Analyzing Collaborative Note-taking Behaviors and Their Relationship with Student Learning through the Collaborative Encoding-Storage Paradigm

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Abstract

The present study (n=357) investigates the effects of collaborative note-taking behaviors on learning performance and the quality of the notes students produce. To more clearly conceptualize note-taking behaviors and the notes that are produced as a result, the present study introduces the collaborative encoding-storage paradigm, in which collaborative writing behaviors are viewed as types of collaborative encoding and the completeness or comprehensiveness of the notes is viewed as a measure of storage. The following collaborative note-taking behaviors were analyzed: volume of words written, edits of others' writing, frequency of writing sessions, and turn-taking. The collaborative storage of the group was evaluated by measuring the completeness of the notes the groups produced. Given the complex nature of the data, with individuals nested within groups, we used a two-level correlation analysis to identify correlations among all variables. Between-person analysis suggested that volume of words, edits of others, and turn-taking behaviors were all positively associated with learning performance. Between-groups analysis suggested that volume of words and frequency of writing sessions were associated with the completeness of group notes. Overall, the results demonstrate meaningful relationships between the frequency of collaborative encoding behaviors and learning outcomes. These results show there are differences in the impact that encoding and storage behaviors have on learner performance, suggesting the effectiveness of collaboration varies depending on variables investigated as well as the level of analysis.

Keywords: Note-taking; Collaboration; Encoding-storage paradigm; CSCL; Interaction

Introduction

Taking notes has long been acknowledged as an effective practice for increasing the depth of information processing (Bretzing & Kulhavy, 1979) and the recall of lecture content (Aiken et al., 1975; Tindale et al., 2007; Oefinger & Peverly, 2020). Note-taking has typically been viewed as an individual endeavor by a learner to record information when listening to a lecture or reading a passage. This conceptualization of note-taking is often framed within the theoretical perspective of cognitivism, which seeks to explain the processes learners implement when acquiring knowledge and the resulting effects on existing mental structures known as schema (Ertmer & Newby, 1993). Within this larger theoretical framework, the encoding-storage paradigm provides a more specific conceptualization of the processes and product of note-taking (Di Vesta & Gray, 1972). When note-taking is viewed within this paradigm, encoding refers to the act of writing down content in an attempt by the note-taker to imprint the information into the long-term memory (Peper & Mayer, 1978), and storage refers to the creation of a written record of relevant information (Di Vesta & Gray, 1972) so that one need not attempt to recall everything that was said or covered in a course (Mueller & Oppenheimer, 2014). While encoding directly benefits the learner by facilitating the movement of information from the working memory to the long-term memory, encoding indirectly benefits the learner through the resulting storage, i.e., the written notes that can be reviewed later (Di Vesta & Gray, 1972). Such storage can usefully supplement the imperfect long-term memory, particularly when reviewing notes for an exam (Kiewra, 1989).

While most of research on note-taking examines contexts where notes are taken by a single learner, recent advances in cloud computing enable multiple students to take notes together in a shared online document. Research on online collaborative note-taking is still in its infancy, although a number of studies have shown benefits to this practice, including higher grades (Orndorff, 2015) and improved recall (Fanguy et al., 2021). Although the cognitivist viewpoint that underpins the encoding-storage paradigm offers a useful explanation of the mechanisms by which individuals process and store information when writing notes collaboratively, none of the studies on online collaborative note-taking have examined the effects of such learning activities through the encoding-storage paradigm. This may be because the encoding-storage paradigm is deemed insufficient to account for the complex relationships and social interactions among group members in constructing notes.

Instead, research has tended to treat online collaborative note-taking as a form of collaborative writing, viewing it within the sociological learning theory of social constructivism, which states that individuals learn through interactions within groups and through the collaborative construction of knowledge artifacts (Kim, 2001). Within this larger theoretical framework, the pedagogical perspective of computer-supported collaborative learning (CSCL) is often used to conceptualize online collaborative note-taking. Within CSCL, learning is understood as a process of interaction among learners using a computer or the Internet (Stahl et al., 2006). CSCL research posits that students who collaborate using technology can benefit by 1) using technology to engage in collaborative processes that lead them to deeper, more meaningful comprehension of the topics being studied (Stahl et al., 2006) and 2) co-constructing new knowledge through this interaction, often in the form of a digital artifact as the group product (Stahl et al., 2014). While these aspects of collaborative learning provide a useful way to conceptualize the complex interactions and relationships among the behaviors of the group members and the notes they create, they do not provide insight into the underlying mechanisms by which concepts represented in the notes enter the long-term memories of the individual members, which is a key contribution of the encoding-storage paradigm and a key issue with respect to note-taking.

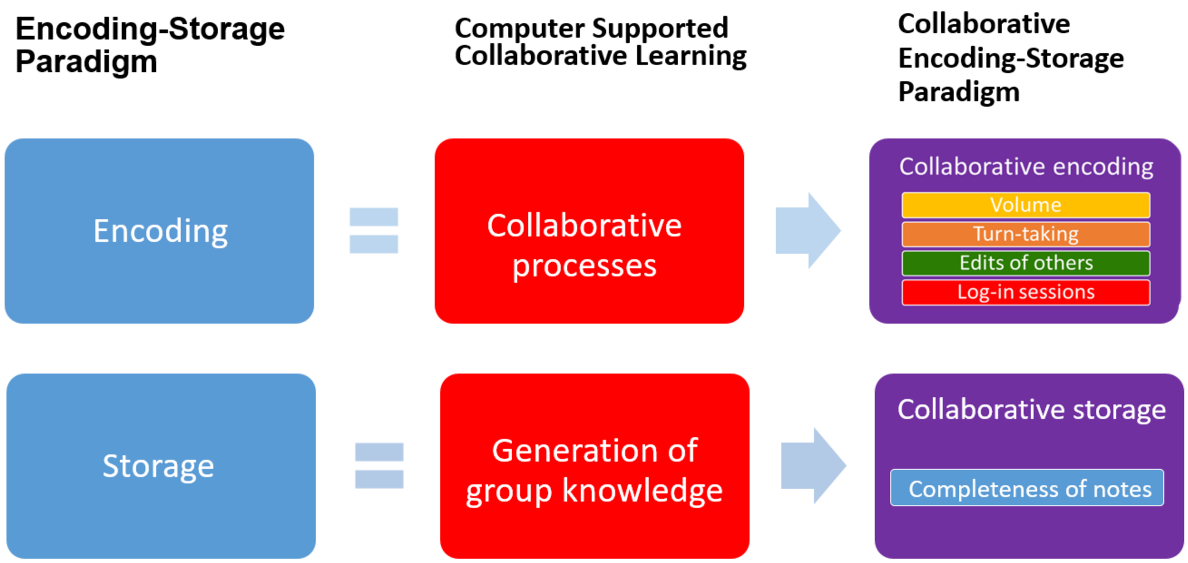
The Present Study

While both the encoding-storage paradigm and the CSCL perspective of online collaborative note-taking help to explain the benefits of collaborative note-taking, each has an important limitation. The encoding-storage paradigm is the predominant theoretical perspective on note-taking research because it provides an explanation of how note-taking improves recall of course contents; however, it is unable to account for the complex ways in which group members collaborate in creating and learning from notes. On the other hand, the CSCL perspective provides a useful way to analyze collaborative behaviors students engage in, and the digital artifact they produce to examine how online collaborative note-taking can benefit student learning outcomes; however, it lacks an explanation of the mechanisms by which students are able to improve their recall of course contents.

Therefore, the present study considers both the CSCL approach as well as the encoding storage paradigm when looking into collaborative note-taking, as shown in Figure 1.

Figure 1

Viewing the Driving Forces of Social Constructivism through the Lens of the Encoding/Storage Paradigm



A limitation of the extant research on collaborative note-taking is that the two aforementioned drivers of the benefits of collaborative learning (i.e., individual collaborative behaviors and creation of group knowledge) are often looked at together so that it is difficult to understand them as separate aspects of learner collaboration. The present study seeks to separate the two previously mentioned aspects of collaborative learning in the context of note-taking (herein, collaborative encoding and collaborative storage) in order to better understand the effects of each on learning performance.

In this study, using the collaborative encoding-storage paradigm, storage will represent the creation of knowledge by the group and will be measured by evaluating the completeness of the notes that the group produces, i.e., how many concepts from the lecture are represented in the notes. Completeness is a conventional measure of storage in note-taking studies and is generally viewed at the level of the individual, i.e., the number of concepts from a lecture that a single learner writes down in the notes; however, this study will view storage as a group-level measure of the total amount of information recorded in the notes that the group members create and share. In the encoding-storage paradigm, encoding is also viewed at the level of the individual, and prior measures of encoding generally analyze how much an individual student writes and how much content can be recalled on a subsequent exam (Di Vesta & Gray, 1972; Kiewra, 1989; Mueller & Oppenheimer, 2014). However, when learners take notes collaboratively, there are many more writing (and therefore encoding) behaviors that they can engage in because group members may respond to and interact with one another's contributions. Therefore, we view productive aspects of contribution to the collaborative notes as "collaborative encoding" that can be viewed at both the individual and group levels. Specifically, the following collaborative writing behaviors will be considered as encoding variables: the amount of writing students contribute, the number of turns they take during the writing process, the number of edits they make to the writing of other group members, and the number of writing sessions the learners engage in.

Literature Review

The Relationship between Collaborative Encoding Behaviors and Individual Learning Performance

According to the encoding-storage paradigm the process of listening and writing down notes enables learners to encode concepts from a lecture into their long-term memories (Di Vesta & Gray, 1979). The words written are often seen as the primary encoding behavior that students can engage with when they take notes. This notion is supported by recent research showing that active note-taking leads to improved performance on tests and quizzes (Oefinger & Peverly, 2020). Studies on note-taking have consistently shown a strong positive correlation between students' note-taking volume (i.e., the number of words written down when taking notes) and their subsequent learning outcomes (Haynes et al., 2015; Kiewra, 1987). More specifically, Mueller and Oppenheimer (2014) found that the volume of students' notes strongly and positively correlates with students' ability to recall the information from lectures.

While volume is the most commonly cited encoding behavior, there are other potential encoding behaviors that students may engage in, particularly when they are collaborating. In the context of collaborative note-taking, consideration must be given to writing behaviors that involve learners interacting, directly or indirectly, with one another's work. These writing behaviors might be considered as types of collaborative encoding behaviors that may affect students' learning performance.

A key learning benefit of collaboration is that it increases learners' engagement with the complex and various opinions and interpretations that are possible with a given topic of study (Trentin, 2009). In the context of collaborative note-taking, this means that students can deepen their understanding of course content by interacting with other members' understandings and interpretations of course concepts as represented in the collaborative notes. The degree that learners interleave their responses with others' texts can serve as a useful measure of the interactivity of the group's collaborative process (McKinlay et al., 1993). These turns that learners take, where they interleave text with one another, help give a picture of the shape or nature of the encoding that is occurring during collaborative note-taking.

Another collaborative behavior that may be a type of encoding is the edits students make to the writing of others, a process that has been shown to increase students' understanding of the content they are writing about (Blau & Caspi, 2009). In one study, increased edits of others were found to positively correlate with students' ability to clearly express their ideas and to use evidence to support claims within a collaborative document (Yim et al., 2017). In the context of note-taking, such interactions provide learners with increased opportunities to engage with the contents written in the notes and to encode their contents collaboratively with group members; and from the perspective of CSCL, this allows the construction of meaning (Stahl et al., 2014.)

A further encoding behavior that is relevant to both collaborative and individual note-taking is the frequency of writing sessions that a learner engages in. Sessions can be viewed as a form of encoding in that the learners returning to the page is necessary for them to produce volume. Studies have shown that, in general, students who log in and interact more often in online learning environments perform better than those who do not (Jo et al., 2015) and that increasing total sessions during collaborative activities improves individual performance (Manathunga & Hernandez-Leo, 2016). To explain how writing sessions can affect learning performance in collaborative learning settings, a higher frequency of writing sessions among members of a group can signify a more actively sustained approach to collaboration over a period of time, whereby students' written contribution may garner feedback and responses from fellow group members (Kessler & Bikowski, 2010). CSCL research has shown that written collaboration develops and deepens if it is actively sustained over time, enabling students to benefit from exposure to varying viewpoints and perspectives of their groupmates (Kessler & Bikowski, 2010).

The Relationship between Collaborative Encoding Behaviors and the Storage Quality of the Notes

The amount of volume that students produce when collaborating and the degree to which they cover the concepts in the lesson are manifestations of the degree of knowledge generated within the notes as well as the student's degree of collaboration when creating the notes (Adeniran et al., 2019; Doberstein et al., 2019; Ruhl & Suritsky, 1995). As the notes themselves represent the storage aspect of the encoding storage paradigm, it is important to examine how the collaborative encoding variables previously mentioned interact with them. Research has shown that more frequent logins by group members to interact with one another during collaboration leads to the creation of higher quality discourse among them (Kent & Cukurova, 2020). Furthermore, turn-taking seems to have similarly beneficial effects on groups' ability to produce higher-quality documents (Erkens et al., 2005). Learners may also choose to edit notes contributed by other members in order to provide feedback, correct misinformation, or to add content that was omitted (Landay, 1999; Singh et al., 2004), thereby improving the quality of the document.

The Relationship between the Quality of the Notes and Individual Learning Performance

While some research suggests that increasing total student productivity in collaboration (volume) is the path to learning gains, other researchers suggest that it is the comprehensiveness of the collaborative artifact created that leads to learning within a group context (DeChurch & Mesmer-Magnus, 2010). In the context of the present study, the question is then, what effect does the quality of notes (storage) have on student performance? Research has shown that items that are contained within a set of notes are more likely to be recalled (Einstein et al., 1985). Furthermore, students with complete sets of notes that cover the materials of interest to the class outperform those who do not have a complete set of notes (Raver & Maydosz, 2010). Therefore, the storage element of the storage encoding paradigm suggests that those groups of learners with more complete notes should outperform groups with less complete notes.

Research Questions

The present study looks at groups taking collaborative notes in an online scientific writing class and seeks to understand the relationships between the processes of collaboration and learning and knowledge creation (i) among individuals and (ii) among groups. Based on this framework, the present study has five main research questions with constituent hypotheses.

RQ1. For students, what is the relationship between collaborative behaviors and learning?

H1: When students engage in more collaborative encoding behaviors, they perform better on tests.

H1a: When students *produce a higher volume of words*, they perform better on tests.

H1b: When students *have more frequent writing sessions*, they perform better on tests.

H1c: When students *edit more of their group members' writing*, they perform better on tests.

H1d: When students *take more turns*, they perform better on tests.

RQ2. For groups, what is the relationship between collaborative behaviors and learning?

H2: When groups engage in more collaborative encoding behaviors, they perform better on tests.

H2a: When groups *produce a higher volume of words*, they perform better on tests.

H2b: When groups *have more frequent writing sessions*, they perform better on tests.

H2c: When groups *edit more of their group members' writing*, they perform better on tests.

H2d: When groups *take more turns*, they perform better on tests.

RQ3. For groups, what is the relationship between collaborative behaviors and group note completeness?

H3: When groups engage in more collaborative encoding behaviors, the completeness of their group notes improves.

H3a: When groups *produce a higher volume of words*, the completeness of their group notes improves.

H3b: When groups *have more frequent writing sessions*, the completeness of their group notes improves.

H3c: When groups *edit more of their group members' writing*, the completeness of their group notes improves.

H3d: When groups *take more turns*, the completeness of their group notes improves.

RQ4. For groups, what is the relationship between group completeness and test scores?

H5. When groups have *higher levels of completeness*, they perform better on tests.

Methodology

Learning Context

The present study examines the experiences of 357 students engaged in collaborative online note-taking in 17 different classes of a graduate-level scientific writing course at a Korean university. Each of the 357 students was randomly assigned into 81 groups making the average group size 4.41 students (5 groups of 3 students, 38 groups of 4 students, and 38 groups of 5 students). The demographic variables for the participants can be seen in Table 1. All participants were majoring in STEM (science, technology, engineering, and math).

Table 1

The Demographic Variables for the Participants (N = 357)

Gender	**Male**	**Female**		
	261	96		
Nationality	**Korean**	**Foreign**		
	293	64		
Degree	**Masters**	**Ph.D.**		
	268	89		
Age	**Min**	**Max**	**Avg**	**SD**
	20	55	26.97	4.55

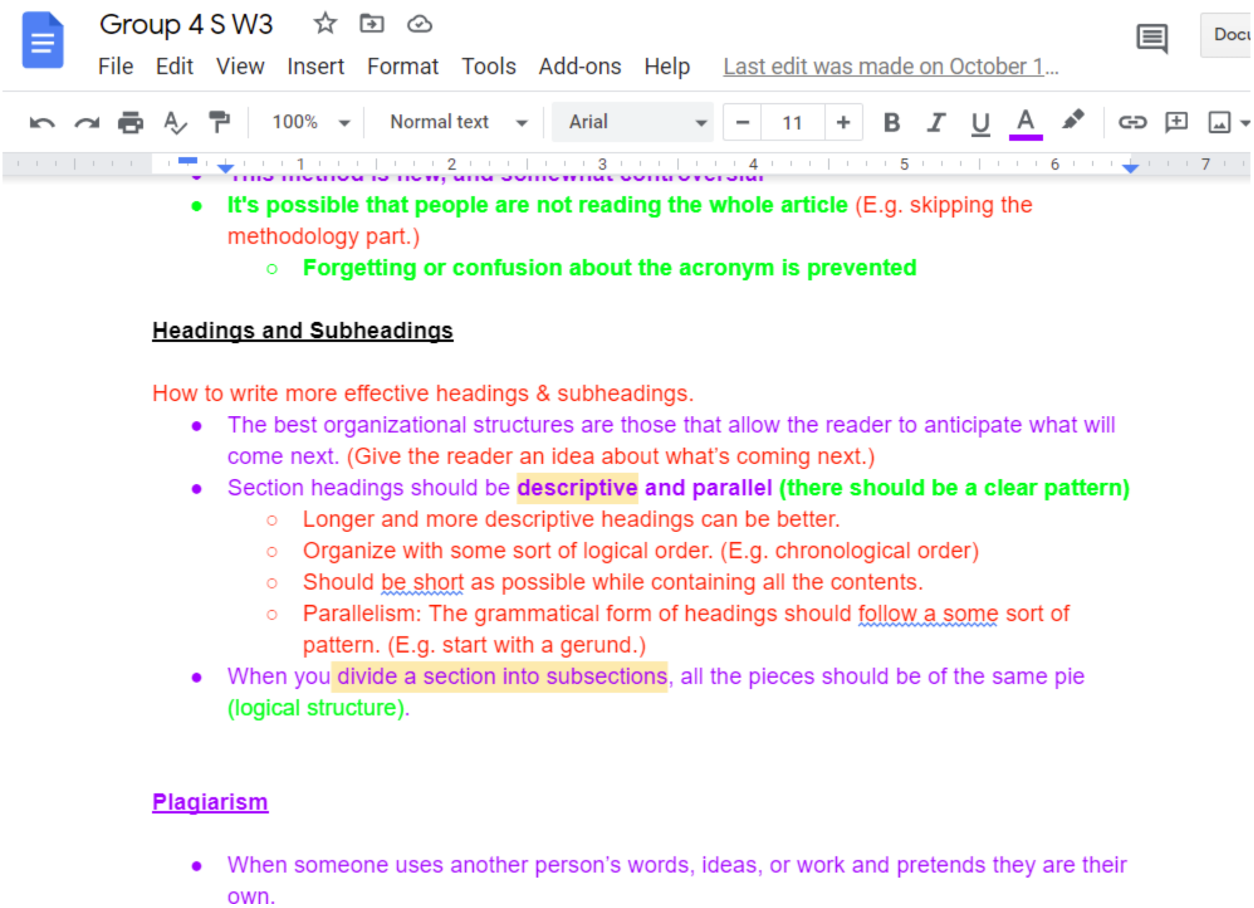
The purpose of the scientific writing course examined in this study is to teach graduate students how to publish their research in a peer-reviewed journal. All lecture contents for the class were presented in the form of online videos available for streaming on the university learning management system. There were a total of 10 instructional weeks, with each instructional week including between 4 and 8 online lecture videos, totaling 56 videos for the semester. The videos ranged in duration from 4:56 to 24:50, with an average duration of nearly 12 minutes. During a given instructional week, students were also to take collaborative notes in the same set of small groups of 3-5 students. Each course section comprised 8-25 students.

The collaborative notes for a given instructional week were taken using a designated Google Document created and monitored by the course instructor. Therefore, each group collaborated on a total of 10 note-taking documents corresponding to the 10 instructional weeks of the course. Because the lecture videos were provided on the course learning management system, students could rewatch the videos as often as they wished and could pause, fast-forward, and rewind while taking notes. At the end of each instructional week, students were required to take an online test on the concepts covered in the instructional videos for that week, as tests are acknowledged to provide a good measure for students' understanding of course concepts (Herold et al., 2012; Kamuche, 2011). Students were encouraged to refer to the collaborative notes they had taken on video lectures for a given instructional week while taking the related test. Test questions were designed to cover lecture topics including but not limited to academic writing conventions, ethics of scientific communication, and navigating the process of submitting a completed manuscript to an academic journal. The course instructor deemed such topics to be appropriate for assessment with tests.

The data used in the present study was then extracted from the collaborative notes that groups produced to analyze how groups approached collaborative note-taking: volume, completeness, and writing sessions (see Wang et al., 2015 for open-source software). A screen capture of a set of collaborative notes created during the pilot study for this project can be seen in Figure 2.

Figure 2

Sample Collaborative Notes Taken Online Using Google Docs



Measures

Completeness. Completeness was used as a measure of the storage quality of the notes that student groups produced. After the conclusion of the semester, the quality of the collaborative notes was measured in the form of *Completeness*, or the total amount of meaningful concepts from the video instruction that were represented. This was done using a rubric based on instructor-generated summaries of the information contained in the online lecture videos. The informational units contained in each lecture for a given week were represented in sequence, and the graduate teaching assistant for the course evaluated each set of collaborative notes as having "included" or "not included" each informational unit from the lecture. The complete rubric for completeness can be seen in the file labeled "completeness rubric" at https://osf.io/5t8vw/?view_only=3514f73b64b1497a9948e1a544d565bc

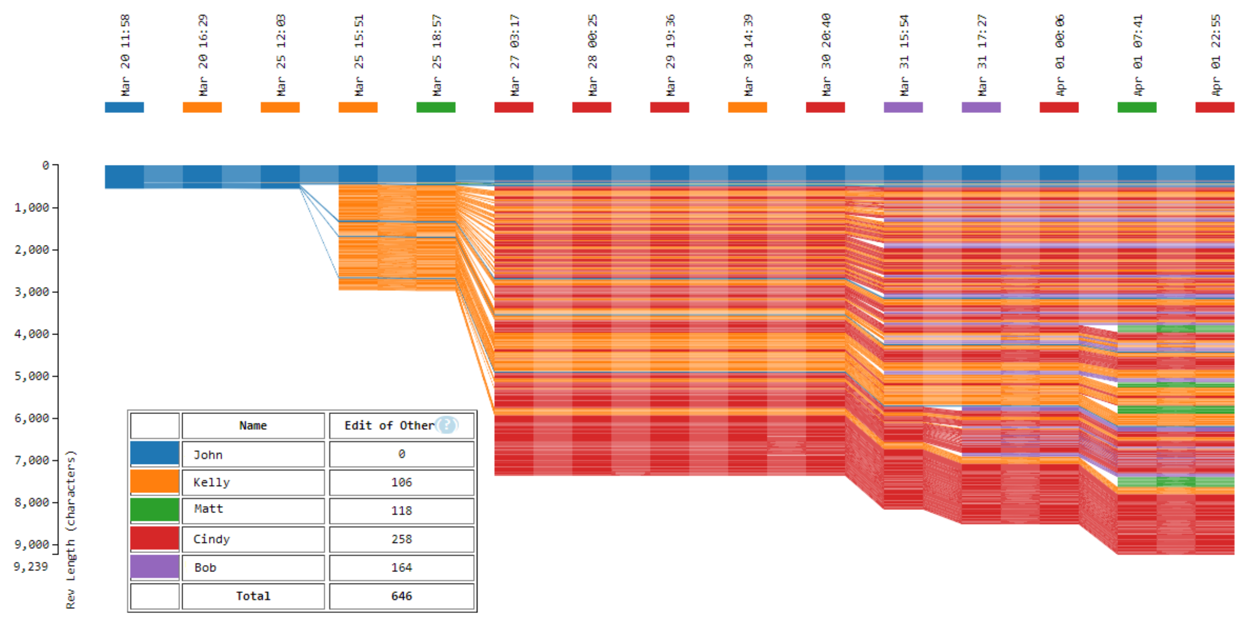
Volume. The total number of words written by all group members in a given set of notes after editing served as the variable for *Volume*, a measure of encoding. After a given instructional week, the volume of a given set of notes was assessed by using the "word count" feature of the Google Docs platform. The total word count of the entire note-taking document was obtained from the word count feature of Google Docs and with additional programming written in the Python language (URL removed for blinding). The volume was counted for each constituent member of the group to provide a between-persons variable, and the variable was also aggregated to create a between-groups variable.

Writing Sessions. The total number of times that group members logged into a set of notes to contribute writing to a given set of collaborative notes provided the *Writing Sessions* variable, a measure of encoding. In the present study, a Google Chrome add-on for Google Docs called DocuViz was used to extract the number of sessions in which each member logged into the collaborative document to contribute notes each week. The number of sessions was counted for each constituent member of the group to provide a between-persons variable, and the variable was also aggregated to create a between-groups variable. At the top of Figure 2, the writing sessions of each student in a group are shown as colored boxes with session dates and times above them.

Edits of Others. The *Edits of Others* variable was used to measure to what extent members of a group actively revised writing contributed by their fellow group members. This encoding variable was operationalized by calculating the total number of characters that were inserted and/or deleted by constituent group members. The DocuViz add-on was used to calculate the number of characters each member edited of the writing of his/her groupmates, as shown below in Figure 3. The number of characters edited by each constituent member of the group was tallied to provide a between-persons variable, and the variable was also aggregated to create a between-groups variable.

Figure 3

DocuViz Visualization of Student Notes



Turn-Taking. The *Turn-taking* variable was used to measure the degree of interactivity among group members in taking collaborative note-taking. A *Turn* was defined as an unbroken string of text contributed by a single user for each week. Therefore, a turn was counted each time the author changed with a given note-taking document, and the number of turns within a document served as the *Turn-Taking* variable, a measure of encoding. More frequent changes in authorship signal higher degrees of interaction among members of a group when creating notes, while less frequent changes in authorship represent lower interaction levels. Turns were automatically counted within Google Documents using a customized computer system called

Collab_Notetaking (URL removed for blinding). The number of turns was counted for each constituent member of the group to provide a between-persons variable, and the variable was also aggregated to create a between-group variable.

Test Scores. There were a total of 10 online multiple-choice tests during the semester, with each corresponding to an instructional week. The tests were used to measure students' ability to recall and understand the content contained in the lecture videos. Each test contained between 8 and 30 multiple-choice questions based on the contents of the video lectures from the corresponding week. The students were allowed one attempt at the tests, which were timed (2 minutes per question), and the students had until 6pm on the Friday of each week. The test questions allowed for more than one answer option to be chosen, with partial credit being awarded when fewer than the total number of correct options were chosen. However, if an incorrect option was chosen, the entire question was marked incorrect, with no credit being awarded; this was done to discourage indiscriminate guessing on questions where the student lacked understanding of the course content. Each of the 10 tests was equally weighted to account for 3% of the student's total group points for the class, so that tests counted for a total of 30% of a student's total score in the course. Cronbach's (1951) alpha coefficients for the test scores for each week were = .68, .62, .60, .69, .81, .64, .78, .58, .65, and .85, respectively, suggesting that the tests are a moderately reliable measurement of each week's instructional focus. Details of each test item and its relationship to the instructional content can be seen here labeled "quiz items and video list" and can be seen here: https://osf.io/5t8vw/?view_only=3514f73b64b1497a9948e1a544d565bc.

Analysis

All analysis was undertaken with the assistance of the MPlus 7.4 program (Muthen & Muthen, 2012). Descriptive statistics for all six variables of interest included estimates of (1) between-persons and (2) between-groups intra-class correlations (ICCs). To test all hypotheses, one two-level null model specifying all possible correlations between the six variables at the (1) between-persons and (2) between-groups was specified. Because group Completeness varied for each group, it was included in the between-group analysis only.

Results

Basic descriptive statistics for each of the four variables of interest in the study are provided in Table 2. Averages are calculated across all ten weeks. For example, each of the 357 students contributed a certain volume of words for week 1. The average individual volume across all weeks is presented in Table 2. However, descriptives for values for Completeness vary slightly. Completeness varied at the group level, so in this case, respective group members were assigned the same value each week.

Table 2

Descriptive Statistics for Measures of Collaborative Note-taking

Variable	*M*	*SD*	Min	Max	Descriptor
Volume[1]	257.75	106.99	54	775	Total words contributed by member per week
Completeness[2]	77.21	54.73	19	252	Total concepts represented by group per week
Writing Sessions[1]	1.84	1.25	0	12	Total sessions by group per week
Test Scores[1]	2.07	0.54	0	3	Mean test score by group per week
Edits of Others[1]	461.08	1140.47	0	2,394	The number of keystrokes students make over another's writing

Turn Taking[1]	7.04	7.47	0	53.75	The number of times the author changed within the document

Note. Descriptive statistics given for all possible values across all weeks (grand means); [1]values in variable vary each week individually; [2]value in variable varies each week by group only.

Additional descriptive statistics, pertaining to variance components for each variable, are presented in Table 3.

Table 3.

Intraclass Correlation Coefficients for Collaborative Note-taking Variables

ICC	**Completeness**	**Test Scores**	**Volume**	**Edit of Other**	**Sessions**	**Turn-Taking**
Between Groups	0.023	0.079	0.044	0.030	0.073	0.401
Between Persons		0.159	0.278	0.153	0.249	0.131

Note. ICC = intra-class correlation.

All other results for Hypotheses 1 to 4 are presented in Tables 4 and 5.

Table 4.
Between Persons Correlation Matrix

Variable	**Test Scores**	**Volume**	**Edits of Others**	**Sessions**	**Turn-Taking**
Test Scores	1				
Volume	**0.075*****	1			
Edits of Others	**0.028***	0.088***	1		
Sessions	0.032	0.087***	0.005	1	

Turn-Taking	**0.047*****	0.143***	0.028*	0.034*	1

Note. **p < .05, **p < .01, ***p < .001*

Table 5.
Between Groups Correlation Matrix

Variable	Completeness	Test Scores	Volume	Edits of Others	Sessions	Turn-taking
Completeness	1					
Test Scores	**0.018****	1				
Volume	**0.023*****	0.007	1			
Edits of Others	0.009	**-0.033***	0.013	1		
Sessions	**0.016***	0.018	0.023	0.000	1	
Turn-Taking	0.021	**0.073***	0.038	-0.016	0.048	1

Note. **p* < .05, ***p* <.01, ****p* < .001.

Results from the correlational analysis suggest the following:

H1a: When students *produce a higher volume of words*, they perform better on tests. Reject null

H1b: When students *have more frequent writing sessions*, they perform better on tests. Accept null

H1c: When students *edit more of their group members' writing*, they perform better on tests. Reject null

H1d: When students *take more turns*, they perform better on tests. Reject null

H2a: When groups *produce a higher volume of words*, they perform better on tests. Accept null

H2b: When groups *have more frequent writing sessions*, they perform better on tests. Accept null

H2c: When groups *edit more of their group members' writing*, they perform better on tests. Accept null (note opposite)

H2d: When groups *take more turns*, they perform better on tests. Reject null

H3a: When groups *produce a higher volume of words*, the completeness of group notes improves. Reject null

H3b: When groups *have more frequent writing sessions*, the completeness of group notes improves. Reject null

H3c: When groups *edit more of their group members' writing*, the completeness of group notes improves. Accept null

H3d: When groups *take more turns*, the completeness of group notes improves. Accept null

H4. When groups have higher levels of completeness, they perform better on tests. Reject null

Results for the between-person analysis suggested that Volume, Edits of Others, and Turn-Taking was associated with improved individual test scores. Results for the between-group analysis suggested that (1) Turn-Taking was associated with improved group test scores and (2) Volume and Sessions were both associated with improved group note-taking quality.

Discussion

The results suggest that the various forms of collaborative encoding are associated with both Test Scores and Completeness. However, these effects varied depending on the variable of interest as well as the level of analysis.

Volume is often seen as the primary measure of encoding as it is the student writing down information from the lecture in an attempt to imprint it into long-term memory and to create a written record of information to review later. Volume is therefore seen as the main pathway through which learners derive benefits from note-taking. However, when looking at volume, the results of the present study are nuanced and difficult to parse when integrating them with the extant literature. Firstly, volume had a statistically significant positive relationship with *Completeness*. However, in the present study, volume only had a statistically significant positive correlation with *Test Scores* at the individual level, while in contrast, when comparing groups, the amount of volume the groups produced had no effect on the group's performance. The results suggest that volume is an important driver of storage quality, which supports prior research showing that a greater volume of contribution when collaborating enables students to generate more knowledge on a given topic (Adeniran et al., 2019; Doberstein et al., 2019). In addition, the positive correlation between volume and individual learning performance falls in line with prior research suggesting that taking a greater volume of notes is strongly and positively correlated with the learning performance of individual students (Haynes et al., 2015), specifically with respect to recall (Mueller & Oppenheimer, 2014; Oefinger & Peverly, 2020).

However, no correlation was found between volume and learning performance at the group level. This means that within a group, learners who wrote more performed better, but groups that generated more text did not perform better than those who generated less. When taking notes, students encode information to their long-term memories by writing down the information they hear during a lecture. However, when taking collaborative notes, each student is only responsible for writing down a portion of the total information from a lecture since other parts of the notes are written by groupmates. In this context, the more notes that a student writes down, the more information he/she is able to encode to memory, which is why volume impacts the learning performance of individual students. At the group level, groups must divide up not only the responsibility of encoding but the benefits as well, so that encoding in the form of writing down notes is not an advantage of collaborative note-taking. Rather, the advantage of collaborative note-taking at the group level is the ability to access and utilize the storage that the group produces, when studying for exams. This effect, demonstrated in the present study, provides some empirical basis for previous research that has suggested that when groups generate more complete notes, this leads to higher levels of understanding (Butson & Thomson, 2014).

While volume is the primary pathway to encoding in the collaborative encoding-storage paradigm, writing sessions can be viewed as the *frequency* of learners' encoding behaviors when constructing collaborative notes. In the present study, the number of writing sessions was found to have a significant positive effect on the quality of the notes the groups produced. However, the number of sessions was not found to have any effect on learning outcomes at the individual or group levels of the analysis. The effects of number of sessions on note quality correspond to prior research that found that more frequent sessions in online learning environments lead to improvements in quality of the learners' interactions and the discourse they are creating (Kent & Cukurova, 2020). The findings that writing sessions did not correlate with learning performance at any level of the analysis supports the findings of a recent study by Chai et al. (2020), who found that more frequent sessions did not improve learning performance in and of themselves unless such sessions entailed a substantial volume of contribution by group members. However, such findings run counter to CSCL instructional approaches which suggest that individuals learn through continued interaction with one another and with the learning content (Kessler & Bikowski, 2010). The findings also contradict prior research that found that increased sessions during online collaboration improves individual learning performance (Jo et al., 2015; Manathunga & Hernandez-Leo, 2016) and that the positive effects of note-taking on learning can be enhanced when students revisit and reflect on their notes and revise them with partners (Luo et al., 2016). The present results indicate that the frequency of encoding affects the quality of collaborative storage but has no effect on learning performance at the individual or group levels.

Within the collaborative encoding-storage paradigm, turn-taking can be viewed as the interactivity of the encoding process groups engage in, i.e., the extent to which group members respond to one another and interact when contributing writing to the collaborative notes. The results of this study show no correlation between the number of turns the groups took and the quality of the storage they produced. However, turn-taking had a significant and positive correlation with learning performance at both the individual and group levels. The fact that turn-taking had no effect on the quality of storage is unexpected and contradicts some of the findings from research on CSCL that suggest that in order for groups to more effectively construct knowledge, members should allow their contributions to garner responses and reactions from fellow collaborators while reflecting on the contributions of others (Kessler & Bikowski, 2010). Although encoding in a turn-based manner had no effect on storage, it had a positive effect on learning performance at the individual and group levels of the analysis, results consistent with studies that found that learners benefit from collaborative note-taking because partners can remind them of forgotten information from the lecture (Landay, 1999). The present results suggest that the value of turn-taking is that it is a successful style of encoding information into the long-term memory but that it has no effect on the co-construction of group knowledge (storage). This finding is surprising since CSCL approaches have long contended that the co-construction of knowledge is a product of the interaction among group members, i.e., the free-flowing exchange of information and responses to one another's contributions (Stahl et al. 2006). The present results indicate that highly interactive processes do not necessarily lead groups to better conclusions or deeper knowledge, but rather that interaction helps individual students and learner groups deepen their understanding of what has been learned. Such findings suggest that when learners work together with the goal of producing a high-quality learning artifact, a cooperative approach to group work is advisable, while if the goal of the group is to improve their learning performance, a more collaborative approach to group work will be better.

Edits of others represent the extent to which the encoding process involves group members changing or making corrections to the contributions of other members. The results show that edits of others had no effect on the quality of the storage groups produced. Edits of others were shown to positively affect learning outcomes at the individual level but were shown to negatively affect the learning outcomes of the group as a whole. In other words, when a learner engages in overt correction or rewriting of the contributions of other members, that form of collaborative encoding is beneficial to the learning of the one making the changes but is harmful to the learning outcomes of the other members of the group. While edits from fellow group members have been shown to raise the quality of student writing, students themselves may perceive the editing of others as harmful to the quality of a collaborative document (Blau & Caspi, 2009). Furthermore, research on large-scale collaborative writing platforms, such as Wikipedia, has shown that edits of others' work can incite conflicts within groups (Birnholtz & Ibara, 2012). In Google Docs, the platform used in the present study, confusion or disruption may arise when a member edits the document without consulting with fellow group members, which can discourage further participation in the writing (Birnholtz & Ibara, 2012; Halfaker et al., 2011). So it is possible that, an individual may derive substantial learning benefits by making edits to the writing of others, but at a group level, this may not be a sound strategy for learning, as group members may begin to perceive the edits made by others to their writing and eventually the document itself as of being lower quality and come to trust and rely on the document less in preparing for exams. Considering the effects of edits of others and turn-taking together, the two forms of encoding that are most related to interaction among group members, the present results indicate that interactivity is an important component of collaborative encoding, but only insofar as such interactions are additive, providing additional new information or suggestions (turn-taking), rather than subtractive, removing or replacing the contributions of others (edits of others).

Conclusion

Advanced online communication and collaboration tools, including the Google Docs platform used in the present study, have enabled and facilitated research attempts to better understand the processes students engage in when taking writing collaboratively online. Nevertheless, the complex nature of learner interactions around the collaborative note-taking activities, shaped by the dynamic interplay of multiple social and individual factors, has neither been thoroughly investigated nor conceptualized. Consequently, collaborative note-taking's pedagogical values and effects on individual learners' learning performance remain largely unknown. This article is an early attempt to develop a comprehensive link between the quality of collaborative note-taking (both its process and outcome) and the quality of individual learning.

To achieve this aim, the study has proposed a new framework, called the collaborative encoding-storage paradigm, that views collaborative behaviors resulting in the creation of written notes as collaborative encoding and views the written record of notes that students produce through these behaviors can be viewed as collaborative storage. The results demonstrate the usefulness of those concepts for conceptualizing and evaluating the effects of students' collaborative online note-taking process and outcome in scientific writing instruction. In particular, it is useful to understand how different aspects of encoding behaviors can meaningfully predict the quality of encoding outcomes—document completeness (storage) and quiz scores (information recall).

The study reveals two important implications regarding collaborative note-taking as an instructional approach: one regarding the way students encode collaborative notes and the other regarding the quality of the storage they produce. The first recommendation is that, in order to increase students' recall of learning content, collaborative note-taking groups should be encouraged to increase the amount of writing that they contribute to notes, but not necessarily the frequency with which they contribute. This is especially true with regard to responding to the written contributions of fellow group members, as additive changes and responses were found to be beneficial to group learning performance, while subtractive revisions, i.e., editing the work of others, was found to reduce group learning performance. The second recommendation is that, in order to produce higher-quality notes, collaborative note-taking groups should be encouraged to engage in a sustained writing process, though this process need not be highly collaborative and interactive. Instead, a cooperative approach to writing the notes will be more fruitful when the instructional goal is to produce a higher-quality knowledge artifact. More specifically, instructors should set up collaborative note-taking environments so that it can be easily monitored, and the instructor can encourage regular sustained contribution.

Despite the conceptual and practical contributions of the present study, it is worthwhile to restate that learner interactions in the knowledge co-creation process are complex and difficult to fully monitor, measure, and evaluate. An important limitation of the present study is that it did not include an analysis of embedded comments made by learners when constructing their notes together, as there were two few such comments to analyze. In addition, it is possible that students engaged in back-channel communications and processes that were important to their collaborative processes, but such communications were impossible to account for in the present study because they are, by nature, private. However, taking the outcome of this study as a starting point, subsequent research may aim to refine the ideas of encoding and storage and enhance their explanatory power for more diverse collaborative note-taking activities across different instructional contexts. As noted in this article, new communication tools not only enable students to work collaboratively at a distance but allows teachers to observe students' learning processes without being physically present. More research looking into different communication tools and unique pedagogical affordances provided by each tool can further facilitate the research effort illustrated in the article.

References

Aiken, E. G., Thomas, G. S., & Shennum, W. A. (1975). Memory for a lecture: Effects of notes, lecture rate, and informational density. *Journal of Educational Psychology, 67*(3), 439. https://doi.org/10.1037/h0076613

Adeniran, A., Masthoff, J., & Beacham, N. (2019, June). Model-based characterization of text discourse content to evaluate online group collaboration. In *International Conference on Artificial Intelligence in Education* (pp. 3-8). Springer, Cham. https://doi.org/10.1007/978-3-030-23207-8_1

Birnholtz, J., & Ibara, S. (2012, February). Tracking changes in collaborative writing: edits, visibility and group maintenance. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work* (pp. 809-818). https://doi.org/10.1145/2145204.2145325

Blau, I., & Caspi, A. (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* (Vol. 12, No. 1, pp. 48-55). Retrieved from: http://telem-pub.openu.ac.il/users/chais/2009/noon/1_1.pdf

Bretzing, B. H., & Kulhavy, R. W. (1979). Notetaking and depth of processing. *Contemporary Educational Psychology, 4*(2), 145-153. https://doi.org/10.1016/0361-476X(79)90069-9

Butson, R., & Thomson, C. (2014). Challenges of effective collaboration in a virtual learning environment among undergraduate students. *Creative Education*, 2014. https://doi.org/10.4236/ce.2014.516162

Chai H., Liu Z., Hu T., Li Q. (2020) A New Conceptual Framework for Measuring Online Listening in Asynchronous Discussion Forums. In: Pinkwart N., Liu S. (eds) Artificial Intelligence Supported Educational Technologies. Advances in Analytics for Learning and Teaching. Springer, Cham. https://doi.org/10.1007/978-3-030-41099-5_4

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297-334. https://doi.org/10.1007/BF02310555

DeChurch, L. A., & Mesmer-Magnus, J. R. (2010). The Cognitive Underpinnings of Effective Teamwork: A Meta-Analysis. *Journal of Applied Psychology, 95*(1), 32–53. https://doi.org/10.1037/a0017328

Di Vesta, F. J., & Gray, S. G. (1972). Listening and note taking. *Journal of Educational Psychology, 63*, 8–14. https://doi.org/10.1037/h0032243.

Doberstein, D., Hecking, T., & Hoppe, H. U. (2019, September). What Can Interaction Sequences Tell Us About Collaboration Quality in Small Learning Groups?. In *International Conference on Web-Based Learning* (pp. 61-71). Springer, Cham. https://doi.org/10.1007/978-3-030-35758-0_6

Einstein, G. O., Morris, J., & Smith, S. (1985). Notetaking, individual differences, and memory for lecture information. *Journal of Educational Psychology, 77*, 522–532. https://doi.org/10.1037/0022-0663.77.5.522

Erkens, G., Jaspers, J., Prangsma, M., & Kanselaar, G. (2005). Coordination processes in computer supported collaborative writing. *Computers in Human Behavior, 21*(3), 463-486. https://doi.org/10.1016/j.chb.2004.10.038

Ertmer, P. A., & Newby, T. J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly, 6*(4), 50-72. https://doi.org/10.1111/j.1937-8327.1993.tb00605.x

Fanguy, M., Baldwin, M., Shmeleva, E., Lee, K., & Costley, J. (2021). How collaboration influences the effect of note-taking on writing performance and recall of contents. *Interactive Learning Environments*, 1-15.

Halfaker, A., Kittur, A., & Riedl, J. (2011). Don't bite the newbies: how reverts affect the quantity and quality of Wikipedia work. In *Proceedings of the 7th International Symposium on Wikis and Open Collaboration* (pp. 163-172). https://doi.org/10.1145/2038558.2038585

Haynes, J. M., McCarley, N. G., & Williams, J. L. (2015). An analysis of notes taken during and after a lecture presentation. *North American Journal of Psychology, 17*(1). Retrieved from https://www.researchgate.net/profile/Joshua_Williams4/publication/272417797_An_Analysis_of_Notes_Taken_During_and_After_a_Lecture_Presentation/links/54e3a2000cf2dbf60693a790.pdf

Herold, M. J., Lynch, T. D., Ramnath, R., & Ramanathan, J. (2012, October). Student and instructor experiences in the inverted classroom. In *2012 Frontiers in Education Conference Proceedings*, 1-6. IEEE. https://doi.org/10.1109/FIE.2012.6462428

Jo, I. H., Yu, T., Lee, H., & Kim, Y. (2015). Relations between student online learning behavior and academic achievement in higher education: A learning analytics approach. In

Emerging issues in smart learning (pp. 275-287). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-44188-6_38

Kamuche, F. U. (2011). The effects of unannounced quizzes on student performance: *Further evidence. College Teaching Methods & Styles Journal (CTMS)*, 3(2), 21-26. https://doi.org/10.19030/ctms.v3i2.5277

Kent, C., & Cukurova, M. (2020). Investigating Collaboration as a Process with Theory-driven Learning Analytics. *Journal of Learning Analytics*, *7*(1), 59–71. https://doi.org/10.18608/jla.2020.71.5

Kessler, G., & Bikowski, D. (2010). Developing collaborative autonomous learning abilities in computer mediated language learning: Attention to meaning among students in wiki space. *Computer Assisted Language Learning, 23*(1), 41-58. https://doi.org/10.1080/09588220903467335

Kiewra, K. A. (1989). A review of note-taking: The encoding-storage paradigm and beyond. *Educational Psychology Review, 1*(2), 147-172. Retrieved from https://link.springer.com/content/pdf/10.1007/BF01326640.pdf

Kiewra, K. A. (1987). Notetaking and review: The research and its implications. *Instructional Science*, 16(3), 233-249. https://link.springer.com/content/pdf/10.1007/BF00120252.pdf

Kim, B. (2001). Social constructivism. *Emerging Perspectives on Learning, Teaching, and Technology, 1*(1), 16. Retrieved from https://cmapspublic2.ihmc.us/rid=1N5PWL1K5-24DX4GM-380D/Kim%20Social%20constructivism.pdf

Landay, J. A. (1999). Using note-taking appliances for student to student collaboration. In *FIE'99 Frontiers in Education. 29th Annual Frontiers in Education Conference. Designing the Future of Science and Engineering Education. Conference Proceedings*

(IEEE Cat. No. 99CH37011 (Vol. 2, pp. 12C4-15). IEEE. https://doi.org/10.1109/FIE.1999.841640

Luo, L., Kiewra, K. A., & Samuelson, L. (2016). Revising lecture notes: how revision, pauses, and partners affect note taking and achievement. *Instructional Science, 44*(1), 45-67. https://doi.org/10.1007/s11251-016-9370-4

Manathunga, K., & Hernández-Leo, D. (2016, September). PyramidApp: scalable method enabling collaboration in the classroom. In *European Conference on Technology Enhanced Learnin*g (pp. 422-427). Springer, Cham. https://doi.org/10.1007/978-3-319-45153-4_37

McKinlay, A., Procter, R., Masting, O., Woodburn, R., & Arnott, J. (1993). A study of turn-taking in a computer-supported group task. *People and Computers*, 373-383. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.50.2025&rep=rep1&type=pdf

Mueller, P. A., & Oppenheimer, D. M. (2014). The pen is mightier than the keyboard: Advantages of longhand over laptop note taking. *Psychological Science, 25*, 1159–1168. https://doi.org/10.1177/0956797614524581

Muthén, L.K. and Muthén, B.O. (1998-2012). Mplus User’s Guide. Seventh Edition. Los Angeles, CA: Muthén & Muthén

Oefinger, L. M., & Peverly, S. T. (2020). The lecture note-taking skills of adolescents with and without learning disabilities. *Journal of Learning Disabilities*, *53*(3), 176-188. https://doi.org/10.1177/0022219419897268

Orndorff, H. N. (2015). Collaborative Note-Taking: The Impact of Cloud Computing on Classroom Performance. *International Journal of Teaching and Learning in Higher Education, 27*(3), 340-351. Retrieved from https://files.eric.ed.gov/fulltext/EJ1093744.pdf

Peper, R. J., & Mayer, R. E. (1978). Note taking as a generative activity. J*ournal of Educational Psychology, 70*(4), 514. https://doi.org/10.1037/0022-0663.70.4.514

Raver, S. A., & Maydosz, A. S. (2010). Impact of the provision and timing of instructor-provided notes on university students' learning. *Active Learning in Higher Education, 11*(3), 189-200. https://doi.org/10.1177/1469787410379682

Ruhl, K. L., & Suritsky, S. (1995). The pause procedure and/or an outline: Effect on immediate free recall and lecture notes taken by college students with learning disabilities. *Learning Disability Quarterly*, *18*(1), 2-11. https://doi.org/10.2307/1511361

Singh, G., Denoue, L., & Das, A. (2004, March). Collaborative note taking. In T*he 2nd IEEE International Workshop on Wireless and Mobile Technologies in Education, 2004. Proceedings*. (pp. 163-167). IEEE. https://doi.org/10.1109/WMTE.2004.1281375

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), Cambridge handbook of the learning sciences (pp. 409-426). Cambridge, UK: Cambridge University Press. http://GerryStahl.net/cscl/CSCL_English.pdf

Stahl, G., Ludvigsen, S., Law, N., & Cress, U. (2014). CSCL artifacts. *International Journal of Computer-Supported Collaborative Learning, 9*(3), 237-245. https://doi.org/10.1007/s11412-014-9200-0

Trentin, G. (2009). Using a wiki to evaluate individual contribution to a collaborative learning project. J*ournal of Computer Assisted Learning, 25*(1), 43-55. https://doi.org/10.1111/j.1365-2729.2008.00276.x

Wang, D., Olson, J. S., Zhang, J., Nguyen, T., & Olson, G. M. (2015, April). DocuViz: Visualizing collaborative writing. In *Proceedings of the 33rd Annual ACM conference on human factors in computing systems* (pp. 1865-1874). https://doi.org/10.1145/2702123.2702517

Yim, S., Wang, D., Olson, J., Vu, V., & Warschauer, M. (2017). Synchronous Collaborative Writing in the Classroom: Undergraduates' Collaboration Practices and their Impact on Writing Style, Quality, and Quantity. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing* (pp. 468-479). https://doi.org/10.1145/2998181.2998356