The Interaction of Collaboration, Note-taking Completeness, and Performance over 10 Weeks of an Online Course

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Highlights

- Collaborative learning behaviors impact the quality of note-taking completeness
- Collaborative learning behaviors have some limited impact on student performance
- Note-taking completeness has some limited impact on student performance
- The impact of collaborative behaviors and note-taking completeness increases as groups collaborate together longer

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Abstract

This study examines the effects that online collaborative note-taking has on student performance. The study draws on 10 weeks of data from 273 STEM university students who were collaborating in 61 groups. Group and individual learning were assessed weekly by evaluating the completeness of collaborative note-taking documents and subsequent individual assessments. Analysis suggested up to 23% of the variation in course performance could be attributed to between-group effects. Further, a series of 10 multilevel temporal models suggested no substantive effects in the first half of the course, though in the second half of the course, groups that co-created more complete course notes tended to exhibit improved average student performance. We speculate that the learning advantages afforded to student groups that produce more complete course notes may be delayed. This study adds to the growing body of research into the effects that collaboration has on student learning.

Keywords: Assessment; Collaborative note-taking behavior; Course performance; Multilevel temporal models; Online learning

1. Introduction

Students taking notes as a way to improve learning outcomes is a well-established part of instruction in higher education (Wu, 2020). However, note-taking may place a high demand on individual learners, as note-taking requires them to comprehend content, write it down, and learn simultaneously (Chen, 2013). Accordingly, some researchers have suggested that collaborative note-taking might be more beneficial than individual note-taking for learners (Harbin, 2020; Jansen, Lakens, & IJsselsteijn, 2017). In the case of collaborative note-taking, students may find the process easier as there is potential to divide the cognitive labor required to produce high-quality notes among the participants, which may lead to students being able to focus on the learning materials more closely (Baldwin, Fanguy, & Costley, 2019; Orndorff, 2015). For this reason there has been a move in online educational research to examine the effectiveness of collaborative note-taking on learning (Veletsianos, Pasquini, & Reich, 2016).

Some research suggests collaboration will lead to students enjoying a higher level of retention of the information and skills (Johnson, Johnson, & Smith, 2014), as well as gaining deeper insights into the materials presented in a course of learning (Cress & Kimmerle, 2018). More specifically, studies have examined how collaborative note-taking can alleviate these learning challenges by aiding in the storing and recalling aspects of knowledge. The distinction between using collaboration to reduce each individual's burden, but also to engage in the coconstruction of information is important in the context of collaborative note-taking (Dillenbourg, 1999). This is because notes are given collaboratively in class for two reasons. The first being that learners can share the load of work to create a higher quality document for later use and, and the second being that learners may construct knowledge together through the process of collaborative note-taking (Petko, Schmid, Müller, & Hielscher, 2019).

While the positive effects of collaboration are well documented (Le, Loll, & Pinkwart, 2013), it has been suggested that for an individual to benefit from collaborative group work, the group needs to work together for a sufficient amount of time (Cannon-Bowers, Salas, & Converse, 1993). It has been suggested that the more time groups spend together, the more they develop associated collaborative skills and knowledge through numerous interactions (DeChurch & Mesmer-Magnus, 2010). More specifically, group interactions may become stronger over time, leading to performance benefits for the group (Santos, Uitdewilligen, & Passos, 2015). Furthermore, in the case of collaborative writing specifically, it has been suggested that it may encourage students who may otherwise be struggling in class to be a part of a mentoring, community building engagement with the contents of the class (Krishnan, Yim, Wolters, & Cusimano, 2019).

Therefore, in order to better understand the potential benefits of collaboration on learning outcomes, the present study examines how students' online collaborative behaviors contribute to the quality of group notes online, and in turn, how the quality of those learning artefacts affects student learning over each week of a 10-week online course.

2. Literature review

2.1 Theoretical framework

The present study is framed within social constructivism theory, in which learning is regarded as a social process whereby individuals construct knowledge through interaction with one another (Vygotsky, 1978). Such construction of knowledge may not occur through thinking on one's own, but through cognition that occurs when collaborating and communicating with others (Ashcraft, Treadwell, & Kumar, 2008). Accordingly, social constructivist instructional methods involve a high degree of interaction among learners in the form of collaborative group work assignments, reciprocal teaching, and problem-based instruction (Shunk, 2000). In such environments, instructors should provide rich learning environments and activities that allow for students to actively construct knowledge together through collaboration (Ndon, 2011).

However, more research is needed to determine the extent to which collaboration is beneficial and, specifically, what types of interactions are useful to learners as they construct knowledge together. Of interest in the present study is how such knowledge is co-created within collaborative groups over time and how those collaborative behaviors that the learners engage in leads to better performance. Sharing the cognitive burden of the note-taking process across individual group members, students should then be able to free up mental resources for greater learning (Kirschner et al., 2018).

2.2 How do collaboration and learning interact?

Students who are required to explain concepts or principles to themselves or others will have a greater understanding and more complete recall of those concepts than if they studied by themselves (van Merriënboer & Sweller, 2010). Individuals bring with them their own knowledge and perspective into a group setting that can benefit the learning of the group overall (Kirschner et al., 2018). Through the process of sharing existing knowledge, collective knowledge is established (Kirschner, Kirschner, & Paas, 2011). This collective knowledge can then be applied to the collaborative task or as a way to interpret instruction. Students with greater knowledge of the domain can scaffold information to students with less knowledge (Kirschner et al., 2018). In addition, collaboration also enables student groups to divide up the labor of a cognitively demanding task so that no one member is responsible for an overwhelming amount of work.

When students collaborate when writing, they tend to produce higher quality documents than if they were to write alone (Krishnan, Cusimano, Wang, & Yim, 2018). Prior research on note-taking specifically has suggested that sharing individual notes in pairs (Kiewra, 1989) and taking notes collaboratively in small groups (Orndorff, 2015) enable students to share the burden of trying to listen, understand, and write notes simultaneously, thereby freeing up students cognitively to make deeper connections with the learning content.

There is a cognitive transaction cost in terms of the degree of time and effort required to communicate between multiple parties, as well as the potential for errors in information transfer which may, in some circumstances, offset the advantages of collaboration (Kalyuga, 201; Popov et al., 2017). However, little to no research has explored the point at which the advantages of collaboration for learning might begin to offset cognitive transaction costs over the course of a program of learning. Moreover, there is a paucity of research that identifies the extent to which synthesizing behaviors, such as the reviewing and editing of group members' work, might contribute to the quality of collaboration. Further, particular students may not gain as much from the learning process as others because of unequal participation. It has been suggested that a horizontal division of labor should reduce students' cognitive burden, allowing them to learn more; however, some students may not participate or some group members may dominate group work (Dillenbourg, 1999). This uneven participation may detrimentally affect all learners (Hertz-Lazarowitz, Kagan, Sharan, Slavin, & Webb, 2013). However, empirical research exploring whether or not groups with more evenly contributing members experience improved learning outcomes has yet to be explored.

2.3 Does collaboration change over time?

As previous research has claimed, it is important to look at groups from the perspective of how their collaboration changes over time (Marks, Mathieu, & Zaccaro, 2001). According to Tuckman (2001), there are four stages of group development: forming, storming, norming, and performing. As suggested by this theory, as groups move through these stages, the amount of task-focused collaboration they engage in should increase over time. For effective team work, the members need to work together long and often enough on knowledge building (Cannon-Bowers, Salas, & Converse, 1993). Collaborative knowledge building takes place during the *performing* stage, the most active learning stage (Tuckman & Jensen, 2010). The group's ability to share knowledge has been shown to become more efficient and effective over the course of numerous interactions (DeChurch & Mesmer-Magnus, 2010). They know how other members work, what other members know, and how to work efficiently on the task in the performing stage, reducing unrelated and inefficient interactions and improving performance (Kirschner et al., 2018). Despite inroads into how groups might collaborate better over time, little to no empirical work has been undertaken to explore how these processes might function for online collaborative note-taking (Tuckman & Jensen, 2010).

2.4 Relationship between collaboration and learning over time

Previous research has suggested that, over time, group interactions online become stronger, which may lead to higher quality learning outcomes as the interactions become deeper and more effective (Costley & Han, 2013). Once groups are formed to work together, the learning outcomes from the group work may take time to become established both in terms of group knowledge building processes and retention of information (DeChurch & Mesmer-Magnus, 2010; Gruenfeld & Hollingshead, 1993). Over time, members become more efficient at sharing information and dividing labor, consequently improving group cognition overall (Cooke, Gorman, & Kiekel, 2017). A group's prior experience of working on specific tasks allows learners to create task-specific collaboration skills (Zambrano, Kirschner, Sweller, & Kirschner, 2019). The prior experience the members have with each other as a group and how they might collaborate and work together can affect learning overall (Zambrano et al., 2019).

2.5 Constituent elements of collaboration

There are varied elements of collaborative behaviors that make up learner-to-learner interaction in the context of online note-taking. In the context of the present study, those elements include volume, edits of others, sessions, and the evenness of volume contributed by the group. Herein, *volume* refers to the amount of total words contributed by members of the group. Research suggests that as groups produce a higher volume of words, their levels of learning will increase (Haynes, McCarley, & Williams, 2015). This positive effect of note-taking may not be the same in all cases, as it has been shown that group note-taking has a greater effect for the retention of information than with the recall and application in conceptual matters and that different methods of note-taking, e.g., using long-hand or laptops, may affect performance (Morehead, Dunlosky, & Rawson, 2019). Furthermore, the amount of notes taken about a lecture has not always been shown to increase the amount of information students recall about that lecture, as taking more notes may lead students to simply transcribe the information but not to understand it (Mueller & Oppenheimer, 2014). In regards to collaborative note-taking, research has also suggested that students who take more notes have higher levels of performance (Kam et al., 2005). However, few studies have examined how within-group (i.e., contributions relative to group members) and between-group (i.e., contributions in terms of averages of each group) levels of volume might impact the processes of retention and learning outcomes as groups create collaborative notes over time.

In the present study, students were also able to edit each other's contributions. This editing of others may help other learners because of the potential for feedback, correction of misinterpretations, and the addition of missing content (Landay, 1999; Singh et al., 2004). It has also been shown that students who login more often during learner-to-learner activities will create a better learning environment and may improve learning outcomes for their groups (Kent & Cukurova, 2020; Manathunga & Hernandez-Leo, 2016). However, there is little research looking specifically at how the amount that students edit each other's notes and the amount of logins directly impacts learning outcomes. Furthermore, how these effects might change over time represents a gap in current research.

Though there is some debate about whether collaborative outputs are improved when students contribute evenly to the group's final product (Yim et al., 2017), it is generally considered that balanced group work benefits learners (Zhu, 2012). It is thought that more comparable contributions toward document production lead to an overall improved focus and retention of knowledge (Orndorff, 2015) and quality of collaboration (Olson et al., 2017). As volume of contribution can be operationalized in terms of the number of words contributed to a document by an individual, the evenness of contributions for each group can be operationalized in terms of the balance (or lack thereof) of the contribution to the total word count by each respective constituent member.

In regards to the quality of the collaborative work, evidence suggests that higher quality collaborative products lead to greater learning (DeChurch & Mesmer-Magnus, 2010), as reflected specifically by improved course performance (Oefinger & Peverly, 2020). In the case of collaborative note-taking, one method of measuring document quality is to assess the “completeness” of group notes. Specifically, the extent to which the final version of the notes contains all of the main units of information in the preceding unit of work can be assessed. Using this general metric, there is some evidence that students with more complete notes will perform better than those with incomplete notes, in particular when the contents of the notes correspond with the assessment items (Einstein et al., 1985). It might also be the case that a learner’s contribution to group work may become intertwined with other learners' contributions in a manner that is not in perfect harmony with their own interpretation. This may lead to an increase in learning as the learner adapts to a more complete picture of the contents through collaboration, or it may lead to some confusion (Cress & Kimmerle, 2018). This shows there is a gap in the research as to how the completeness of notes might affect learning outcomes, as measured by weekly assessments, over the course of a semester.

3. The present study

This paper examines how students' online collaborative behaviors contribute to the quality of group notes online, and in turn, how the quality of those learning artefacts affects student learning week-to-week. The variables of 1) volume of individual contributions, 2) the extent to which edits were made, 3) the number of logins per student, and 4) the degree to which group members contributed evenly to the group notes constitute the student's productive behaviors; they are related to how much the student produces in terms of volume, edits of others, sessions, and evenness. This can be contrasted with completion, which is a measure of the quality of the students' collaboration (a group-level artifact). Therefore, how the productive collaboration behaviors (specifically, volume, edits, logins, and evenness) affect the quality of collaborative note-taking was of research interest in this study as well as the effect these productive behaviors had on students' weekly course performance. Furthermore, as collaboration is considered a path to learning, the more complete the group notes, i.e., developed the learning product/artifact, the greater the learning should be. Therefore, the effect that the quality of group notes has on student learning is also of particular interest. This research fills a gap in our current knowledge of group note-taking by looking at the individual elements of collaboration and how those elements change in their effect on performance over time. Following these general lines of enquiry, the following four main research questions are proposed.

3.1 Research Questions

RQ1: How do within-group level productive collaboration behaviors, such as (a) volume of words, (b) edits of others, and (c) number of log-ins affect students' weekly course performance?

RQ2: How do group-level collaborative behaviors such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness affect students' weekly group course performance?

RQ3: How do group-level productive collaboration behaviors, such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness of volume affect the completion of weekly group notes?

RQ4: How does the completion of group notes contribute to weekly student performance?

4. Methodology

4.1 Procedures

The current study employed three phases of data collection for each of the ten instructional weeks. In the first phase, students' co-created notes using Google Documents (based on weekly online video lectures) that were mined to explore the volume of individual contributions, the extent to which edits were made, the number of logins per student, and the degree to which group members contributed evenly to the group notes. In the second phase, the subsequent completeness of group notes was examined by the course instructors using rubrics tailored to assess note-taking completeness of weekly content. Thereafter, in the final phase, at the end of each week, each student took an assessment test designed to assess the degree to which they had learnt and retained knowledge and concepts taught that week.

4.2 Participants and context

The current study tracks the experience of 273 university students participating in a graduate-level scientific writing course at a university in South Korea. While most of the students at the university speak English as a foreign language, English proficiency of graduate students is high, and over 84% of all courses offered in the university are given in English. Accordingly, in the scientific writing course examined in the present study, all instruction and collaborative activities were done in English. The study comprised 273 students forming a total of 61 groups (4.48 students per group; 2 groups of 3, 28 groups of 4, and 31 groups of 5 students). Research has shown that for collaborative learning, groups of between 3 to 6 members will maximize students' levels of self-directed learning and engagement (Loyens, Magda & Rikers, 2008). Students were given the option to choose their own groups on the course Learning Management System, and the vast majority of students self-selected into note-taking groups with familiar students from their own departments and research labs. As only a few students were assigned to groups by the course instructor, the groups could not be purposely scaffolded. All participants majored in science, technology, engineering, and math (STEM) and gave informed consent to participate in the research, allowing for full data mining of their online collaborative contributions. The study utilized a non-representative convenience sample with all participants formally enrolled in the course. The aim of the writing course was to develop student capacity in formal academic writing so that they could publish their research in peer-reviewed journals

(Fanguy, Lee, & Churchill, 2021). Topics included academic writing, research ethics, grammar and formatting concepts, and submission processes to journals. Course content for all 10 weeks was made available online on the university's learning management system with each week comprising four to eight online lectures, amounting to a total 56 videos for the entire course period. Videos were between 5 to 25 minutes in duration. As prior research has shown that note-taking generally (Wu, 2020) and collaborative note-taking specifically (Baldwin, Fanguy, & Costley, 2019; Orndorff, 2015) can help students to better recall the contents of a lecture, students were required to take notes collaboratively using a Google Document monitored by the course instructor and teaching assistant. In order to help students better understand what collaborative notes would look like and what type of information they would include, the instructor provided a set of example notes for the first lecture video that the students were required to watch. Students were asked to each make active individual contributions to the notes each week and to respond to the contributions of others. The instructor and teaching assistant logged into each group's document at the end of each instructional week and provided feedback (in the form of embedded comments within the documents) on the completeness of the notes and the participation of each group member. Through this feedback, the instructor and teaching assistant could encourage less involved participants to contribute more to the notes and to encourage all members to respond to the contributions of others. Participants in the study received no instruction on note-taking skills or strategies as part of the scientific writing course examined in this study or in any other course during their graduate degrees. Students were able to form their own groups of up to four or five students, with some students assigned to a group by the instructor at random. The few instances of students dropping out of the course midway resulted in cases of groups of three students.

The Google Docs platform was chosen for collaborative note-taking in this study because almost all of the participants already had Google accounts. Moreover, prior research has shown that students regard the Google Documents platform as highly beneficial to their writing and ability to collaborate with one another in out-of-class assignments (Zhou, Simpson, & Domizi, 2012) and because use of the platform encourages instructor-driven feedback (Krishnan et al., 2018). However, it is often hard to assess the collaborative processes that a group engaged in when creating the document, as online environments such as Google Documents do not provide obvious visual referents to which student made which contribution (Krishnan et al., 2018). To provide instructors with these visual cues, two Google Doc add-ons – DocuViz and AuthorViz – allow data on students' collaboration in writing to be harvested easily from the documents (Wang, Olson, Zhang, Nguyen, & Olson, 2015). The data used in the present study were extracted from individual student note-taking activity on the respective Google Document notes and included metrics pertaining to (1) volume of words, (2) number of edits to other group member's notes, (3) session logins, and (4) evenness of the group's volume of words. Toward the end of each week, Google Document notes were archived, and the completeness of each document, i.e., the extent to which it covered the main points in the specific video, was assessed via a rubric. At the conclusion of each week, each student then completed an assessment which covered content specific to formal writing each week.

4.3 Instruments

The current study made use of four independent variables, one mediating variable, and one dependent variable. All four independent variables were mined from each group's weekly Google Document. It should be noted that, while the quality of the note-taking content was assessed as part of the course, the data mined directly from the group's weekly Google Document activity were not. Specifically, the volume of words, number of edits, session logins, and volume evenness did not affect student grades, and students were not informed that these four specific variables were measured (only that their online activity would be mined in general). The four independent, one mediating, and final dependent variable of interest will now be described.

4.3.1 Volume

To assess each group member's general contribution to weekly group notes, the total volume of words written by each group member was measured. This within-group variable was assessed viz-a-viz the final version of each group note and ascertained via the Google Docs add-on, DocuViz (Wang, Olson, Zhang, Nguyen, & Olson, 2015), and additional open-source programming written in the Python language (URL removed for blinding). An aggregated between-group variable was also calculated for each week.

4.3.2 Edits of others

The edits of others variable was used to examine the extent to which group members actively revised fellow group members' contributions. This within-group variable was measured by the total number of characters that were inserted and/or deleted by individual group members. Measurement of this variable was made possible by the Google Chrome add-on, DocuViz. The variable was also aggregated to create a between-group variable in the current study.

4.3.3 Session logins

As a measure of general engagement, the frequency with which each group member logged into their respective Google document was assessed in the study. The DocuViz add-on was used to extract this within-group variable, and as with Volume and Edits of Others, each week this variable was also aggregated to a between-group variable in order to provide a measure of overall group engagement.

4.3.4 Volume evenness

To measure the balance of group member contributions, the evenness of the volume of individual contributions of each group was also extracted from the logged data. This between-group level variable was created by first estimating the spread (variance) of the contribution of participants for each group. The variable was then transformed to a measure of evenness for each group by finding its reciprocal. The variable's variance was then stabilized by finding the log of each reciprocal value for each group each week.

4.3.5 Completeness

The current study uses completeness of group notes as a between-groups measure of the degree to which the notes captured meaningful concepts contained within the weekly lectures. All notes were assessed via a rubric tailored to the content represented each week. Informational units were assessed as being either included or not included. The maximum score for each week varied depending on the number of informational units assessed. Alpha coefficients for completeness were generally high at α= 0.88 (100 items, *I*), 0.95 (84 *I*), 0.86 (63 *I*), 0.94 (77 *I*), 0.80 (35 *I*), 0.84 (53 *I*), 0.87 (41 *I*), 0.88 (51 *I*), 0.97 (168 *I*), and 0.98 (258 *I*), respectively, with item-total(rest) correlations positive for all items for all 10 assessments (CTT package's reliability function; Willse, 2018). All items contained in all rubrics can be seen in the file labeled "completeness rubric" at https://osf.io/5t8vw/?view_only=3514f73b64b1497a9948e1a544d565bc.

4.3.6 Weekly course performance

To track student learning, assessments were administered to each student at the conclusion of each of the 10 instructional weeks. Assessments were designed to assess students' capacity to understand and apply the content contained in the preceding lectures. Depending on the week, assessments contained between 8 and 30 MCQ formatted questions. The assessment instruments were administered online and students were given two minutes to complete each question. Partial credit was afforded when students chose just one correct response option when two of the four response options constituted a correct answer. Each weekly assessment result was then weighted at 3% so that all assessments combined counted toward 30% of students' total scores toward the course. Individual results were aggregated weekly to create a between-group assessment variable (course performance). Cronbach's alpha coefficients for each assessment each week were α= .68 (13 *I*), .62 (10 *I*), .60 (15 *I*), .69 (8 *I*), .81 (20 *I*), .64 (12 *I*), .78 (18 *I*), .58 (11 *I*), .65 (13 *I*), and .85 (30 *I*), respectively, suggesting that the assessments were a moderately reliable measure of each week's instructional focus (to note, the low number of items may account for the instances of lower alpha, as Clark & Watson, 1995; López, Valenzuela, Nussbaum, & Tsai, 2015; Taber, 2018). For all 10 assessments, item-total(rest) correlations were positive, suggesting that each item functioned to separate students in a useful way. Details of each item in the assessment and its relationship to the videos is labeled as "quiz items and video list" and can be seen here https://osf.io/5t8vw/?view_only=3514f73b64b1497a9948e1a544d565bc.

4.4 Descriptive Statistics

Descriptive statistics for all six variables of interest are provided in Table 1. Within-group variables, those that varied within groups, are presented in the upper part of Table 1. Between-group variables, including the four within-group variables aggregated to the between-group level and the two variables that only vary at the between-group level, are presented in the lower part of Table 1.

Table 1
Descriptive Statistics for Variables of Interest

Variables	Week 1 *M*(*SD*)	Week 2 *M*(*SD*)	Week 3 *M*(*SD*)	Week 4 *M*(*SD*)	Week 5 *M*(*SD*)	Week 6 *M*(*SD*)	Week 7 *M*(*SD*)	Week 8 *M*(*SD*)	Week 9 *M*(*SD*)	Week 10 *M*(*SD*)
Within-Group Variables (Overall Means and SDs)										
Quiz	1.95(0.53)	2.34(0.46)	2.19(0.46)	2.61(0.46)	1.88(0.50)	2.32(0.44)	1.81(0.43)	1.80(0.46)	1.92(0.48)	1.87(0.49)
Volume	350(295)	200(154)	245(179)	203(168)	253(192)	216(168)	234(211)	236(196)	334(270)	306(229)
Edits	906(2191)	325(574)	464(1048)	365(938)	369(730)	332(651)	392(1024)	431(1074)	575(1294)	451(913)
Sessions	2.48(1.66)	1.88(1.16)	2.04(1.34)	1.77(1.22)	1.74(1.11)	1.78(1.13)	1.63(1.06)	1.68(1.20)	1.79(1.22)	1.59(1.06)
Between-Group Variables (Group means and SDs)										
Quiz (M)	1.94(0.29)	2.33(0.27)	2.18(0.29)	2.61(0.28)	1.88(0.30)	2.32(0.27)	1.81(0.26)	1.79(0.26)	1.91(0.31)	1.87(0.27)
Volume (M)	354(141)	200(83)	248(97)	204(66)	255(77)	217(79)	236(99)	238(97)	336(112)	308(89)
Edits (M)	938(1125)	324(317)	472(644)	367(468)	356(345)	345(360)	395(516)	439(527)	576(622)	454(469)
Sessions (M)	2.48(0.91)	1.90(0.69)	2.06(0.79)	1.77(0.64)	1.73(0.58)	1.78(0.61)	1.63(0.68)	1.68(0.70)	1.79(0.77)	1.60(0.62)
Evenness	0.00(1.36)	0.00(1.27)	0.00(1.14)	0.00(1.27)	0.00(1.44)	0.00(1.23)	0.00(1.40)	0.00(1.50)	0.00(1.17)	0.00(1.32)
Completeness	83(9) *83(9)%*	67(13) *80(16)%*	55(6) *87(9)%*	65(11) *84(14)%*	33(3) *94(9)%*	47(5) *89(9)%*	35(6) *85(15)%*	39(7) *76(14)%*	142(21) *85(13)%*	203(44) *79(17)%*

Note. Number of groups = 61; *N* = 273; maximum possible quiz scores set at 3.00 each week; volume and completeness given to closest integer; means, and standard deviations, given for between-group variables based on vectors of group means; average % scores (*and SDs*) for completeness also provided in italics; groups comprised of 3 to 5 students; descriptive statistics include 273 total students each week as no data reduction due to lack of within group variation necessary.

All within- and between-group variables were also examined for skewness (Appendix A, Table 1A). Results suggested that the variables were generally moderately skewed though Edits, overall, exhibited a generally higher level of positive skewness across the ten weeks.

Mean results for the weekly quizzes ranged from 1.80 to 2.61 (total = 3.00) with *SDs* ranging between 0.44 and 0.53 suggesting a reasonable level of variation in weekly student learning outcomes. Mean volume of words ranged from 200 to 350 (with *SDs* ranging between 154 and 295) suggestive of quite a high degree of weekly fluctuation in student word contributions. The mean number of edits per week also appeared to fluctuate quite highly with means ranging between 325 and 906 (with *SDs* ranging between 574 and 2191). In terms of number of weekly session logins, results were quite consistent with weekly mean logins ranging between 1.59 and 2.48 with *SDs* ranging between 1.06 and 1.66. Finally, the standard deviations of the weekly Evenness (group-level) ranged between 1.14 and 1.50 (see 3.2.4 for variable's transformation); and mean Completeness (group level) ranged between 76 and 94% (*SDs* between 9 and 17%), suggestive of some meaningful variation in group note completeness.

In order to explore group-level effects in the current study, group-level behavior and learning outcomes would need to differ in some systematic way across the 10-week course. To this end, Table 2 provides a description of the extent to which course performance and collaborative productive behaviors vary at the within- and between-group level (see Goldstein, 2003 for review). All intraclass correlation coefficients were estimated with the assistance of the misty (Yanagida, 2020) package using the multilevel.icc function and lme4 method specifications.

Table 2
Weekly Intraclass Correlations of Individually Varying Course Performance and Online Behaviors

IV	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
					Individual Course Performances					
Course Perform	.071	**.154**	**.229**	**.178**	**.181**	**.157**	**.139**	**.112**	**.112**	.083
					Collaborative Productive Behaviors					
Volume	.012	. 092	.081	.000[1]	.000[1]	.000[1]	.000[1]	.028	.028	.000[1]
Edits	.001	.097	**.163**	.009	.031	.076	.032	.000[1]	.000[1]	.053
Sessions	.089	**.113**	**.113**	.037	.038	.051	**.213**	**.110**	**.110**	**.109**
G(N)	59(266)	57(254)	58(262)	57(255)	55(247)	55(247)	58(259)	55(245)	58(260)	56(248)

Note. *G* = number of groups; *N* = number of students; numbers (*G, N*) of groups vary due to lack of within-group variance in variables; bold values represent intra-class correlations over 0.10 (representing more than 10% variance attributable to between group effects); [1]zero values due to relatively large proportion of within-group variance to between group variance in some groups—though between-group variance does exist with weekly *SDs* in *group* means ranging from 66 (week 4) to 141 (week 1) words per week.

Results suggest that 7.1 to 22.9% of course performance could be attributed to between-group effects, i.e., course performance varied in some systematic way by groups. Though variance attributed to group effects for volume, edits, and sessions was generally lower, this was often due to relatively very large amounts of variance within groups. For example, though intra-class correlations for Volume were very small for weeks 4, 5, 6, and 7 (Table 2, with values close to zero), the actual variation in group means was quite large, with standard deviations of 66, 77, 79, and 99 words per week (see Table 1, row 6, Weeks 4, 5, 6, and 7, respectively), suggesting that average group volume varied to a sufficient level warranting an investigation into its effects.

4.5 Main analyses

All data preparation and analysis was undertaken with the assistance of the open-source R programming software (R Core Team, 2020). Prior to carrying out multilevel analyses (Goldstein, 2003), all variables were standardized using the R scale function. This was done to achieve scale comparability across variables. Figure 1 provides an illustration of the main and supplementary multilevel models run for each of the ten weeks.

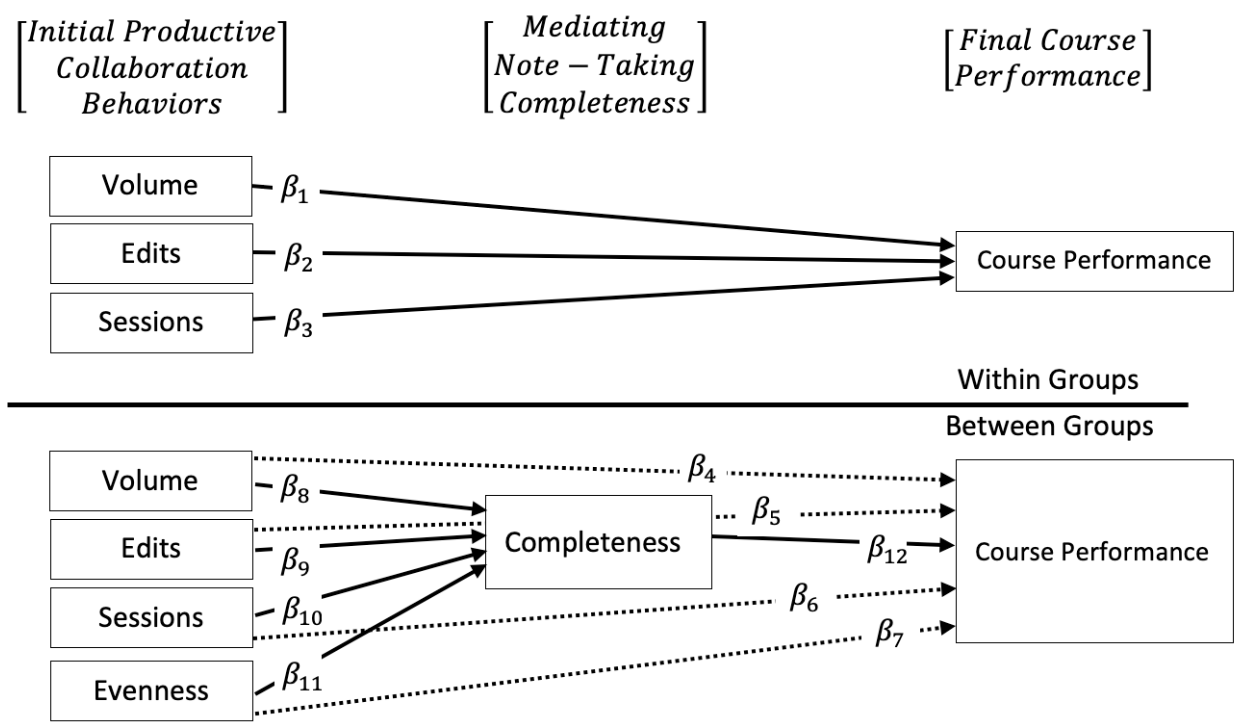

Figure 1. ***Multilevel Temporal Model for Group Note-Taking Completeness and Course Performance***
Note. Main multilevel temporal model represented by solid lines; supplementary model, testing between-group effects of initial note-taking behavior on course performance, represented by dotted lines; for the model, all β values represent standardized regression coefficients.

For each week, the main model included estimates of effects for β_1, β_2, and β_3, and β_8, β_9, β_{10}, and β_{11}, and β_{12}. Additionally, for each week, to address RQ2 concerning the effects of group-level collaborative behaviors on course performance, a supplementary model was run for coefficients β_4, β_5, β_6, and β_7. For the supplementary model, all variances and covariances at the within-group were specified in a saturated level so as to only examine between-group effects.

4.5.1 Research questions and specific effects

RQ1 asks, How do within-group productive collaboration behaviors, such as (a) volume of words, (b) edits of others, and (c) number of log-ins affect weekly course performance? To answer this question, coefficients β_1, β_2, and β_3, from the main model were examined each week.

RQ2 asks, How do group-level collaborative behaviors such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness affect students' weekly group course performance? To address this question, coefficientsβ_4, β_5, β_6, and β_7, identified in a supplementary model, were examined each week.

RQ3 asks, How do group-level productive collaborative behaviors, such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness of volume affect the completion of weekly group notes? To answer this questions, coefficients β_8, β_9, β_{10}, and β_{11} were examined each week.

RQ4 asks, How does the completion of group notes contribute to weekly group student performance? To address this question, coefficient β_{12} was examined each week.

All multilevel models were undertaken with the assistance of the lavaan (Rosseel, 2012) package's sem function. All models used robust maximum likelihood estimation (MLR) to account for the moderate to high level of skewness (Appendix A, Table 1A). All models converged successfully. Finally, the f^2 effect size is used as a means of interpreting the extent to which the variance is explained in each dependent variable, i.e., completeness and student performance, where $f^2 = R^2/1\text{-}R^2$ (Cohen, 1992) with f^2 values of 0.02, 0.15, and 0.35 considered small, medium, and large.

5. Results

5.1 RQ1: Effect of collaborative productive behaviors on within-group student performance

Table 3 provides results for RQ1 asks, How do within-group productive collaborative behaviors, such as (a) volume of words, (b) edits of others, and (c) number of log-ins affect subsequent student course performance? Specifically, β_1, β_2, and β_3, were estimated for all ten models. Results in Table 3 for within-groups effects suggest that only the volume of words had a statistically significant effect on student course performance twice in the first five weeks, and four times in the last five weeks.

5.2 RQ2: Effect of collaborative productive behaviors on between-group course performance

Table 4 provides results for RQ2: How do group-level collaborative behaviors such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness affect the weekly course performance? Specifically, β_4, β_5, β_6, and β_7, were estimated for all ten models. Analysis suggested that, in terms of between-groups effects, only Session Logins had a substantive effect in Week 1 (β_6 = .584, p < .05), and Edits of Others had a substantive effect in Week 5 (β_6 = -.383, p < .05). Because no consistent substantive direct effects were identified, in accordance with Baron and Kenny (1986), no formal post-hoc tests of mediation, to test whether or not Completeness acts as a mediator, were undertaken.

5.3 RQ3: Effect of collaborative productive behaviors on note completion

Table 3 provides results for RQ3: How do group-level productive collaboration behaviors, such as (a) volume of words, (b) edits of others, (c) number of log-ins, and (d) evenness of volume affect the completion of weekly group notes? Specifically, the effect of β_8, β_9, β_{10}, and β_{11} were tested. Results suggested that Volume of Words had substantive effects for nine of all ten weeks.

5.4 RQ4: Effect of completeness on course performance

Table 3 provides results for RQ4. Specifically, β_{12} was estimated for each week. Results found that the subsequent between-group effect of note-taking completeness on group course performance was substantive for four of the last five weeks of the course. While this pattern was generally positive, note-taking completeness had a significantly negative effect on group course performance in Week 8 (β = .495, p = .015).

Table 3

Summary of Effects from Main Multilevel Temporal Models for Weekly Group Completeness and Course Performances

Independent Variables	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Initial Online Note-Taking Behavior Effect on Course Performances [Within-Group Effects]										
Volume of Words ($_1$)	.085	.147*	.223*	.081	.122	.110	**.187*****	.149*	.137*	**.229*****
Edits (of others) ($_2$)	-.047	-.083	-.037	.036	-.063	-.028	-.068	.041	-.006	-.083
Session Logins ($_3$)	.102	.000	-.104	-.042	.099	.065	.081	-.006	.000	-.037
$R^2(f^2)$	.021(.021)	.022(.22)	.041(.043)	.009(.009)	.029(.030)	.017(.017)	.039(.041)	.028(.029)	.018(.018)	.044(.046)
Initial Online Note-Taking Behavior Effect on Note Completeness [Between-Group Effects]										
Intercept	.004	-.049	-.015	-.071	-.030	.011	-.035	.107	-.035	-.047
Volume of Words ($_8$)	**.331****	**.488****	**.637*****	.215	**.386****	.335*	**.570*****	**.525*****	**.694*****	**.841*****
Edits (of others) ($_9$)	-.049	.119	-.145	.122	-.126	.067	-.129	.073	-.028	.059
Session Logins ($_{10}$)	.118	-.037	.061	-.148*	-.022	.137	.116	.066	.001	-.115
Volume Evenness ($_{11}$)	**-.392****	-.078	.093	-.306	-.284	-.046	.132	-.079	-.022	.061
$R^2(f^2)$	.441(.789)	.337(.508)	.309(.447)	.261(.353)	.315(.460)	.193(.239)	.249(.332)	.391(.642)	.488(.953)	.624(1.66)
Note Taking Completeness Effect on Course Performance [Between-Group Effects]										
Intercept	.008	-.025	.028	-.030	.041	-.052	-.088	-.117	.014	-.056
Completeness($_{12}$)	.108	.444	.109	.358	.466	.441*	.458*	-.495*	**.689*****	.198
$R^2(f^2)$	.012(.012)	.197(.245)	.012(.012)	.128(.147)	.217(.277)	.194(.241)	.210(.266)	.245(.325)	.475(.905)	.039(.041)

Note. ***R^2= total variance explained in outcome variables; f^2*** = ***$R^2/(1-R^2$***); **p* < .05, ***p* < .01 in **bold**; ****p* < .001 **bold and underlined**; all values, unless stated otherwise, represent standardized beta coefficients (see Figure 1); group and student sample sizes per week given in Table 2.

Table 4

Summary of Effects from Supplementary Model for Weekly Group Completeness and Course Performance

Independent Variables	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Initial Online										
				Note-Taking Behavior Effect on Course Performance [Between-Group Effects]						
Intercept	0.021	-0.062	0.043	-0.040	0.018	-0.028	-0.063	0.104	0.000	-.073
Volume of Words ($_4$)	-.382	.282	.067	.329	-.203	.267	.269	-.228	.376	-.001
Edits (of others) ($_5$)	-.404	.104	-.097	-.058	**-.383***	-.354	-.304	-.293	-.276	-.189
Session Logins ($_6$)	**.584***	.161	-.296	-.024	.137	.056	-.182	.270	-.043	-.008
Evenness of Group Vol. ($_7$)	-.529	-.088	.048	.137	-.608	-.008	-.318	-.106	-.090	-.293
$R^2(f^2)$	.494(.976)	.269(.368)	.106(.119)	.064(.068)	.417(.715)	.162(.193)	.258(.348)	.203(.255)	.198(.282)	.112(.126)
Group and Student										
					Sample Sizes					
G(N)	59(266)	57(254)	58(262)	57(255)	55(247)	55(247)	58(259)	55(245)	58(260)	56(248)

Note. *G* = number of groups; *N* = number of students; numbers (*G, N*) of groups vary due to lack of within-group variance in variables; *p < .05 in **bold**; all values, unless stated otherwise, represented by standardized beta coefficients.

6. Discussion

Research has suggested that the taking of notes in groups greatly improves students' retention of long- and short-term retention of information and the development of creative conceptual understanding of content (Luo, Kiewra, & Samuelson, 2016). In this respect, the current study falls in line with current research into online collaboration and note-taking, but only to a certain degree as results herein suggest that (1) these benefits are not enjoyed across all elements of collaboration and (2) these effects are not consistent throughout the semester. Results from the current study provide an empirical contribution to understanding how elements of collaborative note-taking might contribute to an improved understanding of course content with effects generally exhibited toward the end of the semester.

There is some literature that suggests that groups may not initially collaborate well together, but that collaboration may improve over time (DeChurch & Mesmer-Magnus, 2010). To look into this claim more explicitly, the present study looked at individual- and group-level collaborative behaviors and how those behaviors were associated with note-taking completeness and subsequent learning week-to-week. This was done to give richer insight into the effects of elements of collaborative note-taking that is lacking in extant research literature.

Findings from the present study suggested that, within groups, volume of words contributed to improved course performance especially toward the end of the semester (Table 3). This results supports the idea of the *self-explanation principle* which claims that when students explain something to themselves or others, it may improve the retention of the information they are teaching (Van Merriënboer & Sweller, 2010). As can also be seen in Table 3 for Sessions and Edits of Others, there were no significant effects discovered across any weeks. This is an interesting finding as previous research suggests that students who as individuals log in more often to online learning environments have greater levels of achievement (Firat, 2016). However, previous research has not looked at logins as a factor in collaborative learning at the individual level, but rather only at logins in general. Also, previous research has suggested that editing others' work helps improve learning by providing feedback to other members of the group (Singh et al., 2004). However, in the present study, students' edits of others appeared to not lead to higher quiz scores. Results from this study found no direct effect of group volume, sessions, edits, or evenness on group course performance, and further found that no consistent pattern of effects was exhibited across the ten-week semester (Table 4). This finding contrasts research on the topic which suggests that types of collaborative productive behaviors do impact learning outcomes, making this finding particularly noteworthy. Interestingly, while volume did have an effect at the level of the individual group member (within group effect), it did not improve quiz scores at the level of the group. Furthermore, there is research that suggests that group interactions become more balanced over time, which may lead to greater transfer of knowledge and greater knowledge creation (Zhu, 2012). However, the present study shows that as the semester progresses, the relative evenness of group members' contributions has no substantive effect on average group course performance. Also, sessions (Jo et al., 2015) and edits of others (Yim, Wang, Olson, Vu, & Warschauer, 2017) have been tangentially been claimed to be of benefit to learners; however, in the present study, where these effects were examined closely, there seems to be no benefit for learners engaging in these types of behaviors in average weekly course performance. These results call into question the current understanding of "more collaboration is better", and suggest that great levels of collaborative behaviors do not lead to improved learning outcomes.

This study found that, in general, in the latter part of the course, higher levels of collaboration in the form of volume (relative to other groups) led to more complete notes being taken. The general effects, demonstrated here, provide some empirical basis for previous research that has suggested that when groups begin to operate in a more detail-oriented way, i.e., work to generate more complete notes, this leads to higher levels of information, comprehension, and higher collaborative artefacts (Butson & Thomson, 2014; Volet, Summers & Thurman, 2009). Also, the present study supports research that shows that as time passes, interpersonal connections are improved, which leads to improved group processes (Marks, Mathieu, & Zaccaro, 2001). Furthermore, as the semester progressed, the association between volume and completeness seemed to grow. This general pattern suggests that increased group productivity begins to result in an improved quality of group notes, but only as the semester progresses. This is unsurprising, as the more students engage in note-taking behavior, the more detailed the information in the notes should become.

Among the variables investigated in this study, only completeness had a positive relationship with student weekly learning outcomes, and this effect only seemed to be expressed towards the end of the semester (with one instance of inconsistency). More specifically, as the semester progressed, the relationship between document quality in the form of completeness and student course performance increased. This is similar to results in previous research that has shown that as the group interacts with each other over time, the interaction becomes more positive and the impact of the collaboration on learning increases (Tuckman & Jensen, 2010). There is some further tangential support in the literature for this as there is evidence that groups become more efficient at transferring information over time as they become more familiar with each other and the collaboration processes (Cooke, et al. 2017). However, this research offers a more in-depth analysis of this phenomenon than previous research by looking at 10 consecutive weeks of note completeness and the relationship between each week's completeness and course performance.

Therefore, this study provides a higher resolution picture of an important effect in online group learning in general and collaborative note-taking specifically. This research is a step in providing an empirical framework that allows for replication in other learning environments that may look at the indicators and how they might vary in their effect on learning in other contexts.

Of the three variables investigated in regards to within-group individual performance and course performance (volume, edits of others, session), only volume had any effect on course performance and this effect was statistically significantly positive towards the end of the semester. This means merely being a group that is collaborating is not the most effective thing for a learner. The learner as an individual must produce notes themselves, and this production of notes should be sustained throughout the semester. For this reason, when students are put into groups, they should be encouraged to be more productive as individuals regardless of the amount of collaboration they may or may not have with other individuals in their group. Furthermore, this productivity should be sustained throughout the semester.

Between-group volume, edits of others, evenness, and sessions appeared to have no direct effect on between-group course performance, as the semester progressed. However it is reasonable to suggest that production became more meaningful because volume's effect on note quality seems to build, as did the effect that note quality had on group course performance. This general pattern leads to the suggestion that prolonged sustained group note-taking work and revision activities may be beneficial in online learning environments. Specifically, trying to increase the amount of volume students produce and sustaining or increasing that volume over time should, according to the results of the present study, lead to better course performance and higher quality notes. So, while the overall group productive elements of student collaborative behaviors (volume, edits, sessions, evenness) that the students in the present study engaged in did not increase in their effect on quiz scores over time, it is reasonable to suggest that their interactions became more meaningful and effective as the semester progressed as completeness seemed to have a progressively positive influence on course performance. This leads to the suggestion that prolonged sustained group work may be more beneficial in online learning environments.

Many cases of collaboration in educational contexts are single instances of collaboration, where learners gather together to perform a single task and then may not work together again, or may work together again, but on a very different type of task. In such a case, students are put together to complete a single task (a week's work often) and may not collaborate in a group with the same composition for the rest of the semester. The present study suggests that this might be a mistake, and that over time the effectiveness of the volume of work students take when note-taking will benefit their performance. Furthermore, there are computer based tools that allow instructors to look closely at student collaborative behaviors to see the types of behaviors that students are engaged in. Visualization tools like Docuviz can be easily used by instructors to have a better understanding of how groups interact and use this information to shape the interaction in a way that can benefit students and create a high-quality learning environment.

7. Conclusion

This study looked at how the amount of collaboration when students write notes in an online environment interacts with weekly learning outcomes over the course of a semester. Findings suggest that collaboration in note-taking and the completeness of notes may not contribute to students retaining more information when taking assessments the way that has previously been conceptualized. Interestingly, this study suggests that the overall level of group collaboration, per se, has no direct effect on student performance at any point over a course of learning, and that only collaboration toward building quality learning artefacts results in improved group learning, perhaps only after an initial period of forming, storming, and norming. This suggests that the length of time students interact together is an important factor when setting up group work; it is important that students have enough time to develop more beneficial and meaningful interactions.

This type of collaboration and extraction of data is only possible in the context of computer-supported collaboration, and for this reason the present study adds to our understanding of the use of computers in higher education. Some researchers have suggested that the downsides of group activities may lead to them being detrimental for simpler tasks whereby the transaction cost of interaction outweighs the learning benefits derived from collaboration (Kirschner et al., 2009). It may be the case that the notes taken in the present study represented a simple task, and, as such, the possible benefits of collaboration behaviors may be washed out by the transaction cost of interacting. For this reason, while the present study gives valuable insight into collaborations' effect on learning, it may not be completely generalizable to other situations where learners collaborate.

Future research will involve more subjects so that this can be addressed. An important step might be to compare students who took collaborative notes with those who did not take notes at all/or only took individual notes. This will help establish if collaborative note-taking is a viable and effective strategy to be used in online learning contexts. An important avenue for this research will be more in-depth analysis of student notes in the form of how students interact and what factors may lead to more students benefiting from group work. Instrumentation to track psycho-social interactive components during online collaboration behavior (i.e., instances of feelings of support and encouragement, conception of team identity, etc.), also constitute an important way forward for the field for the purpose of developing more in depth understanding of collaboration. As the present study was conducted in an English as a foreign language learning environment, it is worth considering whether and how language proficiency would affect students' ability to participate in note-taking and to engage in editing and commenting on the work of their peers. However, in this study, there was a very high and consistent level of participation from nearly all subjects. Considering this and the aforementioned high level of English proficiency of graduate students at the institution, it is likely that issues related to language proficiency did not inhibit participation and collaboration greatly. A final limitation of this study is that it did not account for possible backchannel communication through face-to-face meetings, instant messaging, teleconferencing, or phone calls. While these interactions are likely to have affected the working process of the groups, they are difficult to account for, as they involve the private conversations and communications of group members.

Future research could also look into how students' perceptions of their online behaviors impacted the performance in the weekly quizzes. This might help build a more multidimensional perspective on the collaboration that occurs in this type of learning context. With the inevitable move toward complete online learning in universities, current open-source research technologies (such as Google Docs, associated add-ons, and openly available software, including R statistical software) allow for the careful tailoring of research designs to move this field forward. A more nuanced understanding of online collaboration and the benefits of note-taking over the course of learning can lead to improved course designs and collaborative learning opportunities.

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Appendix A

Table 1A
Skewness Statistics for Variables of Interest

Variables	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
				Within-Group Variables (Overall Means and SDs)						
Quiz	-1.28	-1.08	-0.76	-2.26	-0.93	-1.43	-1.17	-0.45	-1.36	-0.45
Volume	1.64	1.37	1.80	1.86	2.21	1.60	1.71	2.10	1.97	1.64
Edits	6.46	3.44	5.87	7.01	3.54	4.22	6.77	5.63	5.03	3.55
Sessions	1.49	1.69	1.71	3.24	2.12	1.70	1.53	2.37	2.10	2.20
				Between-Group Variables (Group means and SDs)						
Quiz (M)	-1.04	-0.78	-1.38	-1.21	-1.92	-0.99	-2.07	-0.71	-0.97	-0.30
Volume (M)	0.82	1.46	0.92	0.33	0.13	0.70	0.25	0.69	0.66	-0.08
Edits (M)	2.67	1.80	3.13	3.05	1.23	1.61	2.74	2.68	1.76	1.44
Sessions (M)	0.59	1.48	1.60	2.45	1.05	0.58	1.54	1.49	1.41	1.28
Evenness	0.26	0.24	0.53	0.25	0.03	0.18	0.28	0.95	-0.10	-0.08
Completeness	-1.04	-0.95	-1..48	-1.08	-2.14	-1.43	-1.15	-0.65	-1.23	-1.43

Note. Number of groups = 61; N = 273; volume and completeness given to closest integer; means and standard deviations for between-group variables based on vectors of group means; groups comprised of 3 to 5 students.