found that the presence of a leader was also associated with higher quality. Finally, within a given genre, longer documents were rated higher in quality. These are intriguing results, but in our study they are correlations, and we cannot conclude that they are causal. It could be that effective groups manifest these qualities, and that forcing an ineffective group to participate equally or identify a leader would be a poor intervention.

We were able to identify six styles of collaborative work in these documents. One unexpected style was when a team pasted in a template or example of the kind of document they were writing, and then edited it to fit their particulars. The DocuViz visualization looks as if the original document melts into the final one, with a few traces of the original's structure remaining. This seems like a fruitful strategy, and our visualizations of such documents make it quite clear. This might be a much more common strategy than has previously been identified, and the kind of collaborative writing tools now available make it easier to implement. Another interesting style, which in our corpus we only saw once, was each team member writing a complete version of the assignment, and then a subset of the team editing these, taking the best of each and putting it into a unified structure. This reflects the kind of advice often given about brainstorming (Diehl and Stroebe 1987), that better ideas emerge when each brainstorms independently and then later collected. These two styles, along with the other four, show that there is a bigger and richer picture of how people work together now in writing collaboratively.

5.5.2 Design Implications

Our findings have a number of intriguing implications for the design of collaborative writing systems.

Posner and Baecker (1992) suggested that a collaborative writing tool should explicitly support the six primary writing activities that they described. However, Olson et al. (1993) argued instead that such a tool should be simple and unstructured, allowing the writers to creatively and flexibly use the tool without declaring what activity they are performing. Google Docs has a similarly unstructured character, and we found that our writers worked fluently through their different writing activities.

DocuViz, which shows who wrote what when, could evolve into a useful tool during collaborative writing. If it were easy to tell who wrote what, either via color or by hovering over text, it would help in knowing with whom to discuss some proposed revisions, particularly if they were extensive. Related to this, calling attention to sections of text that had been heavily edited in a short period of time (what we call "seismic activity") could signal to authors that they ought to have a look, especially if they weren't involved in the editing. In contrast, sections of text that had not been edited in a very long time while other sections had been actively edited (what we call "dead air") might be flagged to encourage writers to have a look to see if they are satisfied with the text as it stands. Such flags should of course be discretionary, if individual authors choose not to be interrupted with such notices.

We envision something like an Integrated Writing Environment (IWE), by analogy with the Integrated Development Environments (IDEs) found in software engineering. Eclipse, one such IDE environment, provides a number of supporting features such as version control or being aware of who has done what in the code. We noticed, for example, that our writers often pasted in large chunks of material that had been developed outside of the specific document that the group was working on collaboratively. If they were in the same session, this kind of activity could be made visible to the others, providing awareness of potential upcoming activities, likes large pastes. This could be coupled with alerts about what others on the team had been doing since that individual was last active.

5.5.3 Better Practices

The results of our study have intriguing implications for practice.

5.5.3.1 For co-authors themselves

The results that show longer documents to be rated as higher quality does not necessarily hold outside our study; our class documents tended to be more complete if longer, but, of course, we cannot recommend that all longer documents are better. The other two aspects that were found related to quality, balance of participation and evidence of leadership, though intriguing, cannot yet be turned into suggested practice. It may be that the better students were the ones who welcomed balanced participation and also evidenced leadership. Future work is needed in order to separate out this and other possible confounds. But it is worth pursuing.

Several of the other features, like longer simultaneous sessions with more authors in them as well as their editing each other's work, was associated with them finishing earlier. Once again, we cannot yet show causation because these are correlations, but the results warrant future work.

5.5.3.2 For managers

Several aspects of the results may have implications for those who manage work teams who have to produce documents. The fact that teams can write successfully simultaneously suggest some opportunities for productivity enhancements. There are reported success cases of people running meetings with rotating scribes, sessions where everyone gathers to enter their expertise or opinions about some topics in one long session to be cleaned up later, and people learning from each other while watching them create a document or flesh out an explanation (Olenawa et al., in press). With long sessions of simultaneous work, there is the promise of shortening the effort and lessening the pain involved in capturing software documentation.

In addition, DocuViz itself provides a picture of participation that may prove valuable in assigning credit to those who contributed. As mentioned earlier, one has to be careful to not over-interpret these raw statistics from traces of keyboard activity, as there are other ways to contribute that are very valuable. But DocuViz may give a first glance as to who did what to help deeper evaluation of credit.

5.5.3.3 For educators

Teachers of collaborative writing might also find value in the DocuViz visualizations, which can show not only participation but signatures of various styles and evidence of people editing each other's work. Educational researchers have long been interested in using the computer-based collaborative writing technology to support students' learning. In particular, many studies have been done on how to use these technologies to help students improve their writing skills. Researchers have compared the outcome differences between individual and collaborative writing, where they found that the use of blog-based or wiki-based systems can help students to achieve greater improvement in their writing (Arslan and Şahin-Kızıl 2010; Strobl 2014; Mak and Coniam 2008). Google Docs, in particular, with the simultaneous access and editing feature, can encourage middle-school students to write and revise more frequently than they would have done in a typical literacy exercise (Yim et al. 2014).

5.6 Limitations and Conclusion

We have outlined a few directions for future work in the discussion above. Finding out the causal relationship between quality and various activities that were shown correlated above warrant further investigation.

To more fully understand the Roles that various co-authors play, as outlined in Posner and Baecker's taxonomy, we would need to capture not only their actions with keyboard and mouse but also what they say, how they say it, and in what channels. As we all know, group members might perform differently if they have text-based communication channels, or voice-based, or video-based, or face-to-face. Twenty-five years ago, (Olson et al, 1993) did a complex laboratory study where people could write simultaneously using ShrEdit. It is time to try this experiment design again outside the laboratory with today's tools, including both Google Docs and the new Microsoft Word, where simultaneous writing is offered.

The space of kinds of collaborative writing and writers is enormous, and we choose the student class assignments as the data corpus in this study. We acknowledge that the results and implications from this study cannot be simply generalized to other contexts.

But, we think advanced undergraduates doing collaborative work in the context of preparing for a year-long client-centered project is a good place for a first look at these issues. We mentioned some other case studies, such as Glushko (2015) and Boellstorff et al. (2013) that looked at the writing of book-length documents, and they reported some phenomena that overlap with what we saw. But looking at a larger sample of such projects would be valuable.

There are also many kinds of writers, including different characteristics of collaborations. We looked at advanced undergraduates who were peers. As reported in Chapter 3, there are all manners of different professions where writing is key, and there are many levels of expertise in any profession. The professions and the level of expertise influences people's choices of tools and collaborative writing behaviors. Finally, we suspect that now that simultaneous access is possible, it is likely that there will be a change in the pace and collaborative nature of the detailed work involved in collaborative creation and refining of a variety of digital objects, not just documents.

But our initial foray into this interesting space has shown that writers do take advantage of simultaneous access and editing, and exploit the technology in interesting ways. As writing becomes an increasingly collaborative activity in most arenas, these are interesting trends that we can imagine will be developed and refined even further.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 Summary

This dissertation has revisited research topic of collaborative writing within today's context. We reviewed related literature on collaborative writing from the perspectives of both technology design and user experience, and discussed various designs of information visualization that aim to help explore and potentially support group collaboration. The six research questions stated in Chapter 2 of this dissertation are:

- RQ1: What tools do co-authors use and what do they do in today's collaborative writing?
- RQ2: Why do co-authors choose to use certain tools over other tools, or ways of working together over other ways of working together?
- RQ3: What practices of collaborative writing might be related to the quality of the documents?
- RQ4: Is the taxonomy created by Posner and Baecker 20 years ago still suitable for today's writing collaborations?
- RQ5: How can we improve the design of the systems to better support collaborative writing?
- RQ6: How can we build a useful information visualization tool to help with the research of collaborative writing? Is the visual analytics method a promising way to study collaborative writing?

Each of the dissertation's three studies then uses a different approach to answer a subset of these research questions. The first study explored collaborative writing practices and people's perceptions through semi-structured interviews. This study aims to answer

RQ1: What tools do co-authors use and what do they do in today's collaborative writing, and **RQ2**: **Why do co-authors choose to use certain tools over other tools, or ways of working together over other ways of working together?** We interviewed 30 participants from both inside and outside academic settings, and we focused on revealing new practices or collaboration norms of using the advanced collaboration-support features such as *direct editing* and *synchronous editing*. We found that participants acknowledge the benefits of collaborative writing enabled by these new features, but they also have concerns about *writing privacy* and *attribution of contribution and responsibility*. Due to these concerns, the participants often avoided these advanced features or they devised work-around methods.

Then the second study presented an information visualization system, DocuViz, to help with our research. The visualization, inspired by *historyflow*, utilized the keystroke level data traces of people's collaborative writing behaviors and rendered the evolution of a document's collaborative construction. We illustrated the use of such visualization in research, where we were able to identify commonly-used collaboration styles, and two potentially useful alerts of seismic and dead-air activities. We also envisioned the potential use of this visualization to help co-authors in a writing collaboration. This study was the first step in addressing **RQ6: How can we build a useful information visualization tool to help with the research of collaborative writing? Is the visual analytics method a promising way to study collaborative writing?**

The last study investigated what people's collaborative writing practices are and what practices lead to a better outcome (**RQ1** and **RQ3**). We adopted mixed methods, where we qualitatively and quantitatively coded 96 co-authored documents' quality and many other key features of the collaborative writing that had the potential of influencing quality. Through a statistical analysis, we revealed that two features (*leadership* and *contribution evenness*) were related to higher quality co-authored documents. With the help of our visualization system, we identified six commonly-used styles of working in collaborative writings in the context of students writing class assignments.

6.2 Implications

6.2.1 Implications for Theory

The research contributes an updated view of collaborative writing, in particular, what co-authors do once they can write and edit synchronously. We construct this updated view not only based on 30-year-old studies of lab experiments and interviews, but also from behavioral data in the wild. Utilizing both interview data and behavioral keystroke data, our research takes three different approaches to establish an understanding of today's collaborative writing practices that are supported by widely-used commercial systems and the features that explicitly support collaboration.

Interviews are effective in exploring the question space and revealing users' perceptions and reasoning. From the interview study, we have an in-depth understanding of *why* people choose certain behaviors in addition to what they do. For example, needing to *write privately* while in a group as one of the considerations that influenced people's choice not to write simultaneously, was nonexistent before synchronous editing was implemented and widely adopted in commercially available systems.

Information visualization and visual analytics help researchers explore big, detailed data sets. This research approach can answer some overview questions and reveal patterns of group behaviors. More importantly, the visualization can trigger new questions and propositions that lead to further analysis. For example, in Study II, the tool revealed a number of different styles of contributions, that some groups adopted the same styles, and that contributions varied from being equal to being quite one-sided. This finding therefore suggested that we develop a new measurement of "evenness of participation" in the following statistical study and see how relates to quality.

The research approach used in Study III is distinctive from the ones used in Study I and II is that it uses both qualitative (patterns from the visualization) and quantitative measures from the behavioral data traces to depict a group collaboration. It also highlights their relationships to the quality of the outcome. The results suggest that more balanced participation was correlated with higher rated quality of the documents. We also found that the presence of a leader was associated with higher quality. These are intriguing results, but in our study they are correlations, and we cannot conclude that they are causal. But the results do suggest that the participation evenness and other benchmarks of collaboration are important additions to the existing framework. Also, Posner and Baecker's framework did not address which features of the work affect the quality of the outcome, which is another contribution of our work.

6.2.2 Implications to Collaborative Writing Practices

The results of this dissertation can be directly applied to today's collaborative writing practices, particularly collaboration readiness. We introduce implications in detail in each chapter. Here, we briefly summarized their key points.

6.2.2.1 For co-authors themselves

- Reach an agreement with other co-authors about styles of working, synchronicity, direct editing versus commenting, and each individual's responsibility and contribution (achieve a common ground). This suggestion is based on the findings from **Chapter 3 and Chapter 5,** where we found interviewees and students used various styles of working together, and they had different preferences of various tools and practices. Participants reported the confusion when co-authors in a team used different tools or practices. We also know from the previous literature (Olson and Olson 2013) that achieving a common ground beforehand is important for group collaboration in general.

- Be aware of the new tools and features that support collaboration (technology readiness). This suggestion is based on **Chapter 3**, where some interviewees reported that they were not aware of many existing features (e.g., commenting) or systems (e.g., web-based synchronous editing tools) that support collaboration. To be aware of existing technologies, and to have a higher technology readiness, a user can have more options to choose when she/he needs to collaborate with others.
- Know various ways of working together other than the one familiar style (collaboration readiness). **Chapter 3 and Chapter 5** reported various practices (e.g., commenting versus editing directly) and styles of collaboration (e.g., divide and conquer versus from scratch). Olson and Olson (2013) suggest that knowing other ways of working together, or having a higher collaboration readiness, is important in a group collaboration. Knowing there are other ways of working together can ease the conflict within a team and can help form a smoother collaboration.
- Understand that two aspects that were found related to quality, balance of participation and evidence of leadership (from **Chapter 5**), though intriguing,

cannot yet be turned into suggested practice. Future work is needed in order to separate out this and other possible confounding factors. But the casual relationship between quality and these two aspects is worth pursuing.

6.2.2.2 For managers

- Encourage team members to write simultaneously, because there are opportunities for productivity enhancements. For example, **Chapter 5** reported the more total simultaneous work, the earlier a team finishes the task.
- Monitor team progress and individuals' contributions, and assign credit fairly with the help of a real-time visualization like DocuViz. **Chapter 4** suggested that DocuViz or other visualization systems can be a useful supplement to the existing collaborative writing systems, and **Chapter 3** reported that participants want to have an awareness of each individual's contribution.

6.2.2.3 For educators

- Teachers of collaborative writing can find value in DocuViz visualizations that show evidence of participation and signatures of various styles. **Chapter 4 and 5** illustrated that education practitioners used DocuViz in teaching. The visualization contributes to educators as it can provide an overview view of the progress about groups of students learning English writing.

6.2.3 Implications for the Design of Collaborative Writing Systems

Collaborative writing systems such as Google Docs are being used in many creative ways. We concur with Olson et al.'s (1993) argument that a collaborative writing system should be simple and unstructured, allowing the users to flexibly use the tool. [**Chapter 3 and Chapter 5**]

DocuViz, which shows who wrote what when, could evolve into a useful design feature during collaborative writing. If it were easy to tell who wrote what, either via color or by hovering over the text, it would help in knowing with whom to discuss some proposed revisions, particularly if they were extensive. [**Chapter 4**]

Notifying users that certain sections of text had been heavily edited (what we call "seismic activity") could signal to authors that they ought to have a look, especially if they were not involved in the editing. In contrast, sections of text that had not been edited in a very long time while other sections had been actively edited (what we call "dead air") might be flagged to encourage writers to have a look to see if they are still satisfied with the text as it stands. Such flags should, of course, be discretionary, so that individual authors can choose not to be interrupted with such notices. [**Chapter 4**]

We envision something like an Integrated Writing Environment (IWE), inspired by the Integrated Development Environments (IDEs) in software engineering. Eclipse, one such IDE environment, provides a number of features such as version control or notifications of who has done what in the code. It also provides the opportunity for customization, where third-party developers can design and implement features for the IWE.

With the large user population of one or two dominant IWEs, a good design feature can easily reach a huge number of users. For example, we envision an IWE in the future can integrate audio- or video-based communication channels. Co-authors now report that they use the build-in communication channels a lot, which are mostly text-based. Some of the interviewees also reported that they would chat with each other if they wrote collocated, or open a Skype/Google Hangout session to chat with each other if they worked remotely. A build-in audio-based communication channel can benefit co-authors a lot, as it can capture and archive the communication and discussion together with the written piece of document content. It can serve as a place to host the collective memory and all the decision-making process, which are presently not being captured by the keyboard.

With the emergence of sophisticated Artificial Intelligence (AI) technologies in recent years, we envision that the future collaborative writing systems or IWE will equip advanced AI supports, for example, some helps with grammar or formatting. Now, many word processors and messaging systems embed word auto-completion and auto-correction. It would be really helpful and fairly easy to extend the auto-completion and auto-correction to the sentence level, and to suggest the structure of sentences or paragraphs. The AI algorithm in a writing system can learn from a user's writing and editing history, so that it knows what common grammar mistakes this user might make and it can help correcting these mistakes automatically.

In addition to personalization, the AI algorithm can also be domain specific. Many interviewees in this study, friends and colleagues of mine, and I myself, have spent enormous hours on formatting a document after we finish the actual writing. We need to adjust text font and positions of figures. And we need to adjust them differently, for instance, when we submit a paper to a journal or to a conference. The formatting issue is really time-consuming and annoying. An AI algorithm should be able to help with that the way references can be automatically formatted to fit various journal requirements. The algorithm can learn from a user's behaviors and generate a set of formatting rules for a particular publication venue. Then the collaborative writing system can simply provide a button: once the user clicks on that button, the whole document's format will change accordingly. This design suggestion is not necessarily pinpointed to collaborative writing. It would be useful for solo-authorship too.

From the interview study in **Chapter 3**, participants had different perceptions about synchronous editing, and a few participants had to develop work-around strategies to avoid synchronous editing. This aversion indicates that users might also need a private writing place in addition to the synchronous writing session where they can generate ideas and articulate their words without interruption. We suggest that the design of a collaborative writing tool should support synchronous editing as well as a private writing session (as ShrEdit did (McGuffin and Olson 1992)). And while a user is working in this private window, the writing activity should be visually displayed in a way that informs collaborators that this user is working on some text privately indicating where he is working on it, so the private hard-working author is not considered lazy or away from the keyboard.

6.2.4 Implications for Research Methods

Building and using information visualizations to study collaborative writing is a promising research approach, as illustrated in **Chapter 4**. We examined a corpus of 96 documents produced by undergraduates in a Project Management class, and we were able to identify new, commonly-used styles of working. The richer, longer-term view reveals the previously invisible detailed editing behaviors for visual inspection. Visual analytics helps researchers to explore the variety of people's approaches to creating documents. In addition, we published the DocuViz system as a Chrome browser plugin. That invites researcher and educator communities to freely use the tool and explore collaborative writing scenarios in their domains

6.3 Limitations and Future Work

Collaborative writing is pervasive and complex. A high quality outcome of collaboration depends on many factors, outlined in Olson and Olson (2013). This dissertation touched on three of them: common ground, technology readiness, and collaboration readiness. There is also the factor of the nature of the work. Study III used undergraduates and their class assignments to initiate this line of work, which controlled the type of work and the context. Of course, there are many other contexts that involve collaborative writing, as reported in Study I. It is a natural next step to dive into those contexts. For example, researchers write scholarly publications together, and software engineers write program code together. It would be valuable to look at a large sample of such collaborations to see what the collaboration signatures are and how these relate to outcome quality. An ongoing interdisciplinary project is to use DocuViz visualizations to investigate how English instructors can use collaborative writing as a form of teaching students to learn English writing (Yim et al., under review). Preliminary results suggest that students are more engaged into the writing activities when they write in groups than when they write individually. The learning outcome could be better.

It is worth noting again that Study III only showed the correlations between various activities and quality. It is necessary to design an experiment to examine the causal relationship. Then, better practices for collaborative writing can be inferred.

This dissertation focused on collaboration awareness but did not consider some other important factors of collaboration, such as trust and communication. Because privacy and authorship concerns were reported in Study I, it is important to explore how these concerns may interact with participants' trust levels.

The current study of people's behaviors is purely based on keyboard log data; it is necessary to also capture authors' communication. The collaborators could communicate in various channels: face-to-face, text, or voice- and video-based channels. Research into these communications can help us understand the relationships between communications and collaborative writing activities.

The two debates about the value of synchronous versus asynchronous editing, and editing directly versus commenting are ongoing. These debates could be resolved with an experiment to compare these two ways of working on various collaboration outcome dimensions: the quality of the final writing artifact, the efficiency of the collaboration, the satisfaction of each individual, and the group dynamic. Often, people use these two editing styles together. But in order to get a better understanding of these different activities and even to measure the influence of these activities on collaboration, an experimental study is required.

The differences between asynchronous and synchronous editing may vary with the distance between the writing partners. Further studies are needed to examine the collocated versus remote collaborative writing, and how these factors may influence the recommendations for collaborative writing strategies or practices.

The DocuViz visualization has proved useful in research, but its usefulness to authors themselves has not been validated in a user study. An experiment can serve this purpose by using DocuViz as a real-time intervention to promote awareness and trigger reflections of collaborators in group writing. Furthermore, the cloud computing infrastructure that captures massive detailed behavioral data opens a new era of CSCW research. Further information-visualization designs could be proposed to reveal additional aspects of the data. Along with these data, a user can be portrayed with a combination of behavioral models and habits, which can in turn inform personalized computer systems design.

REFERENCES

1. Recep S. Arslan, and Aysel Şahin-Kızıl. 2010. How can the use of blog software facilitate the writing process of English language learners? *Computer Assisted Language Learning*, 23(3), 183-197.
2. Ronald M. Baecker, Nastos Dimitrios, Ilona R. Posner, and Kelly L. Mawby. 1993. The user-centered iterative design of collaborative writing software. In *Proceedings of the INTERACT'93 and CHI'93*, 399-405.
3. Thomas Ball and Stephen G. Eick. 1996. Software visualization in the large. *Computer*, 29(4), 33-43.
4. Eevi E. Beck. 1993. A survey of experiences of collaborative writing. In *Computer supported collaborative writing*, pp. 87-112. Springer London.
5. Michael Bostock, Vadim Ogievetsky, and Jeffrey Heer. 2011. D^3 data-driven documents. *Visualization and Computer Graphics, IEEE Transactions on*, *17*(12), 2301-2309.
6. Jeremy Birnholtz and Steven Ibara. 2012. Tracking changes in collaborative writing: edits, visibility and group maintenance. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, 809-818.
7. Jeremy Birnholtz, Stephanie Steinhardt, and Antonella Pavese. 2013. Write here, write now!: an experimental study of group maintenance in collaborative writing. In *Proceedings of the CHI'13*, 961-970.
8. Ina Blau and Avner Caspi. 2009. What type of collaboration helps? Psychological ownership, perceived learning and outcome quality of collaboration using Google Docs. In *Proceedings of the Chais conference on instructional technologies research*, 48-55.
9. Tom Boellstorff, Bonnie Nardi, Celia Pearce, and T. L. Taylor. 2013. Words with friends: writing collaboratively online. *Interactions* 20, no. 5 (2013): 58-61.
10. Cornelia Brodahl, Said Hadjerrouit, and Nils Kristian Hansen. 2011. Collaborative writing with Web 2.0 technologies: education students' perceptions. In *Journal of Information Technology Education: Innovations in Practice*.
11. Rafael Calvo, Stephen T. O'Rourke, Janet Jones, Kalina Yacef, and Peter Reimann. 2011. Collaborative writing support tools on the cloud. *Learning Technologies, IEEE Transactions on* 4, no. 1 (2011): 88-97.
12. Teresa Cerratto. 1999. Instrumenting Collaborative Writing and its cognitive tools. In *Proceedings HCP 99 Conference, Human Centred Processes*, 24-26.
13. Teresa Cerratto, and Henrry Rodriguez. 2002. Studies of Computer Supported Collaborative Writing. Implications for System Design. In *COOP*, 139-154.
14. Martin Chemers. 2014. *An integrative theory of leadership.* Psychology Press.

15. Kwangsu Cho and Christian D. Schunn. 2007. Scaffolded writing and rewriting in the discipline: A web-based reciprocal peer review system. *Computers & Education*, 48(3), 409-426.

16. Geoffrey A. Cross. 1990. A Bakhtinian exploration of factors affecting the collaborative writing of an executive letter of an annual report. *Research in the Teaching of English*, 173-203.

17. Bill Curtis, Herb Krasner, and Neil Iscoe. 1988. A field study of the software design process for large systems. *Communications of the ACM*, *31*(11), 1268-1287

18. Laura Dabbish, Colleen Stuart, Jason Tsay, and Jim Herbsleb. 2012. Social coding in GitHub: transparency and collaboration in an open software repository. In *Proceedings of CSCW 2012,* 1277-1286.

19. Oscar Díaz, and Gorka Puente. 2010. Model-aware Wiki analysis tools: the case of HistoryFlow. In *Proceedings of the 6th international symposium on Wikis and open collaboration* (p. 6). ACM.

20. Michael Diehl, and Wolfgang Stroebe. 1987. Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of personality and social psychology*, *53*(3), 497.

21. Andrew Dillon. 1993. How collaborative is collaborative writing? An analysis of the production of two technical reports. In *Computer supported collaborative writing*, 69-85. Springer London.

22. Paul Dourish, and Victoria Bellotti. 1992. Awareness and coordination in shared workspaces. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work*, 107-114.

23. Lisa S. Ede, and Andrea A. Lunsford. 1990. Singular texts/plural authors: Perspectives on collaborative writing. SIU Press.

24. Stephen G. Eick, Joseph L. Steffen, and Eric E. Sumner Jr. 1992. Seesoft-a tool for visualizing line oriented software statistics. *Software Engineering, IEEE Transactions on*, *18*(11), 957-968.

25. Clarence A. Ellis, and Simon John Gibbs. 1989. Concurrency control in groupware systems. In *ACM SIGMOD Record* Vol. 18(2), 399-407.

26. Stefan Elsen. 2013. VisGi: Visualizing Git Branches. *In Software Visualization (VISSOFT), 2013 First IEEE Working Conference on* (pp. 1-4). IEEE.

27. Andy Field. 2009. *Discovering statistics using SPSS*. Sage publications.

28. Linda Flower, and John R. Hayes. 1981. A cognitive process theory of writing. *College composition and communication* (1981): 365-387.

29. Neil Fraser. 2012. Google-Diff-Match-Patch: Diff, Match and Patch Libraries for Plain Text. Retrieved from https://Code.google.com/p/google-diff-match-patch/

30. Jon Froehlich, and Paul Dourish. 2004. Unifying artifacts and activities in a visual tool for distributed software development teams. In *Proc. of the 26th International Conference on Software Engineering*, 387-396.

31. Jolene Galegher, and Robert E. Kraut. 1994. Computer-mediated communication for intellectual teamwork: An experiment in group writing. *Information systems research* 5, no. 2 (1994): 110-138.

32. Tudor Girba, Adrian Kuhn, Mauricio Seeberger, and Stephane Ducasse. 2005. How developers drive software evolution. In *Eighth International Workshop on Principles of Software Evolution* (pp. 113-122). IEEE.

33. Robert J. Glushko. 2015. Collaborative authoring, evolution, and personalization for a transdisciplinary textbook. In *Companion to the Proceedings of the 11th International Symposium on Open Collaboration* (p. 10). ACM.

34. Jonathan Grudin. 1988. Why CSCW applications fail: problems in the design and evaluation of organizational interfaces. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work*, 85-93.

35. Christina Haas. 1989. Does the medium make a difference? Two studies of writing with pen and paper and with computers. *Human-Computer Interaction* 4, no. 2 (1989): 149-169.

36. David A. Harrison and Katherine J. Klein. 2007. What's the difference? Diversity constructs as separation, variety, or disparity in organizations. *Academy of management review, 32*(4), 1199-1228.

37. Andrew F. Hayes and Klaus Krippendorff. 2007. Answering the call for a standard reliability measure for coding data. *Communication methods and measures, 1*(1), 77-89.

38. Lorraine Higgins, Linda Flower, and Joseph Petraglia. 1992. Planning text together: The role of critical reflection in student collaboration. *Written communication*, *9*(1), 48-84.

39. Lester J Holtzblatt, Laurie E Damianos, and Daniel Weiss. 2010. Factors impeding Wiki use in the enterprise: a case study. In *Proceedings of CHI' 10 Extended Abstracts*, 4661-4676.

40. James W. Hunt, and Thomas G. Szymanski. 1977. A fast algorithm for computing longest common subsequences. *Communications of the ACM*, *20*(5), 350-353.

41. Robert Johansen. 1989. User approaches to computer-supported teams. In *Technological support for work group collaboration*, Margrethe H. Olson (Ed.). L. Erlbaum Associates Inc., Hillsdale, NJ, USA 1-31.

42. Carolyn W. Keys. 1994. The development of scientific reasoning skills in conjunction with collaborative writing assignments: An interpretive study of six ninth-grade students. *Journal of Research in Science Teaching*, *31*(9), 1003-1022.

43. Hee-Cheol Ezra Kim, and Kerstin Severinson Eklundh. 2001. Reviewing practices in collaborative writing. *Computer Supported Cooperative Work (CSCW)* 10, no. 2 (2001): 247-259.

44. Michele Lanza. 2001. The evolution matrix: Recovering software evolution using software visualization techniques. In *Proceedings of the 4th international workshop on principles of software evolution* (pp. 37-42). ACM.

45. Mary D. P. Leland, Robert S. Fish, and Robert E. Kraut. 1988. Collaborative document production using Quilt. In Proceedings of the 1988 ACM conference on Computer-supported cooperative work (pp. 206-215). ACM.

46. Paul Benjamin Lowry, Aaron Curtis, and Michelle René Lowry. 2004. Building a taxonomy and nomenclature of collaborative writing to improve interdisciplinary research and practice. *Journal of Business Communication* 41, no. 1 (2004): 66-99.

47. Paul Benjamin Lowry, and Jay F. Nunamaker Jr. 2003. Using Internet-based, distributed collaborative writing tools to improve coordination and group awareness in writing teams. *Professional Communication, IEEE Transactions on* 46, no. 4 (2003): 277-297.

48. Barley Mak and David Coniam. 2008. Using wikis to enhance and develop writing skills among secondary school students in Hong Kong. *System*, 36(3), 437-455.

49. Lola J. McGuffin, and Gary M. Olson. 1992. *ShrEdit: A Shared Electronic Work Space*. University of Michigan, Cognitive Science and Machine Intelligence Laboratory.

50. Antonios Michailidis, and Roy Rada. 1996. A review of collaborative authoring tools. *Groupware and authoring.* Academic Press, London, 9-43.

51. Webb Miller, and Eugene W. Myers. 1985. A file comparison program. *Software: Practice and Experience*, *15*(11), 1025-1040.

52. Alex Mitchell, Ilona Posner, and Ronald Baecker. 1995. Learning to write together using groupware. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, 288-295.

53. Eugene W. Myers. 1986. An O(ND) difference algorithm and its variations. *Algorithmica*, *1*(1-4), 251-266.

54. Christine M. Neuwirth, Ravinder Chandhok, David S. Kaufer, Paul Erion, James Morris, and Dale Miller. 1992. Flexible diff-ing in a collaborative writing system. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work*, 147-154.

55. Sylvie Noël, and Jean-Marc Robert. 2003. How the Web is used to support collaborative writing. *Behaviour & Information Technology* 22, no. 4 (2003): 245-262.

56. Sylvie Noël, and Jean-Marc Robert. 2004. Empirical study on collaborative writing: What do co-authors do, use, and like? *Computer Supported Cooperative Work (CSCW)* 13, no. 1 (2004): 63-89.

57. Ricardo Olenewa, Judith S. Olson, Gary M. Olson, and Daniel M. Russell. under review. Now that we can write *simultaneously,* how do we use that to our advantage?

58. Judith S. Olson, Gary M. Olson, Marianne Storrøsten, and Mark Carter. 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, no. 4 (1993): 321-348.

59. Judith S. Olson, and Gary M. Olson. 2013. Working together apart: Collaboration over the Internet. *Synthesis Lectures on Human-Centered Informatics* 6, no. 5 (2013): 1-151.

60. Judith S. Olson, Dakuo Wang, Jingwen Zhang, and Gary M. Olson. under review. How People Write Together Now: Beginning the Investigation with Advanced Undergraduates in a Project Course.

61. Stephen T. O'Rourke, Rafael A. Calvo, and Danielle S. McNamara. 2011. Visualizing Topic Flow in Students' Essays. *Educational Technology & Society*, 14(3), 4-15.

62. Ilona R. Posner, and Ronald M. Baecker. 1992. How people write together [groupware]. In *System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on*, vol. 4, 127-138.

63. Roy Rada. 1996. *Groupware and Authoring*. Academic Press.

64. Stephen W. Raudenbush, and Anthony S. Bryk. 2002. *Hierarchical linear models: Applications and data analysis methods* (Vol. 1). Sage.

65. Rodney P. Rice, and John T. Huguley Jr. 1994. Describing collaborative forms: A profile of the team-writing process. *IEEE Transactions on Professional Communication*, *37*(3), 163-170.

66. Tim Roskams. 1999. Chinese EFL students' attitudes to peer feedback and peer assessment in an extended pairwork setting. *RELC Journal*, *30*(1), 79-123.

67. Kathy Schwalbe. 2015. *Information technology project management*. Cengage Learning. Chicago

68. Francisco Servant, and James A. Jones. 2012. History slicing: assisting code-evolution tasks. In *Proceedings of the ACM SIGSOFT 20th International Symposium on the Foundations of Software Engineering* (p. 43). ACM.

69. Francisco Servant, and James A. Jones. 2013. Chronos: Visualizing slices of source-code history. In *Software Visualization (VISSOFT), 2013 First IEEE Working Conference on* (pp. 1-4). IEEE.

70. Mike Sharples, J. S. Goodlet, Eevi E. Beck, Charles C. Wood, S. M. Easterbrook, and Lydia Plowman. 1993. Research issues in the study of computer supported collaborative writing. In *Computer supported collaborative writing*, 9-28. Springer London.

71. Mark D. Shermis, Jill Burstein, Derrick Higgins, and Klaus Zechner. 2010. Automated essay scoring: Writing assessment and instruction. *International encyclopedia of education*, 4, 20-26.

72. Vilaythong Southavilay, Kalina Yacef, Peter Reimann, and Rafael A. Calvo. 2013. Analysis of collaborative writing processes using revision maps and probabilistic

topic models. In *Proceedings of the Third International Conference on Learning Analytics and Knowledge*, 38-47.

73. Neomy Storch. 2005. Collaborative writing: Product, process, and students' reflections. *Journal of second language writing* 14, no. 3 (2005): 153-173.
74. Carola Strobl. 2014. Affordances of Web 2.0 technologies for collaborative advanced writing in a foreign language. *Calico Journal*, 31(1), 1.
75. Yunting Sun, Diane Lambert, Makoto Uchida, and Nicolas Remy. 2014. Collaboration in the cloud at Google. In *Proceedings of the 2014 ACM conference on Web science*, 239-240.
76. Susan G. Tammaro, Jane N. Mosier, Nancy C. Goodwin, and Gabriel Spitz. 1997. Collaborative writing is hard to support: A field study of collaborative writing. *Computer Supported Cooperative Work (CSCW)* 6, no. 1 (1997): 19-51.
77. Edward R. Tufte, and P. R. Graves-Morris. 1983. *The visual display of quantitative information* (Vol. 2, No. 9). Cheshire, CT: Graphics press.
78. Filip Van Rysselberghe, and Serge Demeyer. 2004. Studying software evolution information by visualizing the change history. In *Proceedings of 20th IEEE International Conference on Software Maintenance, 2004.* (pp. 328-337). IEEE.
79. Fernanda B. Viégas, Martin Wattenberg, and Kushal Dave. 2004. Studying cooperation and conflict between authors with history flow visualizations. In *Proceedings of the SIGCHI Conference on Human factors in computing systems*, 575-582.
80. Fernanda B. Viegas, Martin Wattenberg, Jesse Kriss, and Frank Van Ham. 2007. Talk before you type: Coordination in Wikipedia. In *System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on,* pp. 78-78.
81. Amy Voida, Judith S. Olson, and Gary M. Olson. 2013. Turbulence in the clouds: challenges of cloud-based information work. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2273-2282). ACM.
82. Lucian Voinea, Alex Telea, and Jarke J. Van Wijk. 2005. CVSscan: visualization of code evolution. In *Proceedings of the 2005 ACM symposium on Software visualization*, 47-56.
83. Dakuo Wang, Judith S. Olson, Jingwen Zhang, Trung Nguyen, and Gary M. Olson. 2015. DocuViz: visualizing collaborative writing. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 1865-1874). ACM.
84. Colin Ware. 2012. *Information visualization: perception for design*. Elsevier.
85. Stefan Wuchty, Benjamin F. Jones, and Brian Uzzi. 2007. The increasing dominance of teams in production of knowledge. *Science, 316*(5827), 1036-1039. Chicago
86. Soobin Yim, Mark Warschauer, Binbin Zheng, and Joshua F. Lawrence. 2014. Cloud-Based Collaborative Writing and the Common Core Standards. *Journal of Adolescent & Adult Literacy* 58, no. 3 (2014): 243-254.

87. Soobin Yim, Dakuo Wang, Judith S. Olson, Viet Vu, and Mark Warschauer. under review. Synchronous Collaborative Writing in the Classroom: Undergraduates' Collaboration Practices and their Impact on Writing Style, Quality, and Quantity.

88. Saijing Zheng, Mary Beth Rosson, Patrick C. Shih, and John M. Carroll. 2015. Understanding student motivation, behaviors and perceptions in MOOCs. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing* (pp. 1882-1895). ACM.

APPENDIX A: Interview Questions in Study I

Question 0: Awareness & Experience

Have you written together with others before? Would you like to tell me a recent experience?

Question 1: Genre, Ways, Roles

What types of document did you write with others? What are all the different ways that you write collaboratively: have you written synchronize or a-synchronize? With whom? What roles do you play? Outside your own organization? Edit others?

Question 2: Tools & Features

What tools or software did you use in collaborative writing? How did you use them? Specific features did you use to support your collaboration? Mobile?

Question 3: The revision history/tracking changes feature

(If revision history/ tracking changes features were mentioned) Do you think it is useful, or not?

How can it be improved?

(if any feature was mentioned) Do you want to have a better view of the revision history/tracking changes?

Would it be useful if users have the DocuViz view (showing the visualization to the participant)?

Question 4: Reasons

Why did you write together with others, instead of writing alone?

Question 5: Perception

Do you like it or not, and why? And how about the output quality?

APPENDIX B: Statistical Analyses Result Tables for Study III

Here we report on the **Hierarchical Linear Models** that were used in the analysis, the summary of which is in Figure 5.15. This analysis used IBM SPSS Statistics version 23 (Field 2009). The data structure is a three-level hierarchical, where the level 3 is ***year***, level 2 is ***assignment type***, and level 1 variable is a repeated measure (***team***). HLM can accommodate non-independence of observations, missing data, and discrepant group sample sizes. We ran various tests to examine the assumptions. The Shapiro-Wilk tests suggest that data is normally distributed at each level. We used Levene's Test of Equality to examine the homoscedasticiy of level-1 residual variance, which is constant. And finally we used Pearson Correlation to determine that my independent variables are not co-varying.

We ran analyses on each of the independent variables that may have an effect on each of the three dependent variables respectively, always controlling for

- ***year,***
- ***assignment type,***
- and ***team*** as a repeated measure.

The four dependent variables included:

- ***quality*** of the final document,
- the ***elapsed time*** from the start to the end of a document,
- how ***close to the assignment deadline*** when they finished,
- and ***document length***.

As recommended by many researchers, we built up multilevel models starting with a "basic" model and then adding in variables, so that we can compare the fit of the models

(Raudenbush and Bryk 2002). To do that, we subtracted the log-likelihood of the new model from the value for the old model (Field 2009).

$$\chi^2_{Change} = (-2Log\ Likelihood_{old}) - (-2Log\ Likelihood_{new})$$

$$df_{Change} = Number\ of\ Parameters_{old} - \ Number\ of\ Parameters_{new}$$

A four stage hierarchical multiple regression was conducted with one of the four dependent variables (e.g., **Quality**). **Team Id** was entered at stage one of the regression to control for group differences. The **Assignment Type** and **Year** variables were entered at stage two. Then we enter one of the independent variables (e.g., **Balance Participation**) at stage three. Once the model at stage three is significant better than the model at stage two, we used the best-fit model at stage three as a base model, and enter another independent variable (e.g., **Leadership**) at stage four to see whether it can improve the model significantly.

For example, in order to compute the ultimate model predicting dependent variable **Quality,** we selected the best-fit model (based on lowest AIC score) at stage three from the three models (with **Document Length, Balance Participation,** and **Existence of Leadership** as independent variables respectively) presented in Table B.1. Then we used the model with **Leadership** and all the control variables as the basic model**,** added one of the other independent variables into the model at stage four. Afterward, we can compare the χ^2_{Change} between the basic model and the new model. If the change is bigger than the critical values for the chi-square statistic with 1 degree of freedom, 3.84 (p<.05) and 6.63 (p<.01), this change is highly significant and the model is significantly improved. Therefore, we get the model with **Leadership** and **Balance Participation** as independent variables and **Quality** as the dependent variable, as presented in Table B.2.

Table B.1. Three Models with Document Length, Balance Participation, and the Existence of Leadership as Independent Variables Respectively. Dependent Variable is Quality.

Parameter	Beta	S.E.	p-value	Beta	S.E.	p-value	Beta	S.E.	p-value
Intercept	67.60	4.15	<.01	76.53	3.05	<.01	67.63	3.54	<.01
Year 2011	3.12	3.57	0.39	2.50	3.73	0.51	3.96	3.46	0.26
Year 2012	6.05	2.95	0.05	4.71	3.12	0.14	4.37	2.80	0.13
Assignment 1	12.65	3.56	<.01	13.08	3.29	<.01	9.57	3.29	<.01
Assignment 2	8.60	3.68	<.05	11.03	3.23	<.01	9.00	3.46	<.05
Assignment 3	11.73	3.51	<.01	13.69	3.17	<.01	12.05	3.36	<.01
Longer document	**0.00096**	0.00048	<.05	-	-	-	-	-	-
Balance	-	-	-	**44.38**	15.64	<.01	-		
Leadership	-	-	-				**8.70**	3.11	<.01
AIC equivalent	757.58			753.88			754.00		

Table B.2. Ultimate Model predicting Quality, with Balance Participation and Existence of Leadership as Two Independent Variables, Controlling for Year, Assignment Types, and Team.

Parameter	Beta	S.E.	p-value
Intercept	69.42	3.42	<.01
Year 2001	2.42	3.40	
Year 2012	4.33	2.79	
Assignment 1	12.57	3.19	<.01
Assignment 2	8.17	3.24	<.01
Assignment 3	11.60	3.14	<.01
Balance	**50.36**	15.15	<.01
Leadership	**9.87**	2.97	<.01
AIC equivalent	745.71		

Table B.3. Eight Models, Each Model Has One Individual Independent Variable. The Dependent Variable is Earlier Finish

Parameter	Beta	S.E.	p-value	Beta	S.E.	p-value	Beta	S.E.	p-value
Intercept	-463.91	580.95	0.43	275.93	288.40	0.23	14.31	339.63	0.97
Year 2011	219.78	249.96	0.33	350.73	233.17	0.14	241.91	249.95	0.34
Year 2012	961.90	195.56	<.01	1008.96	180.81	<.01	975.06	199.69	<.01
Assignment 1	146.68	246.38	0.55	343.28	244.34	0.16	270.99	243.35	0.27
Assignment 2	-383.31	255.66	0.14	-294.82	246.39	0.23	-189.88	249.79	0.45
Assignment 3	-250.54	249.08	0.32	-277.35	244.14	0.26	-195.04	243.15	0.43
More Authors	**303.33**	144.35	<.05	-	-	-	-	-	-
Total Simultaneous Work	-	-	-	**10.57**	2.97	<.01	-	-	-
Edit Others	-	-	-	-	-	-	**685.20**	277.93	<.05
AIC equivalent	1579.27			1572.38			1577.47		

Parameter	Beta	S.E.	p-value	Beta	S.E.	p-value	Beta	S.E.	p-value
Intercept	1162.89	251.95	<.01	1044.30	228.67	<.01	794.37	216.43	<.01
Year 2001	298.15	237.60	0.22	484.42	240.55	<.05	345.15	248.55	0.17
Year 2012	984.55	186.34	<.01	827.99	185.74	<.01	973.30	195.96	<.01
Assignment 1	231.65	240.98	0.34	170.08	242.09	0.48	142.10	247.04	0.57
Assignment 2	-101.07	253.32	0.69	-46.63	258.44	0.86	-386.35	256.70	0.14
Assignment 3	-69.62	246.46	0.78	-4.42	251.35	0.99	-228.21	248.77	0.36
Leadership	**-717.32**	222.20	<.01	-	-	-			
Number of Solo Author Sessions	-	-	-	**-66.77**	19.87	<.01			
Number of Slackers	-	-	-	-	-	-	**-317.11**	156.47	<.05
AIC equivalent	1555.96			1573.56			1579.57		

Parameter	Beta	S.E.	p-value	Beta	S.E.	p-value
Intercept	231.19	218.16	0.29	-522.22	304.60	0.29
Year 2001	272.69	226.09	0.23	342.10	220.66	0.12
Year 2012	893.18	175.82	<.01	943.16	170.89	<.01
Assignment 1	406.23	238.73	0.09	292.83	228.81	0.20
Assignment 2	-175.01	240.77	0.47	-244.23	233.65	0.30
Assignment 3	-250.30	236.42	0.29	-253.60	230.62	0.29
Longest Simultaneous Session	**19.46**	4.44	<.01	-	-	-
Maximum Authors in a Simultaneous Session	-	-	-	**422.86**	84.57	<.01
AIC equivalent	1566.76			1562.02		

Table B.4. Three Models, Each Has One Individual Independent Variable. The Dependent Variable is Elapsed Time.

Parameter	Beta	S.E.	p-value	Beta	S.E.	p-value	Beta	S.E.	p-value
Intercept	-2221.86	2603.43	0.40	1918.18	1143.59	0.10	1510.01	1005.18	0.14
Year 2001	-967.95	1168.23	0.41	-612.39	1144.51	0.60	-1627.57	1119.37	0.15
Year 2012	-307.45	963.07	0.75	-439.47	945.22	0.65	302.88	914.96	0.74
Assignment 1	-1830.12	1027.83	0.08	-1801.09	1036.18	0.09	-1511.92	981.55	0.13
Assignment 2	1582.78	1070.89	0.14	1476.33	1092.20	0.18	856.23	1050.70	0.42
Assignment 3	5655.62	1035.93	<.01	5435.47	1059.66	<.01	4863.85	1020.49	<.01
Number of Authors	**1499.51**		<.01						
Leadership	-	-	-	**2245.47**	996.15	<.05			
Number of Solo Author Sessions	-	-	-	-	-	-	**349.05**	87.46	<.01
AIC equivalent	1861.69			1844.01			1852.21		

Table B.5. The Only Model with Number of Authors as The Independent Variable Leading to Length of Document as The Dependent Variable.

Parameter	Beta	S.E.	p-value
Intercept	5426.43	704.30	<.01
Year 2001	827.05	801.85	0.31
Year 2012	-1449.57	685.12	<.05
Assignment 1	-2242.03	672.79	<.01
Assignment 2	3043.56	674.32	<.01
Assignment 3	1975.47	659.73	<.01
Number of Authors	**28.57**	13.85	<.05
AIC equivalent	1763.38		

APPENDIX C: Rubrics for Assessing Document Quality for Study III

The data corpus in Study III covers four types of documents:

- **Communication Covenant,**
- **Business Case,**
- **Scope Statement and Work Breakdown Structure,**
- **and Cost, Quality, and Risk Management.**

These tasks are common writing scenarios in a project management process in the field of information technology (Schwalbe 2015). The descriptions and rubrics for each of the writing assignment is attached below:

A **Communication Covenant** is an agreement every member of a team makes about communicating (Schwalbe 2015):

1. promising to communicate regularly (even when the news is bad),

2. promising to answer your email how many times a day,

3. agreeing that you will be using Google Docs for file management,

4. specifying when and where your meetings are (1-2 times a week),

5. promising to notify team mates if you can't make a meeting,

6. agreeing to reasonable punishments if a team mate is late or misses without notifying everyone,

7. promising to volunteer to do things and to do them well and on time.

The document should also include a table of preferred email addresses and cell phone numbers, a title of the file, and the team name. The quality is evaluated based on:

10 points for each of 7 items in the covenant. And 30 points for each of 3 items for contact (name, email, phone).

The second assignment is to use the **Business Case** example in the textbook (Schwalbe 2015) to create a well-formatted, detailed business case for students' projects.

The **Business Case** document should cover

1. Introduction and Background

2. Business Objective

3. Current situation or problem or opportunity

4. Critical Assumption and Constraints

5. Analysis of Options and Recommendations

6. Preliminary Project Requirements

7. Budget Estimate and Financial Analysis

8. Schedule Estimate

9. Potential Risks

10. Exhibits (if any)

The rubric for this document writing is "up to 10 points for each of the 10 sections with the following breakdown". Some referencing points are: "5 points if it just exists, 8 points if it is ok, and 10 points if it is great."

The third task is "following the textbook example as a guide, create a create a well-formatted **Scope Statement and Work Breakdown Structure** to at least 3 levels." The **Scope Statement** should cover:

1. Project Justification

2. Project Characteristics and Requirements

3. Project Management-Related Deliverables

4. Product-Related Deliverables

5. Project Success Criteria

And the **Work Breakdown Structure** should cover the first level:

1. Initiating

2. Planning

3. Executing

4. Monitoring and Control

5. Closing

We used the rubric for this assignment as “up to 20 points for each of the 5 sections with the following breakdown: 10 if it just exists; 15 if it is ok; and 20 if it is great.”

The last assignment is **Cost, Quality, and Risk Management** document. The description is:

“From your Work Breakdown Structure and Gantt Chart, estimate how much this project would cost if you were employed. State in 1-2 paragraphs, how would you control for quality? What measurements would you take in order to make a case that this project was of high quality? List the risks involved in doing this project at each step. Accompany each with a statement about how you would mitigate risk.”

The rubric we used for this assignment is:

“10 points for cost summary/explanation and 10 points for a figure/chart of costs. Up to 40 points for the quality section with the following breakdown:

- 20 if it just exists

- 30 if it is ok

- 40 if it is great

Up to 40 points for the risk section with the following breakdown:

- 20 if it just exists

- 30 if it is ok

- 40 if it is great”