CHANGE OF COLLABORATION OVER TIME: A CASE STUDY OF COLLEGE STUDENTS IN DISCUSSION SECTIONS OF A MATHEMATICS COURSE

BY

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THESIS

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ABSTRACT

Previous research on collaborative learning has found that the quality of collaboration varied across groups with students' interactive patterns, learning goals, etc. Less evaluate the change in the quality of collaboration across time. A case study of a group of four college students who engaged in a discussion section of a mathematics course was performed. Students' collaboration in Week 4, Week 5, and Week 7 was evaluated along four dimensions: convergence, explanation, regulation, and ignoring. Results were mixed regarding if the quality of collaboration improved across time. There was an increase in evidence for knowledge convergence from Week 4 to Week 7. However, results showed a decrease in total explanatory moves and no improvement in regulatory and ignoring behaviors. Possible explanations for these results were discussed. Additionally, this paper suggests implications of these results for researchers who focus on collaborative learning in college discussion sections.

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CHAPTER 1: INTRODUCTION

Collaborative learning has been a well-known and popular topic in educational research and the benefits of practicing collaborative learning have been found. There is sufficient evidence showing that collaborative learning takes a crucial role in both social and academic aspects of students' development. (Johnsons 1989; Pantiz, 1999). From the social aspect, one benefit of collaborative learning is to train students in social skills including expressing, negotiating, and defending their ideas (Johnson et al., 1984). Through this process, students are able to understand their differences and to learn how to build heterogeneous relationships (Webb, 1980). These skills are also an important component of conflict management (Johnsons, 1990). From the academic aspect, collaborative learning motivates students to develop higher-level thinking skills through listening to others' thoughts, discussing with peers and building new ideas together (Webb, 1982). Past longitudinal case studies found that after adopting a collaborative learning model to a classroom, students became more critical than students in other classrooms and were able to hold an objective view of one's work (Whatley & Bell, 2003). These studies indicate the complexity of collaborative learning as not only a type of learning approach but a type of social interaction as well.

The practice of collaborative learning in schools shows that collaboration represents a shift away from traditional teaching pedagogy, which is teacher-centered or lecture-centered, to a student-centered teaching approach (Smith & MacGregor, 1992). A prevalent format of collaborative learning in higher education was the discussion groups and seminars. They represent a broad array of teaching approaches. Some discussion groups are part of a course that mostly consists of lecturing, and the discussion section is to supplement the regular lecture and to provide an environment for students to practice group work. These discussion sections motivate students to exchange ideas of topics being taught in lectures and enhance their understanding even when no student in the group knows the correct answer (Smith, et al., 2009). Thus, studying students' interaction in college discussion sections is an effective way to investigate collaborative learning.

The process of collaborative learning is more than adding up individual work. Past theories that emphasize the value of collaborative learning attempt to indicate what fosters the effectiveness of collaborative learning. Some studies have investigated elements of successful collaboration and collaborative variability across different groups (Mattessich & Monsey, 1992; Barron, 2003), but fewer of them focus on the changes within a single group in the collaboration across time. What has been observed in collaborative groups is that learners are usually strangers in the beginning and become more familiar with each other across time. This indicates that the relationship between students may change as they collaborate more in the group. Swenson and Strough (2008) found that the relationship quality of group members was related to the group performance on the task. According to the study, a group of acquaintances would perform better at collaborative learning as their relationship became closer. Thus, it is worth exploring students' collaboration across time along multiple dimensions, looking for a change in the quality of collaboration between earlier and later weeks.

Collaborative learning is a process of constructing shared knowledge or concepts through synchronous or coordinated activities (Roschelle & Teasley, 1995). It occurs in a joint problem space that is a shared knowledge structure including coordinated language and actions. Roschelle and Teasley (1995) argue against traditional theories of cognitive psychology which considers collaborative learning merely as a process inside each individual's head. Instead, they propose that collaborative learning occurs in a space that integrates individuals' shared language, situation, and activity. This theory led to the design of their study which emphasized conversation analysis, protocol analysis, and their relation to the construction of a joint problem space. The analysis of collaboration included how students introduced knowledge to the space and how they monitored divergence in individual concepts. Based on this theory, Barron (2003) proposes a dual-mode that consists of both a content space and a relational space to explain the cognitive and social aspects of the joint problem space. She indicates that successful collaboration requires people to attend to both spaces simultaneously. A content space consists of the problem to be solved and a relational space consists of interaction between group members. One needs to address one's epistemic process as well as others'. According to Barron, this process may involve asserting one's work, sharing insights, expressing confusion, etc. The dual model was then used to investigate the social and cognitive factors that contributed to productive collaborative learning and to indicate variability in collaboration across different groups. A correlation between the learning outcome of a group and how students respond to each other's correct proposals was found. Students in successful groups were more likely to accept correct proposals and less likely to reject or ignore correct proposals. Barron investigated variability in collaborative learning across groups and the factors that were correlated with the learning outcome. The dual space model, which was based on the model of joint problem space, provides insights for the present study which examined the change in the quality of collaboration along multiple dimensions.

The concept of "quality of collaboration" has been proposed in past studies and there are some elements mentioned in many of them. One element that can represent the quality of collaboration is the construction of shared knowledge (e.g. Detienne et al, 2012; Roschelle & Teasley, 1995; Teasley et al., 2008). Roschelle (1992) has found that knowledge convergence occurs during collaborative learning. He conducted a case study of paired students working together on physics problems and analyzed how achievement of shared knowledge occurs as a social outcome. Using a qualitative method, Roschelle did a microanalysis of utterances the students produced and evaluated collaboration along three dimensions: conversational action, conceptual change, and shared knowledge. There was a framework of progressively increasing evidence for knowledge convergence used to assess the extent to which students converged (Roschelle, 1992). In the framework, the lowest level of evidence was a smooth continuation to the next topic. A higher level could be characterized by a simple affirmative acknowledgment. A verbatim recitation represented a level even higher. The highest level of evidence for convergence is a mutually acceptable elaboration of a concept. The finding supported this progressive framework and showed that convergent conceptual change was achieved through negotiation of the meanings in conversational interactions.

Studies that followed Rochelle's (1992) paper have focused on the construction of shared knowledge in collaborative learning. Some studies measured knowledge convergence by quantifying the process (Jeong & Chi, 2007; Weinberger et al., 2007; Mercier, 2017). Weinberger (2007) indicates two approaches to explore how knowledge convergence occurred: knowledge level approach and transactivity approach. The knowledge level approach evaluates the knowledge of the task and the knowledge of the team. The transactivity approach emphasizes how students refer to others' contributions. It captures the dynamics of the construction of shared knowledge. Past studies focused on the relationship between students' interactive patterns and knowledge convergence. Jeong and Chi (2007) measured both shared knowledge gained in each group and students' individual knowledge gain from the task by calculating the increase in knowledge pieces. The study revealed that the group with more interaction produced more common knowledge. Knowledge convergence originated from the interaction between different pairs of students. The construction of common knowledge was from interacting with a specific partner, which showed that knowledge convergence could change with changing the person one collaborated with. Mercier (2017) adopted a different method to evaluate knowledge convergence. In the study, students were required to explain to the experimenter about their strategies for building a structure. Knowledge convergence was measured as the number of principles that both students in the pair explained. Both knowledge level approach and transactivity approach were adopted. Change in knowledge level was evaluated by measuring the gain in new knowledge or exchange of previous knowledge. The transactivity was examined by comparing whether the change in knowledge differed between groups with different goals and whether the knowledge gain was correlated with each group's interactive pattern. The study found that groups with a learning goal generated more common knowledge than groups with a performance goal. Further analysis of students' interactions indicated that different interaction behaviors influenced the dynamics of constructing common knowledge. What was not fully investigated in these studies was whether knowledge convergence changed across time when staying with the same partner/s. This leads to the first research question of the present study: did a group of students show increasing evidence for knowledge convergence across time?

The dual space model in Barron (2003) discusses the connection between the content space and the relational space. One focus on the connection is on how knowledge is shared with one's partners. This process includes convincing others by explaining one's own ideas. Explaining is commonly found in the process of constructing shared knowledge (Roschelle, 1992). Learning to formulate explanations is important not only to one's thinking but also to the group's collaboration. Interventions that encourage students to explain in group discussions can significantly increase students' collaborative performances (Coleman, 1998). An explanation can be evaluated regarding the complexity, which is represented by the number of concepts referred to in the explanation (Coleman, 1998). It can also be measured based on its quality regarding the accuracy and completeness of explanations (Webb et al., 2009). Roscoe and Chi (2008) investigated the different patterns between knowledge-telling and knowledge-building of explanation. Knowledge-telling is simply paraphrasing statements and facts, while knowledge-building consists of different methods that integrate concepts and generate inferences. This includes generating novel examples, reviewing materials, etc. Explanations stimulated by a peer's questions are more likely to be knowledge-building than knowledge-telling. Since their study focused on peer tutoring, it emphasizes individual differences in explaining but did not examine if they change or develop with time. In a college discussion section where students are assigned to groups instead of peers, it is worth studying individual's behavior in the group. The present study investigated not only change in patterns of explanations of a group across time but individual differences in explaining as well. The second research question, regarding this point, was whether there was any change in strategies of students explaining across time or any individual differences in such strategies.

In a discussion section at the university, group work is usually managed by students although the Teaching Assistant may provide instructions and answer questions. Students do not only construct ideas in the content space but also manage participation in the relational space. Group regulation is one of the notable directions of studying the relational space in collaborative learning (Mercier et al., 2014). Three types of regulated learning contribute to collaboration: self-regulation, co-regulation, and shared regulation (Järvelä & Hadwin, 2013). Self-regulation is grounded in social cognitive theory and it extends the concept of learning beyond cognitive processes. Although this process occurs in both solo work and collaborative tasks, it requires each student's individual effort to manage their own cognitive process in collaborative learning and does not involve the interaction between students. Co-regulation, compared to self-regulation, operates when individuals hold their own perspectives and attend to each other's perspectives simultaneously. Shared regulation occurs when individuals construct shared goals and perceptions and produce collective progress. In another study that emphasizes the role of co-regulation in collaborative learning specifically, shared regulation is considered to be the most effective mode of co-regulation (Volet et al., 2009). The study investigates co-regulation of university students who work on a group assignment with no teacher supervision. Each group of students has had two meetings, and the percentage of time for which co-regulation occurs in each meeting has been measured. The result partly supports the assumption that in the second group meeting students should produce more co-regulation. However, since the content of each meeting for each group was determined by students and not controlled, the study is inadequate in addressing change in regulation across time. In this paper, the group of students investigated took three discussion sections of the same duration and were assigned similar problem-solving tasks in each section. Thus, it was easier to emphasize the change in group regulation across time when other factors (i.e., the environment, the task, etc.) were controlled. The third research question of the present study was to test the assumption that there was a greater opportunity for co-regulation to occur after the group of students had met multiple times.

Barron (2003) quantifies conversations in her study by measuring how participants responded to each other, which included rejecting or ignoring others' proposals. Webb (2013) also argues that failure to seek or obtain effective feedback from peers is a process that inhibits collaborative learning. Both studies suggest that ignoring the behavior is a negative factor for high-quality collaboration. There are several reasons for which a person gets ignored in group work. Students may ignore statements that they do not acknowledge or repeat their ideas when another person is asking a question (Barron, 2000). Compared to acquaintances, conversations between strangers are disrupted more frequently (Kent et al., 1981) and the overall performance of collaboration of strangers is lower (Swenson & Strough, 2008). These results suggest that the quality of collaboration may increase as the group members know each other better. This leads to the assumption that ignoring behavior in a group may decrease across time. The present study tested this assumption by measuring the instances of ignoring that occurred in the group in every discussion section and attempted to answer the research question that whether ignoring behavior decreased across time.

To conclude, past studies have provided much evidence for variability in collaboration across groups and individuals. However, fewer studies focused on change in collaboration across time. The present study integrated the factors that were assessed in past studies and evaluated the quality of collaboration along four dimensions. Four research questions, one for each dimension, were addressed:

1. Did the group show increasing evidence for knowledge convergence across time?
2. Was there any change in strategies of students explaining across time or any individual difference in using strategies?
3. Was there an increase in co-regulation across time?
4. Did ignoring behavior decrease across time?

CHAPTER 2: METHOD

Design

This study is part of a multi-year, design-based implementation project (Penuel et. al., 2011); the current work is a case study of one group during a single implementation cycle. Data were collected in a discussion section of an undergraduate mathematics course that taught applied linear algebra. The course fulfills a requirement for many STEM majors and enrolls about 2,000 students per year. The discussion section had twenty-nine students and one teaching assistant (a math graduate student) who answered students' questions as needed. In the third week of the semester, students were assigned to eight groups of three or four and stayed in the same group throughout the semester. The course was 13 weeks long with the first 8 weeks in-person and the last 5 weeks online due to the university's policy during the COVID-19 pandemic. Data collection for the project began in week 4 to allow time for group assignment and training on the software that was used. Each group was recorded by a camera and a tabletop microphone or a hanging microphone assigned to it.

Participants

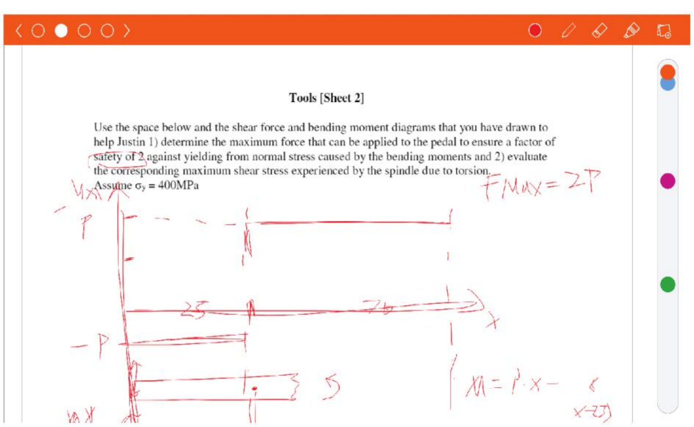
Four discussion sections of one hundred and eight undergraduate students participated in the project. The group of four students selected for this case study was from a section of twenty-nine students who attended the same section each week. Students in this class attend a lecture three times per week and a discussion section once per week. One group of students were selected for this case study. Data from this group were collected in five weeks. It had five 50-minute videos but only three of them were selected and analyzed due to one student's absence in the other two weeks' videos. The group was selected because, for a case study, I wanted to study an active group of students that vary in participation through the weeks. Thus, the group was selected because a review of the video data showed that the students in this group provided a great number of interactive moves, and there appeared to be some variation in their engagement in the task across discussion sections. Four students were labeled as S1, S2, S3, and S4 for the convenience of coding. From the video, it is clear to see each student's body movements as well as eye gaze. Sometimes it is possible to see the screens of their tablets and from there it can be inferred which page they are on. Verbal interaction is the primary interaction that takes place in the video and the audio data was collected by the tabletop microphone.

Software

Students worked collaboratively on a worksheet with problem-solving tasks using software on tablets that were provided to each student by the research team embedded in the tablet that synchronized within their group. This software was specifically designed to support collaborative learning, and the creation of joint representations in engineering courses, synchronized across tablets in a group, allowing students to work in the same workspace; this implementation was the first iteration in a non-engineering context. However, the students had not begun to work on tablets until Week 4 due to various technical issues of the recording devices and the software in the first 3 weeks. Figure. 1 shows the interface of the software. In the upper-left corner was the page navigator indicating which page each student was on. In the upper-right corner were the basic writing, erasing, and selecting tools. The scroll bar on the right side of each page had colored dots showing each student's location on the page.

Figure 1

The Interface of the Software Students Used in Class



The Tasks

The tasks assigned to students consisted of problems from a "problem bank" that was maintained by the mathematics department. The professor of the course designed these problems with the following structure:

- There would be a few calculation problems at the beginning of the worksheet to help students get started.
- The major body of the worksheet focused on typical conceptual problems that required students to use mathematical concepts from the course.
- There was one applied problem at the end that was a conceptual problem in a real-world scenario.

The mathematical concepts of the problems are different each week. Week 4 was about LU decomposition and matrix inverses. Week 5 was about the definitions of vector spaces. Week 7 was about the basis for a vector space and dimension.

Data sources

The video of the group was recorded in a lab classroom by a camera on the ceiling. The audio of the group was recorded by a tabletop microphone on the desk. Videos were transcribed by the author and checked by another graduate student, using a play script format with speaker's names (i.e., S1, S2, S3, S4), timestamps and line numbers. The time stamps were tagged every three to four minutes because, after reviewing the transcripts, it showed that the group produced approximately 30 to 50 turns of conversation every three minutes. Timestamping was to help the author jump to a specific point of conversation, and 30 turns usually contained an appropriate amount of information for the author to review. Line numbers indicated the turns of the interaction. For all analysis, transcripts were viewed alongside the videos to capture the speaker's tone, gesture, etc.

Data Analysis

In the first stage of data analysis, the transcripts were content logged for the highlights of students' interaction. Themes were noted and then used as the basis to create a coding scheme. In the second phase, a coding scheme of four dimensions (see table 1) was created based on highlights observed from transcripts and frameworks used in earlier studies. The study used the following four dimensions as criteria to assess students' collaboration: 1) convergence, 2) explanation, 3) ignoring, and 4) regulation.

Convergence

Table 1

Codes for Convergence

Code	Description	Example
Acknowledgment only	Short expressions of acknowledgment of one's statements without complementary information or an intent to move the conversation forward.	“That’s right.”
Acknowledgment repeating only	Repetition of one's statements indicating acknowledgment. Repetition can either appear alone or follow a short expression of simple acknowledgment (i.e., "yes," "right").	S1: "That'll be the first one, I think" S2: "It's the first one."
Acknowledgment prompt conversation	Expressions of acknowledgment of one's statement followed by either complementary information of the topic or words that move the conversation forward (e.g. asking for an explanation of the current topic or starting a discussion on a new topic, etc.)	S1: "I think you are right. It's not invertible because the determinant is zero." S2: "That works. How did you get it?"

Explanation

This study aimed to find out the change in strategies students used when they explained to others instead of the accuracy of their explanations. Thus, the framework of categorizing explanations in prior research was not used. The present study used an inductive approach to generate four codes from the transcript to analyze explanations (see Table 1). These codes were extracted from interactions in which ideas were given by one student to another. Analyzing these interactions indicated how ideas were generated and transmitted in the group.

Table 2

Codes for Explanation

Code	Description	Example
External sources	Directly referred to external sources to explain an idea or justify one's work	“The lecture note says…”
Narration	Narrate what steps one has taken to answer the question; muttering to self does not count)	“I just added these numbers up, and it gives the answer.”
Suggestion	Suggest a possible answer to or method for the task	"Let's just assume that it is three"
Example	Provide a scenario or example to explain a concept or provide a solution	“If the matrix is 1000, then its vector...”

Regulation

Codes for regulation were initially identified from the content logs of data by extracting students' moves that relate to group dynamics but independent of the specific topic in the task assigned. Halpin and Winer (1975) proposed two major clusters of leadership moves: consideration and initiation, and Li et al. (2007) broke them down into five categories that were more desirable to their study. After repeatedly watching the videos and reading the content logs, the present study combined and modified the clusters into two different categories and built a coding scheme based on them (Table 4).

Table 3

Codes for Regulation

Code	Description	Example
Progress management	Statements or questions of the working progress of the task	"Which question are you at?"

Table 3 (continued)

Codes for Regulation

Code	Description	Example
Reference to peer work	Referred to another student's words, idea, or work	"Did you mention that this matrix is invertible?"

Ignoring

There was only one code in this dimension that was ignoring (Table 3). Ignoring was coded when a student explicitly asked a question to a particular student or the group and there was neither verbal response nor nonverbal cues that show someone in the group was listening to the question. Nonverbal cues observed from the video as responses were:

1. Eye contact with the speaker
2. Eye gaze toward the speaker's tablet
3. Shake or nod one's head

When a question was specifically directed to a particular student who did not answer, ignoring was not coded if someone else in the group responded. This was because the study examined the ignoring behavior based on the group. Thus, ignoring was coded only if someone was ignored by the whole group.

Table 4

Codes for Ignoring

Code	Description	Example
Ignoring	When a student explicitly asked a question to a particular student or to the group there was neither verbal response nor nonverbal cues that show someone in the group was listening to the question	Student 1: "did you guys already get the answer?" Student 2, 3 & 4 looked at their tablets and did not respond.

It should be noted that in coding explanation, convergence, and regulation, the unit of analysis was the turn. One turn was counted when 1) the speaker stopped talking and stayed silent for more than three seconds, or 2) the speaker finished a whole sentence and another speaker started to talk, or 3) the speaker did not finish a whole sentence and was cut off by another speaker. If the student used two or more moves from different dimensions in one turn, all the moves were counted. Ignoring coding was not turn-based because the student did not necessarily receive a response in one turn. It was observed that after repeating a question the student could catch another student's attention and receive responses, which was not counted as ignoring.

CHAPTER 3: RESULTS

This study set out to examine the changes in four dimensions of collaboration over time. First, data were transcribed and the number of total turns each student made in each week was measured and presented in Table 5. S2 and S3 together took more than two-thirds of the total turns of the group every week. For the other two students, S4 took more turns than S1 did in Week 4 and Week 5. Taking more turns does not necessarily mean being more productive in learning in the group. Thus, the transcripts were coded to find out the number of turns for each dimension. The following section will present results for each dimension and address the research questions proposed in the introduction.

Table 5: Numbers of turns made in each section by each student

Student	Week 4	Week 5	Week 7
S1	55	53	60
S2	193	145	193
S3	140	177	138
S4	92	89	22
Total	480	464	413

Research Question 1: Did a group of students show increasing evidence for knowledge convergence across time

To understand how knowledge convergence changed over time, the data was coded using the coding scheme described in Table 1. Three levels of convergence were assessed regarding how much the convergence prompted interaction. They are Acknowledgment Only, Acknowledgment Repeating, and Acknowledgment Prompt Conversation. Figure 3 showed the overall trend of the convergence pattern from Week 4 to Week 7. The result showed an increasing trend in total moves that could indicate different levels of evidence for convergence increased across time, with the lowest number of 13 moves in Week 4, 12 moves in Week 5, and 31 moves in Week 7. When examining the number of moves at each level, the result showed a gradual increase in Acknowledgment Only moves across time but no change in the number of Acknowledgment Repeating moves. There were more Acknowledgment Prompt Conversation moves in Week 7 than in Week 4, but zero move observed in Week 5.

Figure 2

Total Moves of Convergence in Each Section

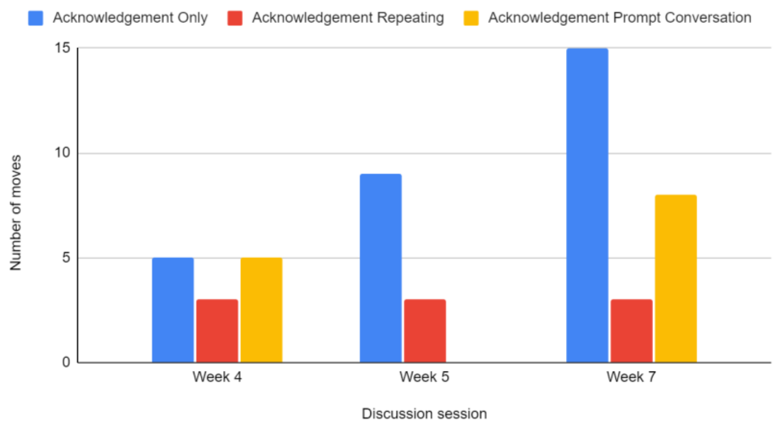


Table 6 is an episode that shows Acknowledge Prompt Conversation moves in the group's discussion on a true or false question. It shows how Acknowledgment Prompt Conversation moves drove ongoing interaction and led to the construction of shared knowledge. When S2 gave his answer to the true or false question, S3 did not just acknowledge the answer. Instead, she also gave her own justification for the answer which prompted S2 to indicate a different opinion. Then they addressed their divergence in how to understand the question. One might imagine that if S3 simply acknowledged S2's answer without adding additional information or proposal, there would be no opportunity to reveal the students' different understandings of the topic. Thus, compared to Acknowledgment Only and Acknowledgment Repeating moves, an increase in Acknowledgment Prompt Conversation moves had a stronger connection with more knowledge convergence.

Table 6

An Example of an Acknowledgment Prompt Conversation Move

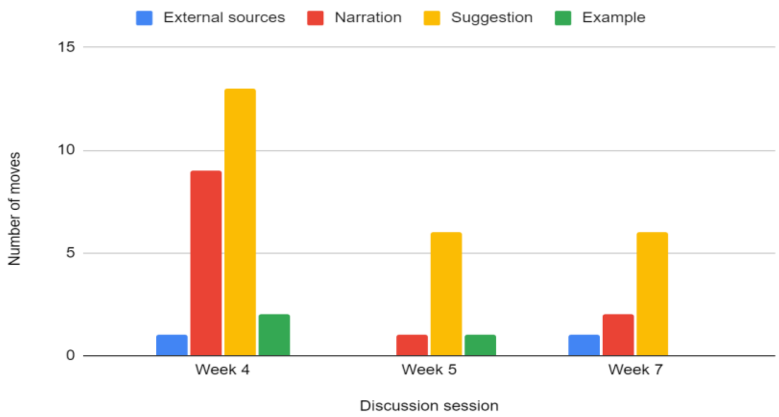
Speaker	Dialogue	Code
S1	Is five true?	
S3	If a set of spans and its T is a set of linearly two vectors...	
S2	Well, you will find it true if T is linear	
S3	Right. Overall I think this is true because then you have more than the vectors that are in the vector space.	Acknowledgment Prompt Conversation
S2	But we are looking for dependent. Some of them are gonna be in the set.	
S3	Well it means T has the set, not the vectors are dependent.	

Research Question 2: Whether there was any change in strategies of students explaining across time or any individual differences in such strategies?

To investigate the strategies students used to explain in collaboration, students' verbal interaction was coded using the coding scheme in Table 2. Referring to external sources, narrating, suggesting, and offering examples were the four techniques for explaining the group used in the study. There were a total of 25 explanatory moves in Week 4, 8 moves in Week 5, and 9 moves in Week 7. The result showed a decrease in the total number of explanatory moves across three weeks. Figure 3 is the distribution of uses of these techniques across three sessions. Students in the group used suggestion as a technique most frequently to explain their ideas, with a mean of 8.3 moves in every session. The second frequently used was narrating, with a mean of 3.7 moves. Referring to external sources and offering examples were least frequently used, the former with a mean of 0.7 moves and the latter with a mean of 1 move. An individual difference in strategies was also observed. In Week 4, S1, S2, and S4 preferred to use suggestions when explaining while S3 was the only student who preferred narration over other techniques. In Week 5, the group's on-task conversation dropped compared to the previous week due to technical issues of S3 and S4's tablets.

Figure 3

Total Moves of Explanatory Techniques in Each Section



When coding the suggestion, which was the most frequently used technique, a pattern of two types of suggestions emerged. It is worth noting them here for the benefit of a detailed investigation if needed in the future. Suggestions observed could be categorized into direct and indirect oneness regarding the tone and subject used in them. A direct suggestion gave clear instruction on how to solve a problem. Table 7 is an episode that shows a direct suggestion.

Table 7

An Example of a Direct Suggestion

Speaker	Dialogue	Code
S2	Did you get the span for the first one?	
S4	I think the question says that the vector is...[muttering the question]. So **you just have to try and write** the vector as the span because it could be written of the span that doesn't…[looking at S2 and stopped talking]	Suggestion
	[On-task discussion ongoing]	
S2	I'm trying to think about the countering- I'm trying to think about countering examples	
S4	Yeah	
S2	And **let's just assume** that this one is invertible, so AD...We know	Suggestion

that AD minus BC is not equal to zero, so that means…

In Episode 2, S4 gave S2 a direct suggestion starting with the second-person subject "you" and told S2 to "try and write the vector as the span". This suggestion clearly indicates the possible action S2 can take to "get span for the first one". A direct suggestion could also use an imperative tone, which is shown in the following example.

An indirect suggestion did not give any clear instruction on actions to be taken to answer the question. Instead, the student attempted to suggest by expressing his/her thoughts and feelings. This type of suggestion more likely used the first-person subject "I". Unlike a direct suggestion that was prompted by a question, an indirect suggestion was not necessarily preceded by a question. Table 8 is an episode that shows an indirect suggestion in the group's collaboration.

Table 8

An Example of an Indirect Suggestion

Speaker	Dialogue	Code
S2	When you make them inverse...you would need to inverse them on the left side. That's not what we are looking for. It's not gonna multiply in the end.	
S1	[laughs] Okay.	
S2	I don't really want to. **I'd rather just move on**. I can test it on my own but I don't think that's really necessary for that question.	Suggestion
S1	Yeah.	

Research Question 3: Was there a greater opportunity for co-regulation to occur after the group of students had met multiple times?

Figure 4 showed that there was more progress planning than reference to peer work. There were more than twice as many regulatory moves in Week 4 (n = 8) and 7 (n = 9) than in Week 5 (n =3). The individual difference was indicated in Figure 5. S2 was responsible for the majority of regulatory moves in Week 4 and Week 7. In Week 5, regulatory moves were evenly distributed among S2, S3, and S4.

Figure 4

Number of Regulatory Moves in Each Section

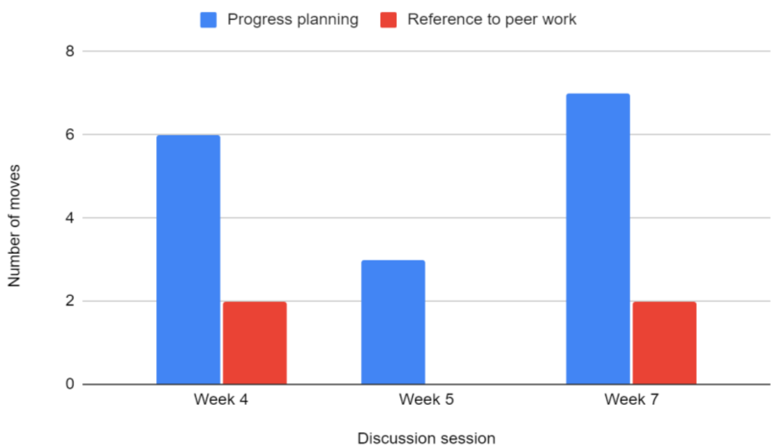
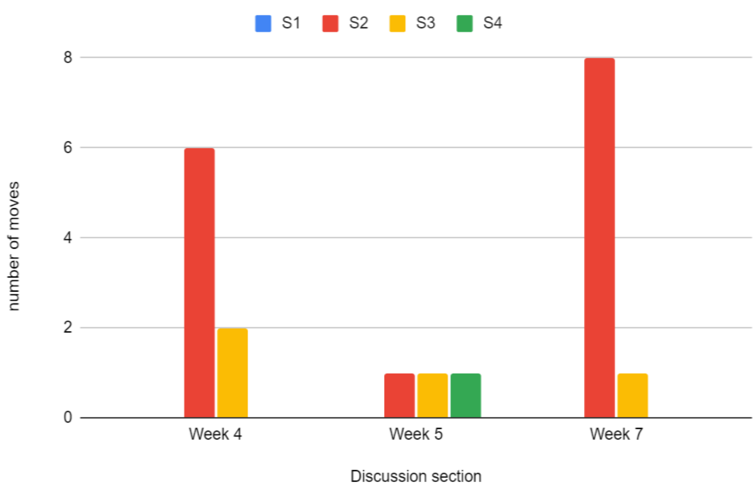


Figure 5

Regulatory Moves Each Student Took in Each Section



In terms of group progress, S2 was the student who managed the group progress most frequently. His action of bringing up the group's progress effectively initiated discussions on the task. Table 9 shows an example of a regulatory move that occurred at the beginning of the section in Week 4, when S1, S3, and

S4 just finished some off-topic discussion and attended to the worksheet. It shows how S2's regulatory move initiated the on-task discussion.

Table 9

An Example of a Regulatory Move

Speaker	Dialogue	Code
S2	How did you guys…You guys already did one? [looking around others' tablets]	Progress planning
S1	Yeah…what?	
S2	One. Where did you guys-	
S3	Um…	
S1	I did the rest of the operation for the identity matrix.	
S2	[looking at the question and muttering to himself]	
S1	[looking at the question] Did you guys remember we make matrices invertible? We make the possible V invertible?	
S2	Um...	
S3	Is this a two by…Oh, what makes it possible to be invertible.	

In this example, S2 asked the group if they did question one because he saw that S1 went to page 2 and started reading question 3 while other students were still on page 1. S2's question led S1 to tell the group what he just did for question one and to initiate a discussion on the question.

Another similar episode occurred in the second half of the section. The students were working on the worksheet at different paces through the first half of the section. S2 and S1 just finished an argument over one topic and S2 realized that he was looking at the wrong question. At this moment, when S3 said that there were just question 5 and question 8 left before they completed the worksheet, S2 asked about question 6, which was done by S3 independently. This triggered S3 to narrate what she did to answer question 6 and to find out a confusing point of the question. Then she raised her hand and asked TA for clarification.

Research Question 4: Did ignoring behavior decrease across time?

The result did not indicate a decrease in ignoring behavior across time. Figure 6 shows that ignoring took place more frequently in Week 5 than in Week 4 and Week 7. To better understand the instances of ignoring, the percentage of turns that were ignored for each student in each week as well as the average percentage across three weeks were calculated and shown in Table 10. Except for S3 who was never ignored, average percentages of turns being ignored for S1, S2, and S4 were 1.2%, 0.9%, and 1.0%. This indicated a negligible difference in ignoring among the students when combining data across weeks. However, as can be seen by the data, the amount of ignoring was not high for any student.

Figure 6

Number of Instances That Each Student Got Ignored in Each Section

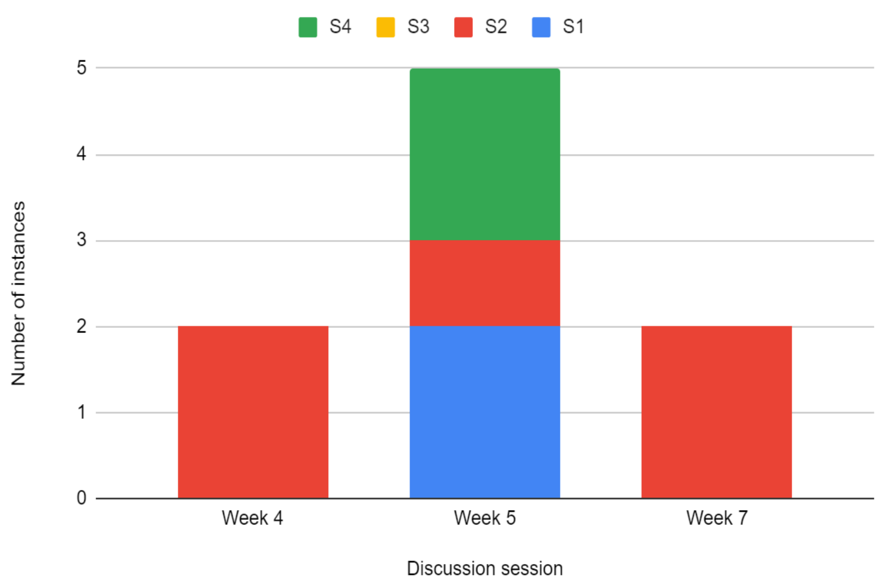


Table 10

Percentage of Turns Ignored for Each Student in Each Section

Student	Average percentage across three weeks	Week 4	Week 5	Week 7
S1	1.2%	0.0%	3.8%	0.0%
S2	0.9%	1.0%	0.7%	1.0%
S3	0.0%	0.0%	0.0%	0.0%
S4	1.0%	0.0%	2.2%	0.0%

CHAPTER 4: DISCUSSION

This study explored the change in the quality of collaboration of a group of students in mathematics discussion sections across time. Based on the elements evaluated in previous research, this case study selected four dimensions that were convergence, explanation, regulation, and ignoring to examine the quality of collaboration. The quality of collaboration of the group differed among discussion sections. However, further interpretations of the result show that it did not change fully across time. The following section gives a detailed interpretation of the result of each research question and provides more insights on possible factors that correlated to the change in collaboration.

For the first research question, “did the group show increasing evidence for knowledge convergence across time, the result partly supported that evidence for knowledge convergence increased from Week 4 to Week 7. However, the increasing trend did not apply to every level of evidence for convergence in the study. Acknowledgment Only moves increased across weeks. These moves were considered to lack students’ intention to move the conversation further or to build on each other’s ideas. According to the progressive model of increasing evidence for convergence, simple affirmative acknowledgment (i.e., “That’s right,”“Yes”) was at the second-lowest level (Roschelle, 1992). This means that these moves provided insufficient evidence for the construction of shared knowledge to occur although they showed agreement between students. Acknowledgment Repeating moves provided more evidence than Acknowledgement Only ones, by showing that one who acknowledged also processed the information from one’s peer. However, there was still no further information added on, which did not lead to the co-construction of concepts. Acknowledgment Prompt Conversation moves provided the strongest evidence for convergence because they revealed how students provided complementary information of the topic discussed or asked others to clarify their statements.

Although an association has been found between more interaction and more common knowledge (Jeong & Chi, 2007), it was not supported by the present study. Regarding the total turns of conversation, the group produced each week, there was very little difference in the amount of interaction among weeks. However, an increase in evidence for knowledge convergence across weeks was observed. A possible explanation for this is that in the past study the correlation between interaction and common knowledge generated was examined across multiple groups for which other variables (i.e., tasks) were controlled. Compared to the past study that was conducted in a laboratory setting, the present study observed students who were attending a real-world college discussion section where the Teaching Assistant might intervene and students' behavior received minimal intervention from the researcher. To test the correlation between the amount of interaction and the production of common knowledge, an effort to analyze the interactive pattern is needed. The total number of turns should not be the only variable considered. Turns consist of intervention of the Teaching Assistant and topics beyond the assigned task need to be extracted and examined separately.

For the second research question, "whether there was any change in strategies of students explaining across time or any individual differences in such strategies", the decrease in the total number of explanatory moves across time implied that less exchange of ideas occurred in Week 5 and Week 7 than in Week 4. This did not mean that students' overall interaction decreased overall because the total number of conversational turns did not drop across time. One possible reason for the decrease in explanation is that students responded to each other's questions not with an explanation but with confusion or uncertainty. They were less confident in explaining the concepts of tasks assigned in Week 5 and Week 7 to others. The difficulty of tasks in each week remains to be investigated to fully justify this reason. Measuring turns with questions or confusion is also needed to indicate students' responses to questions other than explaining.

It was worth noting that students most frequently gave suggestions over other techniques each week. As discussed in past studies, explanations can be categorized into knowledge-telling and knowledge-building. Explanation in the form of simple knowledge-telling was rarely observed in the present study, partly because students had high autonomy in deciding when and how they would like to explain in the discussion section. The purpose of explaining for them was not to simply tell the facts to others but to help others understand. This is consistent with the theory that explanations motivated by questions are more likely to be knowledge-building than knowledge-telling (Roscoe & Chi, 2008). Among the four techniques observed in the present study, directly referring to external resources was the case when students were most likely to 'tell' the knowledge instead of building on it. As the result revealed, it was the least frequently used technique by all students every week. One explanation for this is that very few questions in the tasks required students to simply paraphrase mathematics definitions or formulas. Instead, they tested students' ability to build on concepts from the course and to apply them in real-world scenarios.

For the third research question, "was there an increase in co-regulation across time," a pattern contrast to entirely shared regulation was observed. The theory of entirely shared regulation indicates that students in the group hold shared goals and produce collective progress. However, in an effective collaborative group, it is still possible to have one individual who manages the group's motivations and knowledge co-construction (Mercier et al., 2014). In the present study, the total regulatory moves S2 made were five times more than those made by other students. This student appeared to be the only individual who managed the group level progress and attempted to motivate knowledge co-construction. He also maintained his leadership role in both Week 4 and Week 7. In Week 5, the number of regulatory moves dropped dramatically and no individual appeared to lead the group. This is largely due to the technical issue S4 and S3 had in the first half of the class. The issue caused their tablets to freeze, which made them disengage from the group occasionally. S1, who was the only student S2 could discuss questions with, appeared to be the least active student in verbal interactions. This caused difficulty for S2 to keep track of group progress.

The finding on S2's leadership role should be evaluated along with the result of ignoring the behavior. S2, who made more regulatory moves than other students did, also got ignored more frequently than others. And none of S2's regulatory moves was ignored, implying no direct correlation between these two dimensions. Although S2 was the only student who was ignored in Week 4 and Week 7, the average percentages of turns ignored for each student did not imply a higher chance for S2 to be ignored. It should be expected that ignoring would decrease across time, but it was not supported by the finding. One explanation for this is that ignoring was rare especially when compared to the other three dimensions. A simple comparison of numbers would not yield desirable implications on ignoring the behavior. To more effectively evaluate the influence of ignoring on collaborative learning, the concept of ignoring should be extended. In the present study, ignoring was coded only when a student’s words were fully neglected, receiving neither verbal response nor nonverbal cue from anyone in the group. However, a broader concept of ignoring can be defined based on if one receives effective feedback from a response. Webb (1991) studies nonresponsive feedback and its influence on collaborative learning. The concept of nonresponsive feedback includes the definition of ignoring in the present study. It also consists of cases when one responds to others but ignores the error in the information one receives. By expanding the concept of ignoring, more ignoring-related behavior will be analyzed to provide additional evidence for change in ignoring across time.

Limitations

As noted in the introduction, the goal of the present study was to provide evidence for the dimensions of collaboration that students would still struggle with across time. The findings of the present study indicate that there will be an increasing chance for a group of students to construct shared knowledge across time. This can occur with minimal intervention from an instructor. In real-world scenarios, some instructors encourage students to share ideas in group discussions. This will provide students with more opportunities to construct shared knowledge. Regarding role-taking in group assignments, an instructor might expect that effective collaboration is when no individual dominates the discussion and the regulation of the group is fully shared. However, the present study implies that distributed regulation does not indicate the high quality of collaboration. For example, the quality of collaboration decreased due to the technical issue in Week 5, where the regulation was more evenly distributed compared to that in the other two weeks. But the high ignoring, low explanation, and low knowledge convergence indicated that the overall quality of collaboration in Week 5 was relatively low. The present study also indicates that the pattern of collaboration along some dimensions is fixed. Students' preference for suggesting others when explaining did not change across time. This is partly due to the similarity in the structure of the three tasks. The influence of changing the task structure on students' use of explaining techniques remains to be investigated. The instructor of the class should be encouraged to design tasks with more diverse problem sets, which will train students to adopt more techniques in explaining their ideas. Many past studies on group collaboration, including the present study, only coded verbal interaction but did not analyze students' writing about the task assigned, which leads to missing information from students' writing. Especially for a study in a computer-supported environment, students are impacted by each other not just by verbal communication. In the present study, the role of the synchronous tablet, which was an important medium of collaboration, was not investigated. More dimensions regarding the features of the tablet need to be considered to study the influence of the tablet on the change of collaboration. It has been observed that students tended to show their writing to others by turning the tablet toward someone, forgetting that their writing appeared on others tablets as they wrote. An investigation on how students' interaction with technology influences collaborative learning is needed.

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APPENDIX A: IRB LETTER

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Office of the Vice Chancellor for Research

Office for the Protection of Research Subjects
528 East Green Street
Suite 203
Champaign, IL 61820

July 11, 2016

Emma Mercier
Curriculum and Instruction
1310 S. 6th St., 396 Education Building
Champaign, IL   708

RE: *Improving collaborative learning in engineering classes through integrated tools for instructors and students*
IRB Protocol Number: 17016

Dear Dr. Mercier:

Thank you for submitting the completed IRB application form for your project entitled *Improving collaborative learning in engineering classes through integrated tools for instructors and students*. Your project was assigned Institutional Review Board (IRB) Protocol Number 17016 and reviewed. It has been determined that the research activities described in this application meet the criteria for exemption at 45CFR46.101(b)(1).

This determination of exemption only applies to the research study as submitted. Please note that additional modifications to your project need to be submitted to the IRB for review and exemption determination or approval before the modifications are initiated.

Copies of the attached, date-stamped consent form(s) are to be used when obtaining informed consent. If there is a need to revise or alter the consent form(s), please submit the revised form(s) for IRB review, approval, and date-stamping prior to use.

Exempt protocols will be closed and archived five years from the date of approval. Researchers will be required to contact our office if the study will continue beyond five years. If an amendment is submitted once the study has been archived, researchers will need to submit a new application and obtain approval prior to implementing the change.

We appreciate your conscientious adherence to the requirements of human subjects research. If you have any questions about the IRB process, or if you need assistance at any time, please feel free to contact me at OPRS, or visit our website at http://oprs.research.illinois.edu

Sincerely,

Ronald Banks, MS, CIP
Human Subjects Research Coordinator, Office for the Protection of Research Subjects

Attachments: approved consent letters

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