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The Development of Collaborative Keys to Promote Engagement in Undergraduate Online Asynchronous Statistics Courses

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ABSTRACT

Many online courses use discussion forums to encourage active engagement and student-to-student interaction in online courses. However, discussion forum assignments often lack much of the structure, format, and accountability that is associated with high-quality student experiences and student-to-student interactions. This paper uses a classroom research model to introduce, develop, and evaluate Collaborative Keys for an undergraduate student population. We will share how the Collaborative Keys were revised to facilitate cooperative learning in an asynchronous online introductory statistics course. We modified an existing social constructivism framework, the Community of Inquiry, to evaluate the essential social elements of student interactions both before and after substantial revisions were made to the Collaborative Keys based on previous investigations. The changes were done to encourage and support student-to-student interactions through the use of group collaborations rather than a whole class collaboration, individual accountability through individual answers, and support for positive interdependence between students by having a shared goal of one final answer for the group. Our initial results suggest that students were more effectively connected with their groups members and social interactions were improved using a revised version of the Collaborative Keys.

Keywords: student-to-student interactions, community of inquiry, social presence, computer-mediated-communication, cooperative/collaborative learning, interactive learning environment

1. INTRODUCTION

Virtual instruction has seen a surge in popularity in recent years, and is valued and utilized for its flexibility, access, and no physical space requirements. Online learning is particularly ideal for students with diverse needs and schedules that make it difficult to physically attend classes. The advantages are even greater for *asynchronous* online learning, where students have flexibility to complete course content at convenient times for them. This flexible timing can improve access for underrepresented populations who may be impacted by unpredictable health issues, work schedules, travel schedules (e.g., student athletes), and commitments caring for high-needs family members.

As online courses often serve an underrepresented student population, it is imperative that these courses maintain high-quality learning experiences for students in such a way that is equitable and inclusive. There is strong research evidence in favor of active and cooperative learning environments to serve historically disadvantaged students, and yet active and cooperative learning environments are particularly difficult to incorporate effectively in the online setting.

This paper introduces Collaborative Keys for the undergraduate student population. The Collaborative Keys are an assignment that invites students to actively engage in small-group discussions in asynchronous online courses. The Collaborative Keys were originally designed for graduate level biostatistics courses (Le & Brearley, 2017; Brearley & Le, 2018). In this paper, we describe a theoretical basis for the updated format Collaborative Keys, and detail how they have been modified in courses for undergraduate social science majors.

Our work follows a classroom research model (a.k.a. action research) outlined by delMas et al. (1999): (1) We use data to identify problems with the initial version of the Collaborative

Keys with our particular student audience; (2) We revised the Collaborative Keys based on a cooperative learning lens (e.g., Johnson & Johnson, 2009); (3) We use a Community of Inquiry (e.g., Garrison et al., 2000) framework to evaluate how the changes appear to have addressed the problem; and (4) We offer suggestions of what should be done next based on what we learned, with directions for future implementation and research.

2. BACKGROUND

Many sociocultural theories of learning posit that learning occurs when students are challenged by interactions with peers and instructors and engaging in a community (e.g., Vygotsky, 1978; Lave & Wenger, 1991). Consequently, a major challenge when designing asynchronous courses is developing formative assessments that create authentic engagement beyond typical discussion forums. Engagement, which is not always present in asynchronous courses, should include both student-to-student and student-to-peer interactions. Authentic and intentional engagement is critical to establishing a community in the virtual course.

Another popular paradigm for teaching and learning encourages the use of active learning. Freeman et al. (2014) survey over 200 studies on active learning and find robust evidence that active learning is associated with increases in student performance, and, conversely, that traditional lecturing without active learning is linked to increased failure rates. There is also evidence that active learning may be linked to improved retention in STEM disciplines. (e.g., Watkins & Mazur, 2013) and better attitudes (e.g., Prince, 2004). Therein presents another challenge for asynchronous online learning: how can students engage in authentic, active learning when they are unable to chat in real-time or touch physical tools that are available in traditional classroom settings?

2.1 Cooperative Learning

One of the most evidence-based approaches to teaching is cooperative learning, a specific type of collaborative learning (Prince, 2004). Meta-analyses have provided overwhelming evidence that cooperative learning is associated with higher achievement, improved self-esteem, improved sense of social support, and other positive outcomes (e.g., Johnson et al., 1998; Johnson et al., 2000). However, these analyses are based primarily on face-to-face courses. Johnson and Johnson (2009) identify five essential elements:

(1) Positive interdependence (mutual goals, joint rewards, shared resources, etc.),

(2) Individual accountability (each individual is assessed),

(3) Promoting interaction (acting in trusting and trustworthy ways, sharing resources, providing feedback, etc.),

(4) Appropriate use of social skills (e.g., communication, conflict resolution), and

(5) Group processing (members reflect together and commit to behaviors to retain or change).

Johnson & Johnson nearly always refer to promotive interaction as occurring in face-to-face settings. It is unclear whether they believe that promotive interaction must be face-to-face, or whether this is just an artifact of the time-setting of their research, which was primarily conducted before online learning was as common as it is today. They do not qualify other aspects of cooperative learning, such as social skills, with face-to-face conditions. Meanwhile, other scholars recommend the use of real-time online discussions for better student-to-student and student-to-teacher interactions (Summers et al., 2005). However, many online courses are

delivered asynchronously, making the interactions more challenging. Students have different schedules, work the course at different times, and complete weekly assessments accordingly. This raises questions about the extent to and nature by which cooperative learning principles translate to online learning. For the purposes of this paper, instead of limiting promotive interaction to face-to-face, we will discuss promotive interaction as student-to-student (or student-to-teacher) and assume it still applies in the online setting.

There appears to be many benefits of cooperative learning for online courses. Opportunities for students to interact with each other and work collaboratively can help create a sense of community and facilitate the learning process (Everson & Garfield, 2008; Mills & Raju, 2011). Even in asynchronous online courses, students can construct knowledge together as they interact with other students (and with the professor). However, one of the biggest challenges in online teaching is creating the key elements of cooperative learning found in a well-designed face-to-face environment and assessing the extent to which the design is meeting intended goals.

2.2 Advantages and Weaknesses of Discussion Forums

One popular pedagogical approach to develop community and encourage active learning is the online discussion forum (e.g., Everson & Garfield, 2008; Schmid, 2013; Grandzol, 2004; Summers et al., 2005). The research literature reports the benefits of discussion forums which include the opportunity for students to actively engage the course material, collaborate with other students (and instructors) and construct knowledge through written conversations (de Lima et al., 2019; Nandi et al., 2012, Balajic & Chakrabarti, 2010, Brower, 2003; Thomas, 2002). Besides the convenience and accessibility, the asynchronous nature of online discussion forums gives

students time to really think and reflect before providing an answer, an advantage over face-to-face settings with group or class discussions (Balajic & Chakrabarti, 2010; Garrison et al., 2000).

Despite these advantages, discussion forums are often an unsatisfactory method for creating student engagement in asynchronous online courses. Burnham, Blankenship, and Brown (2023) describe how, even in a well-designed introductory statistics course, student engagement in discussion forums was not ideal. Students rarely responded to other students, even after adding an incentive to participate. Some of the challenges using discussion forums reported by de Lima et al. (2019) are identified as accompaniment difficulty, structural difficulty, and motivation difficulty.

- *Accompaniment difficulty*. It can be incredibly challenging and time consuming for an instructor to consistently monitor threads and provide quality feedback and guidance/feedback.
- *Structural difficulty*. If many open-ended questions are provided in the forum, the resulting large number of students' posts can be hard to follow, organize, and grade. de Lima et al. (2019) reported that the discussion can become a very long and chaotic list of posts. This can be hard to navigate and may actually harm students' interactions as they lose track of to whom they are responding.
- *Motivational difficulty*. Students disengage from the forum when there is not much instructor mediation or when the forum's features seem outdated compared to current social media technology.

These and similar problems with discussion forums are also reported by Herman & Nilson (2018), Rabbany et al (2014), De Wever et al. (2006), Pena-Shaff and Nicholls (2004), Berge and Collins (1995), Harasim (1990), Hiltz (1990), and Levin et al. (1990).

Based on the research in online teaching and learning, there appears to be several factors that can influence the effectiveness of discussion forums, such as the structure of the course and student attitudes. Tawfik et al. (2017) find that lower levels of student-to-student interactions may result from the course design. For instance, Lucas et al. (2014) and Hou et al. (2009) indicate students are disinterested in discussion forums that are not required. Student engagement and interaction is derived from the class community and how well students know each other. Tawfik et al. (2017) argues that smaller group sizes are needed to increase student student-to-student interaction, and that social presence and a sense of community are positive consequences of working in smaller groups. Finally, a lack of prior knowledge also seems to hinder student-to-student interactions (Tawfik et al., 2017).

The findings above suggest that discussion forums support student learning only in very particular, highly-structured conditions—conditions that are present and that are mostly captured in *cooperative learning.* The following section presents a novel pedagogical tool, Collaborative Keys, as an alternative to discussion forums. The Collaborative Keys are based on cooperative learning theory and address many of the limitations of discussion forums.

3. BRIEF INTRODUCTION TO COLLABORATIVE KEYS

Collaborative Keys (CKs) are documents that contain pre-populated questions developed and selected by the instructor. The CKs allow multiple students to collaborate and share ideas in the document when they work on the course asynchronously (e.g., using Google Docs; e.g., Abrams,

2019; Khalil, 2018; Chu & Kennedy, 2011; Zhou, Simpson, & Domizi, 2012). An alternative to discussion forums, the CKs give students the opportunity to add answers and comments to the document as they work together to create an answer key (i.e. solutions) to the questions. Many of the aforementioned weaknesses of discussion forums are remedied by the CKs. For example, the pre-populated questions guide the discussion and keep the students and their work focused and organized. Our experiences and analysis indicate the CKs do not have the structural difficulties described by de Lima et al. (2019).

What makes the CKs particularly unique, and the focus of the paper, is the structure which guides students to meaningfully engage in the exercise and with each other to complete the CKs. The CKs have undergone several iterations based on the work of Sabbag and Frame (2021, 2022), who empirically explored students' use of the CKs and adapted it accordingly. The following subsections report the initial and revised versions of the CKs.

3.1. Initial Version of CKs

The initial version of the CKs were administered to 29 undergraduate students enrolled in a fully-online, asynchronous course taught at a mid-sized public university in the Western United States during Fall 2018. The course was a simulation-based introductory statistics course for undergraduate social science students. The textbook used was *Introduction to Statistical Investigations* (Tintle et al., 2015). This was a 10-week course (quarter system) with 29 students (7% freshman, 67% sophomore, 4% junior, and 22% senior). Two students were not considered in the analysis: one student did not give consent to participate in this study and another did not participate or complete course activities throughout the quarter.

The structure of this course was designed around the use of the CKs and was modeled after the CKs described by Le and Brearly (Le & Brearley, 2017; Brearley & Le, 2018) for graduate students. In the beginning of the week, students were expected to read and/or watch videos from assigned sections of the textbook resources, complete an online reading quiz, and complete and upload (individually) the answers to two activities. After submitting the activities, the students were expected to work on the CKs as a class. In this initial version of the CKs, a single Google Doc was shared among all students in the class, and every question from the activity was included in the CK. In a typical week, students individually completed two (entire) activities in addition to completing two corresponding CKs, the latter of which would be completed collectively by the entire class. There were a total of 15 CKs throughout the quarter with the number of questions varying from 28 to 42.

In this initial version of the CKs, students could interact asynchronously with their classmates and with the instructor to achieve the shared goal of completing the CK, which in turn would serve as a rubric for each of the activities. Recall the previous discussion about how shared goals help establish positive interdependence which is one of the five principles of cooperative learning. With this version of our CKs, students were required to make two contributions to every CK. Each student's first contribution consisted of a complete answer to one of the questions.

After the pre-established deadline for the first contribution to each CK, the instructor checked the students' answers, added follow-up questions, and added comments to address mistakes without giving away the correct answers. In their second contributions to the CK, the students were expected to reflect on these comments and correct their initial wrong/incomplete answers. Their second contribution could also offer an alternative correct answer to an already

answered question, correct a wrong answer, or ask a question. After the deadline for the second contribution, the instructor checked answers and made additional final comments.

Each CK was visible to the students at the beginning of the week (Sunday). The students were required to submit their own answers to the activity without seeing other students' answers. After submitting their own answers, a link to the actual CK appeared and became available. This restriction was enforced so that students would attempt the activities and provide their own answers instead of simply copying other students' answers added to the CK. This aligns with the individual accountability principle of cooperative learning.

3.2 Problems with the Initial Version of the CKs for Undergraduate Audience

Sabbag and Frame (2021) investigated how the CKs were used by the students and identified limitations in their structure and use. The cooperative learning principles of promotive interaction (student-to-student interactions) or the use of social skills almost never occurred in this initial version of the CKs with this audience (Sabbag & Frame, 2021). It is most striking that most of the promotive interactions that did occur were teacher-to-student interactions and not student-to-student interactions. We will discuss each of these cases briefly.

Some teacher-to-student interactions were observed, but these interactions were short and mostly happened when a student provided a wrong answer. In such instances, the professor provided direct feedback to the student, and unfortunately, very rarely did students acknowledge the feedback or respond. To illustrate, the professor provided a correction to a student's post a total of 127 times in the quarter but only 16% of the time a student provided a follow-up comment acknowledging the professor's comment. Most of the time, the conversation ended with the professor's comment, as with the example in Figure 1. In this example, it would have

been ideal if the student responded with a second try, incorporating the professor's feedback. However, the expectations for participation didn't push the student to do so. This is just one example of what led the instructor to rethink the structure surrounding the CKs.

Question: Do the conditional proportions and segmented bar graph appear to provide evidence that a patient was more likely to die on a Gilbert shift than on a non-Gilbert shift? In other words, does there appear to be a tendency for Gilbert shifts to have a death more often than non-Gilbert shifts? Explain.

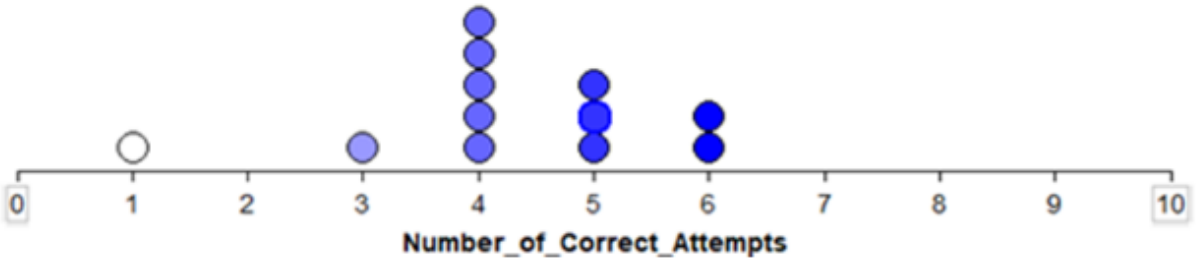
1) STUDENT J: There does appear to be a tendency for Gilbert shifts to have a death more than non-Gilbert deaths because almost no deaths occurred during the non-Gilbert shifts, but almost 20% of shifts with Gilbert had a death, ~~which seems like a statistically significant margin.~~

2) PROFESSOR: Right now, you cannot talk about the results being "statistically significant" because you did not perform a test and found the p-value. So, you could say that you have PRELIMINARY EVIDENCE… but that is it.

Figure 1: Example from question 9 in CK 5.1 with no follow-up comment from the student after the professor provided a correction.

Similar patterns appeared when the professor asked questions. During the quarter, the professor asked a question to a student 86 times, however, only 65% of the time a student replied to the professor. Figure 2 shows an example of a question-answer interaction between the professor and student when a student responded to the professor. However, for the remaining 35% of instances when the professor asked a question, the conversation ended abruptly. An example of this abrupt ending is in Figure 3. After the professor's question, nobody responded. Interactions with this tendency is one primary motivation for revising the CKs.

Question: Consider the graph below. Using the context of the problem, explain what a dot on the plot represents.



1) STUDENT L: The dot plot represents the likelihood of Harvey randomly getting a certain amount of trials correct out of ten trials total.

2) PROFESSOR: This is a very good beginning. So is it correct to say that the dot is the *number of correct trials out of 10 attempts*?

3) STUDENT T: It is correct to say that each dot represents the number of correct trials out of 10 attempts.

4) PROFESSOR: Yep!

Figure 2: Question 13 in CK 2 showing an example of a student answering the professor's question.

Question: What if the researchers used a very small significance level? Say, 0.0001. How does this decision affect the probability of making a Type I error?

1) STUDENT J: This decision will definitely increase the probability of making a type 1 error because it makes It so much harder to get the P-value less than the significance level to reject the null hypothesis.

2) PROFESSOR: This answer is not correct.

α is the probability of a Type I error: P(type I error) = α

The significance level (α) controls the probability that you mistakenly reject a null hypothesis that is true. So, a small significance level makes it very hard to reject the null hypothesis which reduces the chances of a Type I error, assuming that the null hypothesis is true.

Does this make sense?

Figure 3: Question 15 in CK 3.1 showing an example of a professor's question with no answer.

Finally, the professor made a comment (correction or question) to a *specific* student (calling them out by name) 72 times in the quarter, but only 19% of the time this specific student responded to the professor. An example of this is shown in Figure 4. In the remaining 81% of the time the specific student did not respond to the professor (see Figure 5). In short, the initial structure of the CKs did not promote the ideal kind of reflection, self-correction, and student-to-teacher interaction that the instructor was hoping for.

Question: State the appropriate null and alternative hypotheses for testing the researchers' conjecture in symbols.

1) Student K: H0: $\pi = 0$
Ha: $\pi > 0$

2) PROFESSOR: This answer is not correct. In this activity we are comparing multiple groups. So you have many π… one for each group. STUDENT K, can you please re-write the hypothesis?

3) Student K: H0: $\pi_{none} = \pi_{sameroom} = \pi_{guest} = \pi_{citizens} = \pi_{gender}$
Ha: $\pi_{none} < \pi_{sameroom}$
$\pi_{none} < \pi_{guest}$
$\pi_{none} < \pi_{citizens}$
$\pi_{none} < \pi_{gender}$
(I'm not sure if this is correct either.)

4) STUDENT S: I dont think it's possible to write the alternate hypothesis in symbols

5) STUDENT C: I think the Alternative hypothesis would be: Ha: at least one of the five probabilities of a guest reusing their towel is different from the others.

6) PROFESSOR: Good discussion here, ladies. :D
STUDENT K, the null hypothesis you wrote is correct. But the alternative hypothesis needs to be more general.
STUDENT S and STUDENT C are correct. We can write the null hypothesis in symbols but we cannot write the alternative hypothesis in symbols. Here is what you should have :
H_0: $\pi_{none} = \pi_{guest} = \pi_{room} = \pi_{citizen} = \pi_{gender}$
H_a: At least one proportions of rooms reusing towel (π) is different from the others.

Figure 4: Question 4 in CK 7.1 showing an example of the professor asking a question to a specific student and this student responding to the professor.

Question: How would the midpoint change for a 99% confidence interval compared to the 90% interval?

1) STUDENT A: The midpoint would not change

2) PROFESSOR: STUDENT A, can you please explain why?

Figure 5: Question 15 in CK 3.2 showing an example of the professor asking a question to a specific student and this student not responding.

Student-to-student interactions almost never occurred in this initial version of the CKs (Sabbag & Frame, 2021). They only happened when a student provided a wrong answer, and another student provided a follow-up answer but with no acknowledgement of the previous answer and with no social skills such as empathy or support for the student whose post was incorrect. Instead of helping each other, students were mostly trying to get the correct answers independently of one another. Over the course of the entire term, students posted (consecutively) on the same question only 43 times (an average of 3.91 consecutive posts per CK). For nearly

half (19) of those consecutive posts, there was no social acknowledgement of peers (or their answers). This can be seen in posts 4 and 5 in Figure 4. It is possible that student C's response took Student S's response into consideration, but it also could make sense as a stand-alone post. Ideally, Student C would include some acknowledgement of Student S's response using social skills (e.g., prefaces their response with, "I agree with Student S…")

The most student-to-student interaction we observed between students in the initial CKs was a student agreeing with another student, and this only happened 9 times in the entire quarter. An example is given in Figure 6, where Student S gives some evidence that she read student K's response and has considered it enough to voice agreement.

There were 10 instances in the quarter when a student asked a question, and all of these questions were answered by the professor. In only one case, a student made a follow-up comment (see post 4 in Figure 7), but it is unclear if this student is answering the student question on post 3 or answering the professor question on post 2.

Question: What is the value of the parameter if Harley is picking a cup at random? Give a specific value.
1) STUDENT K: The value of the parameter if Harley is randomly choosing a cup is 0.5 or 50%.
2) STUDENT S: I agree with STUDENT K because if Harley is picking a cup at random he has a 1 in 2 chance of getting it correct, which is 0.5
3) PROFESSOR: Nice explanation, STUDENT S!

Figure 6: Question 5 in CK 1.1 showing an example of students agreeing with each other.

Question: Are you comfortable with concluding from this study that the diet used causes a difference in BMI change? Justify your answer.

1) STUDENT I: Yes because the evidence we found suggests there is a ~~correlation~~ ASSOCIATION between a specific diet resulting in women's BMIs going down.

2) PROFESSOR: Answer is not correct. Finding a statistically significant result is not enough to make a causal claim. STUDENT I, what else is needed in the design of the study for you to make a causal claim?

3) STUDENT I: I am not 100% sure, can you point me in the right direction? I know a causal claim is any assertion that invokes causal relationships between variables?

4) STUDENT K: Isn't it that we can make a causal claim because random assignment was used in the study which nullifies any potential confounding variables from affecting the results?

5) PROFESSOR: Very good answer, STUDENT K! :D You are perfectly right.

We can conclude that the Atkins diet causes a higher change in BMI, when compared to ORNISH, LEARN, and ZONE because this is a randomized experiment (random assignment was used). When random assignment is used in the design of a study, all confounding variables are balanced out between groups so we can claim that the explanatory variable (type of diet) causes the changes in the response variable (change in BMI), on average.

Figure 7: Question 20 in CK 9.1 showing the only example of a student asking a question another student following up with a possible answer.

A vocative (i.e., referring explicitly to another class member by name) was used by a student only three times in the quarter. In these three posts, the students were agreeing with a previous student answer (see Figure 6) and providing additional insights to why they were in agreement. In summary, most of the time there was no promotive interaction between students at all, and little social skills employed when making a correction of a peer.

The CKs consistently lacked student-to-student interaction, and what was present was not ideal. The principles of cooperative learning did not appear to be adequately evident in the CKs in the initial structure. Admittedly, the goal of the CKs as presented to the students was to create the answer key to each activity; students did not have tangible motivation to pursue the other important goals of engaging in promotive interaction or using social skills. In addition, the positive interdependence appeared too weak; students did not depend on each other much because in the end the instructor provided the scaffolding needed to get to the final answer. Based on these results, for the next term, the structure of the CKs was revamped to increase

positive interdependence, provide more opportunity to use social skills, and to encourage student-to-student promotive interaction with this undergraduate audience.

3.3 Revised Version of the CKs

The revised version of the CKs was administered to 100 undergraduate students (about 47% freshman, 35% sophomore, 13% junior, and 6% senior) enrolled in the same online asynchronous statistics course at the same university in a subsequent term (Winter 2021). A total of 70 students gave consent to participate in the study, however the sample was reduced to 35 students because we only considered the students with groups in which everyone volunteered to participate in the study.

To encourage the cooperative learning principles of student-to-student promotive interaction, stronger positive interdependence, and the use of social skills, the CKs were adjusted to be completed in small groups of two to four students rather than *whole-class* assignments. Each group collaborated to develop answers to a subset of questions from the corresponding activity. To decrease the subsequent grading load on the instructor and to help focus students' attention on more important statistical concepts, each CK was no longer composed of all the questions from the activities but only the most substantive questions. Another natural consequence of this change was that the professor was no longer a primary participant in the CKs, as her attention was divided among several groups' CKs rather than a single copy for the entire class.

In addition to decreasing the number of questions and setting up students to work in small groups, the requirements to successfully complete each CK were also modified. The groups progressed together through three phases:

1. *Initial Answer* (completed individually; one per student): Students contribute an answer to each problem individually based on their current understanding of the course material. The activities with the questions that would be included in the CK were available by the end of the previous week and students had until Monday 11:59pm to submit their individual answers to the first CK and Wednesday 11:59pm for the second CK.
2. *Discussion* (completed as a group; 1 or more per student): Students view each other's initial answers and other resources provided to help their understanding of the course content. Students are expected to examine each other's answers, reflect on their mistakes, help group members to identify/correct misconceptions, ask/answer each other's questions. Based on these actions, students contribute discussion comments highlighting features they think should be included in a final exemplary answer to each question. Students were required to paste their initial answers into the first CK by Monday 11:59pm, so the group could work on the first CK during Tuesday and Wednesday. For the second CK students were required to post their initial answers by Wednesday 11:59pm, so the group could work on it Thursday and Friday.
3. *Final Group Answer* (completed as a group; only one per group): The group comes to consensus on an exemplary final answer to each question in the CK. The final answer is graded by the instructor. The due date for the first CK was Wednesday at 11:59pm and for the second CK it was Friday at 11:59pm.

The structure of the revised version of the CK as described above is intentionally based on many research-based principles of active and cooperative learning (Johnson & Johnson, 2009). *Individual accountability* is increased as all the students are required to provide their individual

initial answer to each question. Students have positive interdependence through a shared goal of obtaining a final group answer to each question which they know will be graded on correctness.

3.4 Evaluating How the Revised Version of the CKs Addressed the Problems

Student-to-student interactions were much more frequent and rich in this second version of the CKs. Over the course of the entire term, students always posted consecutively on the same question by construction. In contrast to what was observed previously, interactions include social skills and go beyond a student agreeing with another student. Examples include students being vulnerable with each other, referring to themselves using group pronouns, expressing emotion, humor and appreciation. Figure 8 shows students expressing agreement, appreciation, using group pronouns, being vulnerable, and asking and answering questions. More information about this and examples of student interactions will be included in the next section of the paper.

There were 272 instances in the quarter when a student asked a question, and 85% of those questions were answered by another student(s). The average number of questions asked in a CK was 22.67, compared to only ten times in the first version *over the entire term*. In the revised version, the average number of questions asked *and answered* in a CK was 16.42 (in the initial version there were 0 of these). Examples of students asking questions of each other in the revised CK can be found in Figure 8 and Figure 9.

Question: Based on the confidence intervals do you have evidence of a significant difference between the Ornish and LEARN diets? How are you deciding?

INITIAL ANSWERS

STUDENT K: no we don't since zero is contained in the interval.

STUDENT N: Yes there is evidence of a significant difference between the two because Ornish is in the negative range while the LEARN is still positive.

STUDENT A: Based on the confidence intervals above, there is not evidence of a significant difference between the Ornish and LEARN diets; the confidence interval contains zero, providing no significant difference when comparing the two diets.

DISCUSSION

1) STUDENT N: This question was confusing to me so I just took my best guess. Can someone explain it?

2) STUDENT A: I mean the way I did it, an interval is statistically significant if it doesn't contain zero if it contains zero, that means the null hypothesis cannot be rejected. So I just looked at which interval didn't contain zero. Does that make sense? Also, unless there's any objections I think we should use my answer for the final answer, it seems the most comprehensive and detailed.

23) STUDENT N: That is so helpful, omg thank you!! Yes let's go with that for our final response.

24) STUDENT K: ya pretty much you can tell by if it has zero in the interval

FINAL GROUP ANSWER

Based on the confidence intervals above, there is not evidence of a significant difference between the Ornish and LEARN diets; the confidence interval contains zero, providing no significant difference when comparing the two diets.

Figure 8: Question 17 in CK 9.1 for group 19 showing an example of students asking and answering each other's questions.

The substantial improvement in asking questions is likely due to the revised structure; requiring students to come to consensus lends to questions such as that in Figure 9. Here, students are seeking confirmation from the group. Sometimes the questions were more cognitively oriented, such as that given in Figure 8.

Question: Interpret the p-value. Note that I am NOT asking about the strength of evidence against the null hypothesis, I am asking for an *interpretation* of the p-value (e.g. the p-value is the probability/proportion of ….)

INITIAL ANSWERS

STUDENT K: The p value of .0330 is the proportion of simulated samples with a sample proportion of .055 or greater, assuming the null hypothesis is true.

STUDENT C: The p-value shows that there is a 0.0370 chance of obtaining the observed statistic or greater if the null hypothesis is true.

STUDENT T: The P-value of .0330 shows the simulated samples if the null is true.

STUDENT S: The p-value of 0.0280 is what we obtained from our data. This means that there is a 2.8% chance of getting a statistic greater than the null hypothesis.

DISCUSSION

1) STUDENT K: Okay looks like we all got about the same here, but I think we should definitely add the actual statistic (.055).

2) STUDENT S: Yes, I think having the actual statistic in our final answer is important. STUDENT K since your answer includes the final statistic do you want to go with yours?

3) STUDENT K: Sure sounds good!

4) STUDENT C: I got my wording for this answer from the Ch 1 textbook videos on interpreting p-values. I think for this answer it's important to look at what the p-value is telling us about the population not about our simulation. Is it okay if we use my answer for the final?

5) STUDENT S: Sure! I'm good with using yours STUDENT C.

6) STUDENT T: Let's go with STUDENT C.

FINAL GROUP ANSWER

STUDENT C: The p-value shows that there is a 0.0370 chance of obtaining the observed statistic or greater if the null hypothesis is true.

Figure 9: Question 12 in CK 8.1 for group 27 showing an example of students seeking consensus for the final group answer.

A vocative was used by a student 781 times in the quarter (see posts 2 and 5 in Figure 9). The average number of vocatives in a CK was 65 across all groups, which amounts to about six vocatives per CK per group. With the initial version, vocatives were used by students only three times in the entire quarter. When a vocative was used, students were displaying many different social interactions such as agreeing with a previous student's answer, being vulnerable with each other, expressing emotion, humor, or appreciation, and asking a question.

In summary, the revised CKs showed great improvement in the quantity of interactions between students such as question asking/answering and using vocatives. We suspect that by

reducing the group size, the shared goal of coming up with a final group answer to each question required more direct *positive interdependence* when students compare and discuss their answers to identify mistakes and corrections. Moreover, this structure encourages more student-to-student promotive interaction, because the students are motivated to engage with each other to come to a consensus. Finally, we see much more evidence of students using social skills. With these changes, the revised version of the CKs encourages collaboration among the students much more than the previous version.

4. COMMUNITY OF INQUIRY

Before looking deeper at comparisons across the versions of the CKs, we pause briefly to offer our analytical framework. We selected this framework after conducting a thorough literature review of many of the frameworks that capture various aspects of student interaction in online courses. Some frameworks have a theoretical background based on cognitive and metacognitive knowledge (Henri, 1992), social constructivism (Gunawardena et al., 1997; Veldhuis-Diermanse, 2002; Pena-Shaff & Nicholls, 2004), and community of inquiry (Garrison et al., 2001; Anderson et al., 2001; Rourke et al., 1999).

We selected a research-based framework for discussion forums in online learning environments, *Communities of Inquiry* (CoI; e.g., Rourke et al.1999; Garrison et al. 2000, 2001; Akyol and Garrison 2013), which takes a holistic approach to measuring various aspects of participation in CKs including social, cognitive and teacher presence:

- **Social presence** is "the ability of participants to identify with the community (e.g., course of study), communicate purposefully in a trusting environment, and develop interpersonal relationships by way of projecting their individual personalities" (Garrison, 2009, p. 352).
- **Teaching Presence** is the design, facilitation, and direction of cognitive and social processes for the purpose of realizing personally meaningful and educationally worthwhile learning outcomes (Anderson, Rourke, Garrison, & Archer, 2001).
- **Cognitive Presence** is the extent to which learners are able to construct and confirm meaning through sustained reflection and discourse (Garrison, Anderson, & Archer, 2001)

The CoI framework has been used by other statistics education researchers (e.g., Burnham, Blankenship, and Brown, 2023). Because the structure of the CKs was updated to increase student-to-student interaction and provide more opportunity to use social skills, the following discussion will focus on the social presence aspect of this framework.

5. DISCUSSION: COMPARING THE INITIAL AND REVISED CKS USING A COI SOCIAL PRESENCE FRAMEWORK.

This paper describes the evolving structure of CKs adapted to better serve our undergraduate students. The revised version of the CKs is rooted in many research-based principles. The formative assessment incorporates cooperative learning (Johnson & Johnson 2009) by creating positive interdependence through shared resources and shared final answers. The students participate in groups of about three students (as suggested by Tawfic et al. 2017) and the CK assignment is included as a course requirement (as suggested by Lucas et al 2014). The structure

of this assignment encourages students to work together and use social skills to achieve the shared goal (Johnson & Johnson 2009) of having answer keys for the activities of the course.

The cooperative learning principles of promotive interaction (student-to-student interactions) or the use of social skills almost never occurred in the initial version of the CKs (Sabbag & Frame, 2021). Sometimes, students posted a comment/answer immediately after a peer's post, but with no acknowledgement of the previous answer and no social skills to empathize, validate, or offer support for the student if their initial post was incorrect. In other words, instead of helping each other, students were mostly trying to get the correct answers independently. The structure of revised version of the CKs appeared to encourage much more interaction, and more use of social skills see Figures 8 and 9 above.

In addition, in the old version, students initiated questions only 10 times, whereas in the revised version students ask questions of each other 272 times. Perhaps in the smaller group context students felt bolder to ask their questions, whereas in the initial version it might require more courage to ask a question as it is asked in front of the entire class instead of in small groups.

Moreover, in the old version, the students relied on the professor much more to supply answers. Most of the questions were answered by the professor, whereas in the revised version, students answered each other's questions hundreds of times. Although we don't make assertions about the quality of the questions, the revised version appears to put more onus on students to answer each other's questions rather than relying on the professor to do so.

Overall, the revised version seemed to encourage students to exceed contribution expectations, however, the expectations were different in the two versions of the CKs. In the initial version, students were explicitly instructed to contribute two posts per key. Whereas in the

revised version, the implicit expectation was that students would contribute at least one post to the Discussion for each question in each CK to come up with a final group answer collaboratively. However, no direction was given in terms of the number of posts expected per student. Figure 10 shows the proportion of students that exceeded expectations for each CK. The proportion of students that exceed expectations using the revised CKs is consistently higher than the proportion of students that exceed expectations using the old CKs. In fact, after the first midterm, the proportion is almost always 0 using the old CKs. The difference between them is more notable prior to the first midterm and, in many of those CKs, the percentage is higher than 50%! However, the proportion does significantly decline after the midterm using the revised CKs. Although we aren't making inferences about the quality of the posts was improved, this plot still suggests that the revised structure invites students to engage more frequently.

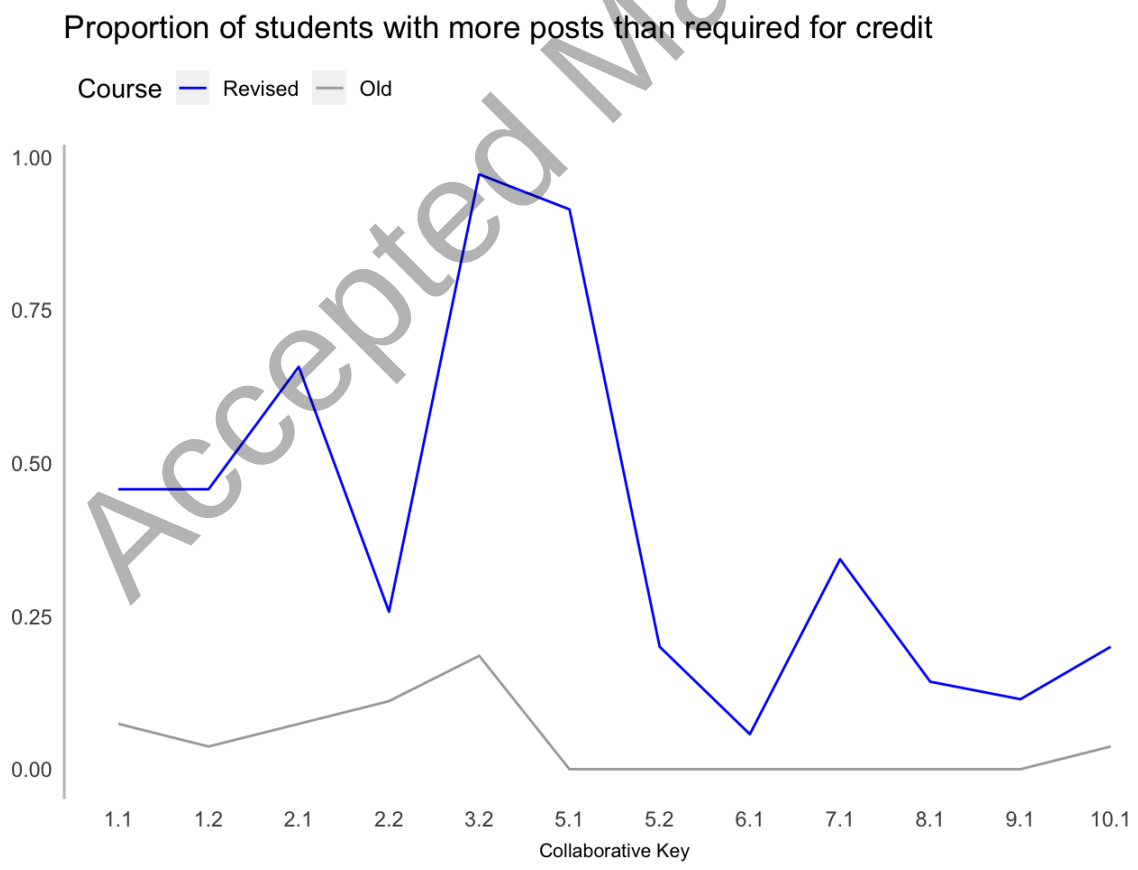


Figure 10. Comparison of proportion of students exceeding quantity of post expectations over time. For the initial CKs, explicit expectations were 2 posts per key. For the revised CKs, implicit expectation was one discussion post per question. Although proportions are generally higher among the revised CK structure, in both there is a marked decrease in quantity after the midterm.

5.1 Social Presence Indicators

To more rigorously evaluate the nature of and changes in social presence using the different versions of the CKs, we adapted a rubric for evaluating discussion forums applied to the CKs. Table 1 gives the three social presence categories, the 10 indicators of social presence in the CoI operationalization and definition given by (Rourke et al., 1999), and an example of how we adapted it for the CKs. The process of adapting the CK was based both on theory as well as several iterations of coding according to the new rubric independently, meeting to discuss areas of concern when codes would be unclear, proposing an alternative option, and then repeating until no areas of concern remained.

Indicator	Definition	Example	Adaptation to CKs
AFFECTIVE			
Expression of emotion	Conventional expressions of emotion, or unconventional expressions of emotion, includes repetitious punctuation, conspicuous capitalization, emoticons.	"I just can't stand it when….!!!!", “Anybody out there!"	emoji's, “lol”, “ops”, “woot woot”, “wow”, "I am glad", "I appreciate", “haha”, “oh shoot”, " !!! "
Use of humor	Teasing, cajoling, irony, understatements, sarcasm**.**	The banana crop in Edmonton is looking good this year	“lol”, “haha” counts as emotion and humor
Self-disclosure	Presents details of life outside of class, or expresses vulnerability.	"I just don't understand this question"	"I honestly do not really understand", "I don't know", "Not sure', "I did this wrong,"
INTERACTIVE			

Indicator	Definition	Example	Adaptation to CKs
Quoting from others' messages	Using software features to quote others entire message or cutting and pasting selections of others' messages	Software dependent, e.g., "Martha writes:"	Direct quotes
Asking questions	Students ask questions of other students or the moderator.	"Anyone else had experience with WEBCT?"	If there is a "?" then it's a question even if the grammar isn't technically a question
Answering questions *****new category	Students answer a question that was asked	----------	Only categorize if a question was asked.
Complimenting, Expressing appreciation	Complimenting others or contents of others' messages.	I really like your interpretation of the reading	"good job", "yours is the best" or "yours is more accurate", "you're right", "nice"
Expressing agreement	Expressing agreement with others or content of others' messages.	"I was thinking the same thing. You really hit the nail on the head."	"great", "solid" "I agree", "sounds good", "yep", "yes", "okay", "my answer is wrong too", "looks good", "all our answers are the same" …
COHESIVE			
Vocatives	Addressing or referring to participants by name.	"I think John made a good point."	"I agree with Kay"
Addresses or refer to the group using inclusive pronouns	Addresses the group as we, us, our, group	"Our textbook refers to . . . " " I think we veered off track ..."	Categorize all "we" even if it refers to math/stat ideas and conclusions.
Phatics, salutations	Communication that serves a purely social function; greetings, closures.	"That's it for now" "We're having the most beautiful day"	"thanks" to a compliment, "no problem", "It is ok..."

Table 1: Indicators of social presence according to the CoI framework.

Several strategies were implemented to provide validity evidence in support of the qualitative results. Initial training involved several researchers coding the same CKs and meeting to discuss discrepancies and refine the framework as needed. The iterative process was repeated

until satisfactory inter-rater reliability was achieved (90% inter-rater agreement or above), and the adapted framework appeared stable.

Based on the indicators defined in Table 1, the rubric was applied to both the initial and revised CKs. Table 2 gives a summary of how often the indicators are present. All the indicators are considerably higher using the revised version, just as the new structure was designed to encourage. For example, the revised version of the CKs averaged over 70 posts with students offering self-disclosure per key, whereas the old version averaged only about 1 post with self-disclosure per key. It should be noted that it is difficult to compare across versions because the structure and expectations are different. Nevertheless, these results provide strong evidence that the revised CKs are conducive to stronger social presence from students in this undergraduate audience.

Table 2 also illustrates how the engagement transferred from the instructor to the students. Two of the categories from Table 1 ("Complimenting, Expressing appreciation" and "Expressing agreement) were integrated into one category due to difficulties in discerning specific student's and instructor's comments like "Nice!", "Great", or "Solid". Focusing on this category, in the old version the instructor complimented or expressed emotion or agreement over 19 times per key whereas students did so about once per key. There is a sharp contrast in the revised structure: student posts included complements or expressions of appreciation or agreement over 212 times per key! Even despite the difficulty comparing the different structures, these numbers suggest that students appear to have taken over the responsibility to complement and express appreciation for each other.

Category	**Indicator**	**Old CKs**		**Revised CKs**
		Instructor	**Student**	**Student**
Affective	Expression of emotion	5.91	0.55	10.83

	Use of humor	0.00	0.00	2.75
	Self-disclosure	0.64	1.18	77.83
Interactive	Quoting from others' messages	0.09	0.00	2.00
	Asking questions	7.82	0.64	22.67
	Answering questions	0.45	7.36	19.33
	Complimenting, Expressing appreciation & agreement*	19.75	1.18	212.08
Cohesive	Vocatives	9.82	0.27	65.08
	Pronouns	8.55	6.27	126.58
	Phatics, salutations	1.09	0.27	0.58

Table 2: Average number of posts for each indicator per CK. Sample size for the initial version was 27 students and for the revised version was 35 students. A table considering the different sample sizes and showing the average number of posts per student is available in Supplemental online material.

6. LIMITATIONS, IMPLICATIONS, AND FUTURE DIRECTIONS

As is common in classroom research (e.g., delMas, Garfield, & Chance, 1999), we conclude by reflecting on our study and offer suggestions for what instructors seeking to try CKs should consider. We also offer suggestions of what research should be conducted next based on what we learned.

Our results seem promising for online statistics education research, showing evidence of how carefully structured online assignments (CKs) might encourage and provide opportunities for students to create a community of learning through social interactions. It seems feasible that other instructors could incorporate CKs into their classes as well, as a CK is simply composed of statistical questions that instructors likely already use in their courses. Admittedly, there is some additional effort required for the instructor in that in the first couple weeks of the term, it is

necessary to give more detailed feedback to students not only about statistical understanding (as usual) but also feedback regarding expectations for the interactions. (This does require time and patience.) Using CKs in a course also requires careful consideration of assignment due dates and workload (not only for the student but also for the instructor). It is critical that the instructor establishes a schedule that allows time for students to work on the questions individually first and then as a group. The spacing is critical; without enough time, students will provide very superficial input and comments. Moreover, instructors need to consider the difficulty of the questions on the CKs. Ideally the CK would not be composed (only) of straightforward questions with low level of difficulty, as such questions would not encourage many insightful discussions among students.

There is still much more to be explored. CKs have the strength that they add structure and organization that online discussions forums lack (de Lima et al. 2019). Yet, in the context of a statistics course, most of the questions on the CKs in this study had an implied right answer and otherwise mostly wrong answers. Very few questions were open to students inventing new ways of thinking, contributing highly personal and creative ideas, or developing their own measures and methods to tackle a problem. It remains to be explored the extent to which the benefits of the revised CKs could be applied to more open-ended questions that demand more creativity and innovation or require students to draw from their individual personal experiences to collectively develop an answer. On the other hand, the CKs were built from questions in the *Introduction to Statistical Investigations* curriculum (Tintle et al., 2015), which emphasizes explaining reasoning and looking for connections between concepts. Little is known about whether the behavior of students on CKs would be similar in more traditional courses that emphasize procedures.

Within the social presence aspect of CoI's there is more to be explored. Trends over time were observed and will also be explored in future studies. Future research could explore whether interactions change over time as well as possible explanations (e.g. students are becoming more efficient, more comfortable with course assignments; Sabbag and Frame, 2021). This study focused solely on social presence. Future research will focus on cognitive and teacher presence of the CoI framework as they apply to CKs. More specifically, future studies are needed to explore how group interactions differ and whether they relate to different levels of student performance. Such studies could look for relationships between CK behaviors and students' scores on psychometrically-sound instruments measuring desired outcomes such as statistical reasoning or statistical thinking. Results may be able to help address a common critique of research on online learning, which is that cognitive learning is often not taken into account (Dennen, 2008). Our work focused on the first four principles of cooperative learning (positive interdependence, individual accountability, promoting interaction, and appropriate use of social skills). The attentive reader will notice that little-to-none of the fifth principle, group processing, was employed in this version of the keys. As a required part of the course, students were asked to complete a weekly group evaluation to report if any group member lacked participation. However, this information was only seen by the professor and therefore there was no opportunity for students to discuss improvements to group interaction. Future research could be conducted to examine the extent to which taking time for group processing yields better student interaction and group function.

Finally, this paper focusses on the use of CKs for a social science introductory statistics course; it remains to be explored the extent to which such changes could benefit statistics major

courses, graduate-level courses, or courses in other STEM disciplines. We also can envision a model in which hybrid courses can make use of an appropriate adaptation of CKs.

7. CONCLUSION

This article offers an example of how the classroom research model (delMas, Garfield, & Chance, 1999) can be used to improve the quality of our teaching. We initially used CKs with a cooperative structure, and revised the CKs to more appropriately reflect some missing aspects of cooperative learning. Data were then collected and categorized according to the research-based Community of Inquiry (e.g., Garrison et al. 2000) framework to evaluate how changes appear to have addressed the problem. The results appear promising; there is evidence that the new structure promoted stronger student-to-student interaction and other desirable social presence outcomes for this undergraduate statistics student audience. The students appear to have become less dependent on the instructor and develop more interactions with each other. Finally, we offered suggestions of what should be explored next, including examination of how the social presence variables may be related to other desirable outcomes, in particular cognitive presence and performance on psychometrically-sound measures of student learning.

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Data Availability Statement

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

Ethics Review

The Institutional Review Board from California Polytechnic State University reviewed and accepted this research project (IRB2020-003).

Supplementary Materials

An alternative to Table 2 considering the different sample sizes and showing the average number of posts per student is available in the supplementary materials.

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