Title

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Memorization and Performance During Pandemic Remote Instruction: Evidence of Shifts from an Interactive Textbook

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Abstract
Students believe mathematics is best learned by memorization; however, endorsing memorization as a study strategy is associated with a decrease in learning (Schoenfeld, 1989). When the world changed with the onset of the COVID-19 global pandemic, instruction transitioned to fully remote instruction where many assignments and examinations became open textbook, open note, and even open Internet. In this new world, did students change their beliefs about the role of memorization in learning? Did academic performance change? And did the relationship between memorization beliefs and academic performance change? The current study takes advantage of data collected in an online interactive statistics textbook used by courses before (in-person) and after (remote) the declaration of the COVID-19 pandemic at three institutions, each representing a part of the California Master Plan for Higher Education (e.g., University of California, California State University, and California Community Colleges). Results from 2668 students who used the textbook showed that the UC institution had lower memorization belief scores compared to both the CSU and CCC institutions. Even when controlling for institution and chapter of the textbook, lower memorization belief scores were related to higher performance. Surprisingly, there were no significant differences in either memorization beliefs nor performance before and after transitioning to online remote instruction due to the pandemic. Although much of educational research is conducted in one institution, this kind of research can identify differences across institutional contexts to understand how learning can be affected by different teaching formats, including in-person and online/distance, brought on by disruptive social changes such as a global pandemic.

Keywords: Memorization beliefs, COVID-19, academic institution, academic performance, in-person instruction, fully remote instruction

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Many students believe rote memorization is one of the best ways to learn math, but this strategy often leads to suboptimal performance (Schoenfeld, 1989). At the declaration of the COVID-19 pandemic, as all instructors (including math instructors) switched abruptly to fully online teaching (also called remote instruction or distance learning). In that process, many shifted their pedagogy to allow students to use textbooks, notes, and even the Internet on assessments (Daniel, 2020).

The proliferation of online learning materials even before the declaration of the pandemic made it possible to compare student attitudes and performance as the world changed. The Better Book approach (Stigler et al., 2020, housed at CourseKata.org) is an example of such a project that had been tracking performance-related attitudes (such as beliefs about memorization) and learning in statistics courses across a variety of campuses and contexts. Our book is not "better" than other statistics books, but rather there is a continuous improvement process that allows this book to get better based on student data. So, the "better" in Better Book refers to the process of getting better. Specifically, the Better Book project focuses on using student data from an interactive online statistics textbook to help instructors, researchers, and developers continuously improve methods of teaching concepts and skills that take a long time to learn. Our study capitalizes on the opportunity presented by the Better Book model not only to examine the relationship between memorization beliefs and long-term statistics learning across institutions but to additionally examine how pandemic-related changes in pedagogy may have affected this relationship.

Before delving into the details of our study, we will review the pre-COVID-19 research on how memorization beliefs relate to learning, the impact of online learning on memorization and performance, and possible differences across institutions.

Students Believe Memorization is an Efficient Learning Strategy

Students believe that memorization is an efficient learning strategy, especially in mathematics. In interviews and surveys, many students profess that memorizing long lists of math facts or algorithms without trying to gain a conceptual understanding is a productive learning strategy (Boaler et al., 2000; Givvin et al., 2011; Redish et al., 1998). Students have such a strong belief in the centrality of rote memorization such that they believe that people who are best at mathematics must be the best at such memorization (Crawford et al., 1994). Memorization is also related to the commonly held belief that quickness and fluency are important for success in mathematics (espoused by students, Givvin et al., 2011). This belief in the power of memorization extends beyond mathematics; for example, students view physics as disconnected facts that have no connection to the real world but need to be memorized (Gray et al., 2008).

However, such commonly held beliefs in rote memorization are associated with negative outcomes. Students who believe in the importance of memorization are more likely to give up when faced with a difficult question (Phelps-Gregory et al., 2020). They are thus less likely to engage in productive struggle (engaging, unpacking, and trying new things to solve a problem without success for a prolonged time). Holding beliefs about the centrality of memorization is negatively correlated with mathematical performance (House, 2006; Lin & Tai, 2015; Schoenfeld, 1989). Math and science students who believe that these disciplines are static sets of

disconnected facts tend to have lower confidence (Wheeler & Montgomery, 2009) and underperform (Songer & Linn, 1991) compared to peers who conceptualize the field as dynamic and relevant to the real world.

In short, these beliefs are important to study because they are interconnected with other beliefs about what it means to do math or be good at math, study strategies, and subsequent performance. House's cross-cultural research (2006) suggests the relationship between these beliefs and performance is context-dependent. In the United States, low performing students are the most likely group to endorse memorization, but in Japan, high performing students attribute their success to memorization. This implies that these memorization beliefs may vary depending on the learning context and surrounding cultural beliefs about what it means to do math, learn math, and be good at math. Thus, as the context of learning changes, these beliefs and learning may also change.

The Abrupt Transition to Remote Courses (COVID-19 Pandemic)

With the COVID-19 pandemic, the world was transformed. In the United States, as well as in many other countries, many schools shut down in-person instruction and switched to fully remote courses (Daniel, 2020). This was a drastic change for many, especially for students and teachers.

Although research is only just emerging about the consequences of this shift on students, early work suggests that many challenges emerged. Students made very little progress, if any at all, in their education with remote learning (Engzell et al., 2021). Some students felt as if they experienced a loss of knowledge and opportunity. These feelings are consistent with declines in grades, measures of reading and math achievement, and the number of students meeting college admissions requirements (e.g., in Los Angeles Unified School District as reported by Esquivel & Lee, 2021). As research begins to document the effects of remote learning on student learning (Barber et al., 2021), there is an urgency to study any disproportionate impacts on already marginalized or economically underserved communities (Deng & Yang, 2021; Engzell et al., 2021; Goudeau et al., 2021; Soria et al., 2020).

After the initial chaos of the pandemic, many instructors attempted to recreate or re-invent the learning experience on Zoom and other online platforms as the new school year started in the latter part of 2020. In doing so, many policies were relaxed; exams and assignments were now open textbook, open note, open Internet, and in some cases, untimed (Er et al., 2021; Nickerson & Shea, 2020).

In this new world, with new policies and affordances, did students' beliefs about memorization change? Would students feel the need to memorize if they have online resources open to them during assignments and exams? In this paper, we use data from students using our free interactive textbook in face-to-face classes both before and after the declaration of the pandemic to examine these questions. After the declaration of the pandemic, these initially face-to-face classes became fully remote.

Research conducted before the onset of the pandemic has examined how some of the "open" features of online learning could affect learners' beliefs about memorization and

performance. Research on open-book examinations suggested that this feature (perhaps surprisingly) does not necessarily lead to higher scores but does reduce anxiety during the exam as well as the use of memorization in learning (Block, 2012; Broyles et al., 2005; Theophilides & Dionysiou, 1996). In addition, the level of anxiety a student feels has been shown to be lower when an exam is taken at home (Weber et al., 1983) perhaps by virtue of the extended time limit (Boniface, 1985). Video lectures allow students to pause, replay, and manage their own learning but frequently using these features is not necessarily correlated with stronger performance (Le et al., 2010). And we should keep in mind that regardless of the pandemic, learning affordances are "in the eye of the beholder": for some students, online learning is a highly effective and empowering context while for others, it is not (Myyry & Joutsenvirta, 2015).

Student Learning Across Different Institutions

Not only does learning differ across different modalities (e.g., remote versus in-person), the institutional context is an important factor to consider when examining beliefs and performance. Although many university students were on Zoom during the pandemic, students across different institutions face different realities in higher education. Also, students in a particular institution may be more similar because they have selected to attend that institution, live in the vicinity, or have been selectively admitted. Often governments and states (e.g., California) have established different institutions to serve a wide variety of students.

The California Master Plan for Higher Education differentiates public postsecondary education into three different segments: University of California (UC), California State Universities (CSU), and California Community Colleges (CCC). Each type of institution has a purported mission. The University of California system serves as the "state's primary academic research institution" (University of California Office of the President, n.d.) such that in addition to educating undergraduates, it provides the greatest number of doctoral and professional degree programs. Meanwhile, the California State University system primarily focuses on undergraduate education and offers graduate education at the master's level. Lastly, the California Community College system has multiple missions, including providing lower division coursework for students to transfer to 4-year institutions, vocational certificates, and remedial instruction (University of California Office of the President, n.d.).

Although there are many differences in vision and in practice, one sharp distinction that emerges is the acceptance rate or selectivity in regard to incoming students. According to US News, California Community Colleges have an open admission policy (US News, 2022a), meaning a 100% acceptance rate for those that apply, and some California State Universities have up to ~75% acceptance rate (US News, 2022b). These two segments provide a fairly open path for students who wish to pursue higher education. Meanwhile, University of California institutions have acceptance rates as low as 14% (US News, 2022c). Moreover, the UC and CSU campuses are 4-year institutions, and the CCC campus is a 2-year institution (Public Policy Institute of California Higher Education Center, 2017).

Entangled with admission rates, there are large SES differences among the student populations attending these institutions. For example, within UC institutions, there is a higher enrollment of Asian-American students, compared to their Latino and African-American counterparts (Public Policy Institute of California Higher Education Center, 2017). Another large

difference between these institutions is the socioeconomic background of the students. Students from lower SES backgrounds (families making less than $30,000/year) are more likely to attend community colleges compared to students from families with incomes higher than $75,000/year (Public Policy Institute of California Higher Education Center, 2017). Moreover, the rates of degree completion differ among these campuses, with students in UC institutions graduating at highest rates and community college students graduating at the lowest rates (Public Policy Institute of California Higher Education Center, 2017).

The fact that these student populations are quite different as they enter into these institutions and that they graduate at different rates are broad characterizations that hide important differences in the experiences that these students have as they attend college. For example, students who experience financial hardships feel a disproportionate burden applying and attending 4-year institutions due to the cost of tuition, books, housing, and other related expenses (Public Policy Institute of California Higher Education Center, 2017). According to the U.S. Department of Education, community college students, compared to their counterparts at 4-year institutions, are more likely to have full-time employment, dependents, financial independence, no high school diploma, and single parent status (Goan & Cunningham, 2007; Mesa et al., 2014). Although even students at more selective universities also share in some of these struggles, many do not, and we must keep these student experiences in mind as we interpret student attitudes, learning, and performance.

In the current study, we were particularly interested in beliefs about memorization that may affect students' experiences in a statistics courses taken in three different institutions representing the three segments of California's Master Plan for Higher Education. Although these are just individual institutions, not particularly representative of their segment, to our knowledge, there are no studies examining such attitudes and performance across these segments in such a longitudinal manner. Thus, we take these institutions as a starting point for exploring the differences and similarities in student experience in higher education.

Although no comparative studies exist across segments, prior studies have examined beliefs about memorization and mathematics in community college students who were identified for various levels of math remediation. Students taking math in community college generally report high rates of using memorization as a study strategy (Givvin et al., 2011; Stigler et al., 2010). In interviews, community college students expressed that conceptual learning in mathematics was a waste of their time and that the best way to move forward was to memorize the mathematical procedures needed to perform well on the examinations. When prompted, these students were able to reason conceptually but several expressed surprise or disbelief that they could or even should rely on conceptual reasoning in their normal math courses. In our study, we expect students to express strong beliefs in memorization but would go further to compare those beliefs across students taking statistics in several institutions.

Current Study

In this manuscript, we focus on three research questions:

(1) Do memorization beliefs differ before and after transitioning to online learning due to the declaration of the COVID-19 pandemic (e.g., in-person versus fully remote instruction)?
(2) How do these beliefs (as well as changes in these beliefs) differ across institutions (UC, CSU, and CCC)?
(3) What is the relationship between students' memorization beliefs, remote learning during COVID-19, institution, and their performance in the interactive textbook?

Based on prior research on online learning, we hypothesized that beliefs about the importance of memorization would be lower under fully remote instruction compared to in-person instruction. Considering the differences in selectivity of institutions, we predict UC students, compared to CSU and CCC, will have higher performance which has been shown to go together with lower beliefs about memorization. Furthermore, we also expect that memorization beliefs will be negatively correlated with performance. Specifically, students who strongly believe the course will require lots of memorization will perform poorer when compared to students that do not hold that belief, regardless of their academic institution or whether an individual took the course in-person or fully remote.

Method

Our research group has been using an online textbook as the basis of doing educational research and development; we call this the Better Book model of research and development (Stigler et al., 2020). The current focus of the Better Book project is introductory statistics (see CourseKata.org). Stigler et al. 2020 wrote an interactive introductory statistics textbook called "Statistics and Data Science: A Modeling Approach" and created partnerships between instructors, researchers, and developers to examine student data and continuously improve these materials. The long-term goal is to understand and improve how students grasp concepts that take a long time to learn such as those covered in an introductory statistics course.

This textbook has been adopted for introductory statistics courses in a variety of institutions, including high schools, community colleges, and 4-year universities. Moreover, the textbook was adopted even before the declaration of the COVID-19 pandemic when the fully remote instruction was implemented thus resulting in a unique data set of student responses before the declaration as well as after.

Students' responses to formative assessment questions are collected as they go through the pages of this textbook; these pages are typically assigned as homework by their instructor. On each page there are figures, text, videos, as well as embedded formative assessments that are assigned as a normal part of the course. These formative assessment questions range from coding exercises (students learn to code in R, an open-source coding language commonly used by statisticians) to multiple-choice and open-response questions. These questions provide an innovative way to measure learning over an extended period of time (over a whole course), rather than at a single time point. Through the CourseKata.org platform, researchers can analyze de-identified responses about statistical thinking throughout a whole course. In addition to questions about statistics, students are also asked survey questions at various time points in the textbook. For example, Better Book data has been used to explore the relationship between

utility value, behavior engagement, and performance (Sutter et al., 2021) to track the ups and downs in student motivation and learning. Other researchers have explored how students learn R and how their attitudes towards coding change through the course (Tucker et al., under review). For our current study, we will be examining both responses to survey questions as well as students' performance on end-of-chapter review questions embedded in the textbook.

Participants

Data were collected from students enrolled in an introductory statistics course using the textbook *Statistics and Data Science: A Modeling Approach* (Son & Stigler, 2016-2021, CourseKata.org). All participants were enrolled at one of three institutions each representing a component of California's Master Plan for Higher Education: University of California (UC), California State Universities (CSU), and California Community Colleges (CCC).

Data were collected from a total of 2,979 undergraduate students. 280 students were excluded from the analysis due to a lack of response on a key survey question relating to beliefs about memorization. Another 31 students were excluded because they repeated the course, leading to duplications in our data. The final sample (see Table 1) included 2,668 participants. UC (n = 1197), CSU (n = 695), and CCC (n = 776). The participants identified themselves as Female (68.3%), Male (29.3%), Non-Binary (1.0%), prefer not to say (0.2%), prefer to self-describe (0.2%), and no data (1.0%). The participants described themselves as Hispanic, Latinx, or of Spanish Origin (42.0%), Asian or Asian American (23.3%), White (18.4%), Prefer to self-describe (7.9%), Black or African American (3.5%), Middle Eastern or North African (1.7%), American Indian or Alaska Native (0.3%), Native Hawaiian or Pacific Islander (0.1%), and no data (2.8%). The majority of the participants were either in their second (38.5%) or third year (32.3%) of college, followed by first year (17.2%), fourth year (5.7%), others (3.9%), and no data (2.4%). These demographics are broken down by institution in Table 1.

Table 1

Demographic Characteristic of Participants

Baseline Characteristics	CCC		CSU		UC		Full sample	
	n	%	*N*	%	*n*	%	*N*	%
Gender								
Female	434	56.0	494	71.1	894	74.7	1822	68.3
Male	324	41.7	181	26.0	277	23.1	782	29.3
Non-binary	4	0.5	7	1.0	15	1.3	26	1.0
Other[a]	14	1.8	13	1.9	11	0.9	38	1.4
Race/Ethnicity								

Hispanic/Latinx/ Spanish Origin	377	48.6	526	75.7	219	18.3	1122	42.0
Asian or Asian American	110	14.2	55	7.9	456	38.1	621	23.3
White	137	17.6	33	4.8	322	26.9	492	18.4
Black or African American	31	4.0	21	3.0	40	3.3	92	3.5
Other[a]	121	15.6	60	8.6	160	13.4	341	12.8
Class year								
First/Freshmen	328	42.3	35	5.0	95	7.9	458	17.2
Second/Sophomore	218	28.1	148	21.3	661	55.2	1027	38.5
Third/Junior	118	15.2	333	47.9	410	34.3	861	32.3
Fourth/Senior	30	3.9	117	16.8	7	0.6	154	5.7
Other[a]	82	10.5	62	8.9	24	2.0	168	6.3
Grand Total	776	29.1	695	26.0	1197	44.9	2668	100

Note. This table highlights the demographic information of our sample. Other[a] includes participants that prefer not to say, prefer to self-describe, and those that did not provide data.

Data collection occurred over the span of two years, such that each participant was enrolled during one academic term from Fall 2019 to Spring 2021. Given the fact that we collected data from multiple institutions, it is important to note that both the CSU and CCC institutions are on the semester system (15 weeks of instruction), while the UC institution is on the quarter system (10 weeks of instruction).

Therefore, students in the CSU and CCC institutions used the textbook during Fall 2019, Spring 2020, Fall 2020, and Spring 2021 semesters. Of these semesters, both Fall 2019 and Spring 2020 semesters were considered pre-COVID-19 (in-person instruction), while Fall 2020 and Spring 2021 were considered post-COVID-19 (fully remote instruction). Note, by using the language of "pre-" and "post-COVID-19," we do not mean the pandemic itself but pre- and post-the declaration of the pandemic in the local areas that resulted in remote instruction.

For the UC institution, we collected data from Fall 2019, Winter 2020, and Winter 2021 quarters. For the quarter system, we considered Fall 2019 and Winter 2020 as pre-COVID-19, while Winter 2021 were considered as post-COVID-19 (see Table 2). The UC institution did not have any instructors that used the textbook during Fall 2020, Spring 2020, and Spring 2021.

Table 2

Institution by COVID-19 Status

	In-Person Instruction (Pre-COVID-19)			Fully Remote Instruction (Post-COVID-19)		
	Terms	# of classes	*N*	Terms	# of classes	*N*
CCC	Fall 2019, Spring 2020	9	308	Fall 2020, Spring 2021	16	468
CSU	Fall 2019, Spring 2020	19	412	Fall 2020, Spring 2021	12	283
UC	Fall 2019, Winter 2020	3	783	Winter 2021	2	414
Total		31	1503		30	1165

Note. This table shows the breakdown of terms by COVID-19 (in-person vs fully remote), number of total classes provided in those terms, as well as total number of participants.

Schools in California shut down during mid-March 2020, resulting in a fair amount of chaotic variation in the transition to remote schooling. Instructors that taught during the Spring 2020 semester began with in-person instruction but abruptly transitioned to remote; Winter 2020 quarter classes went remote during finals week, and Spring 2020 quarter classes were fully remote. Although there was variation in which chapters were completed before the transition, across all Spring 2020 semester classes, at least the first four chapters of the textbook were taught while instruction was still in-person. Thus, we restricted our analysis to the first four chapters of the textbook across all institutions and terms.

Design

The present study used a non-experimental, correlational research design. Our predictor variables of interest were COVID-19 (before and after the declaration of the pandemic which coincides with the shift to remote instruction) and Institution (UC, CSU, and CCC). We are interested in documenting any differences in memorization beliefs as well as the relationship between memorization and performance. However, it is important to note that we initially intended to fit a multi-level model to our data given that students are embedded in classes, embedded in institutions. Unfortunately, based on the number of classes in the UC institution compared to the CSU and CCC institutions (see Table 2), we were unable to run that analysis.

Materials & Procedure

The study made use of student data (on memorization beliefs and performance) from the interactive online textbook (Son & Stigler, 2016-2021, CourseKata.org). The book is accessed via the course in the learning management system (LMS), (e.g., Canvas, Moodle) used by their campus. Thus, all responses occur at the location of their choice at a time that makes sense given

the context of the assignment. Each instructor set their own deadlines (e.g., homework due every Monday, homework due before class, etc.) but all instructors assigned the chapters of the textbook in the same relative order (e.g., Chapter 1 due before Chapter 2).

Memorization Beliefs

As part of the "better book" project (Stigler et al., 2020), a 14-item survey (see Appendix A) is embedded at the beginning of the online textbook (right before the Chapter 1 pages). The survey was assigned as part of the first homework assignment (which often included Chapter 1). The approximate time to complete the survey was 10 minutes. Students were informed that their responses in the survey would not count toward their grade in the course. Because the survey was available when the course was available in the LMS, students were able to complete the survey even before the first day of class.

In this study, we will focus on a survey item where students were asked about their beliefs about memorization. Specifically, item 10 of 14 (see Appendix A) on the survey states, "I expect this course will require a lot of memorization." All classes from Fall 2019 to Fall 2020 answered this question with a 5-point scale. Winter 2021 (quarter) and Spring 2021 (semester), classes used a 6-point scale (1 = "Strongly Disagree," 2 = "Disagree," 3 = "Slightly Disagree," 4 = "Slightly Agree," 5 = "Agree", and 6 = "Strongly Agree"). To compare across all students who answered this question, we recoded the 6-point scale responses into a 5-point scale. "Slightly Disagree" (3) and "Slightly Agree" (4) from the 6-point scale were counted as a 3 on the 5-point scale.

The textbook also provides multiple measures of student performance. We focused on our analysis on the review questions that appeared at the end of each chapter. These review questions were a set of 13-21 multiple choice questions on a page that asked students to transfer their cumulative learning to a new data set that had not yet been discussed. All classes analyzed in this research gave credit solely for students' completion of these review questions, so homework scores were not affected by correctness.

Each set of review questions queried students on a new context with a new data set. Some chapters had two sets of review questions (each with a different context, e.g., data from lakes versus bicycle trips) presented on two different pages. Chapter 1, being an introductory chapter, only had one set of review questions. Chapter 2, 3, and 4 all had two sets of review questions. Therefore, there were a total of 7 sets of review questions. All students completed each assessment at the discretion of their instructor. However, some instructors only assigned one of the two sets of review questions for Chapters 2, 3, and 4. We decided to base our data analysis using the higher score of each set of review questions. The rationale for this was so that if one assignment was never assigned, the second assignment, by default, would have the higher score and would be included in the study. In total, each participant had four scores, one for each chapter.

Results

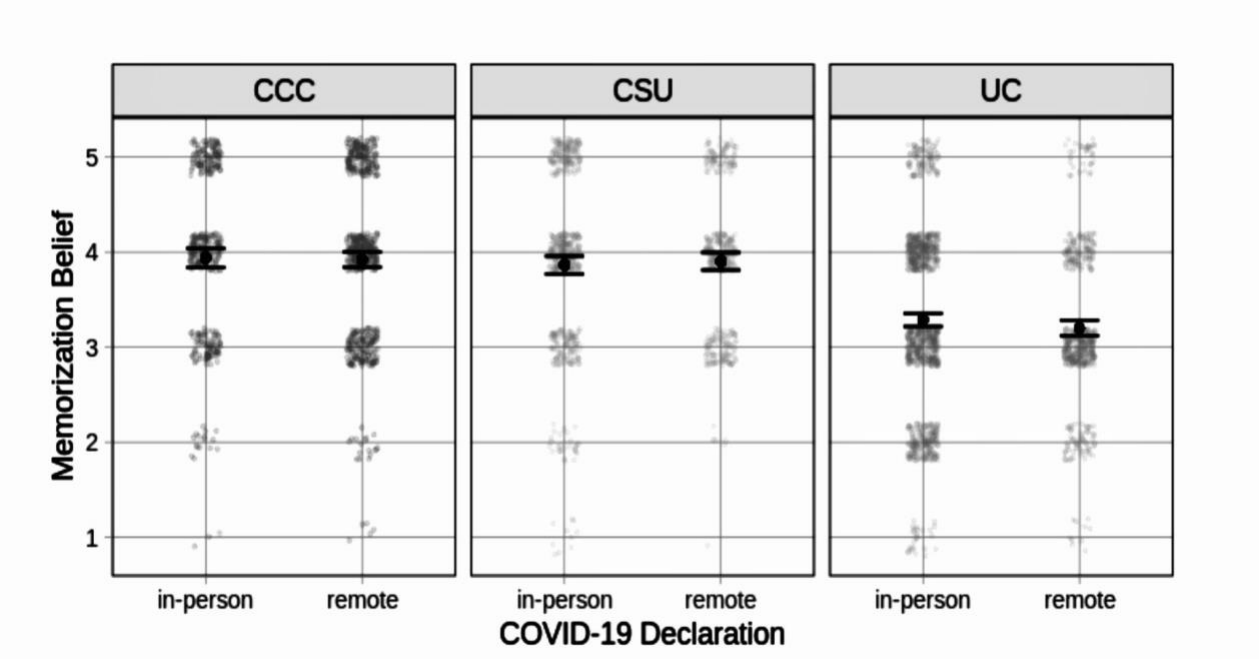
Memorization Beliefs

In this set of analyses, we examined the first two research questions: Do memorization beliefs differ before and after the declaration of the COVID-19 pandemic (e.g., in-person versus fully remote instruction)? and Do memorization beliefs differ across institutions (UC, CSU, and CCC).

A 2x3 ANOVA was performed on students' memorization beliefs scores. The first independent variable was COVID-19 with two levels: in-person instruction and fully remote instruction. The second independent variable was institution with three levels: CCC, CSU, and UC. This analysis revealed a significant main effect of institution ($F(2, 2662) = 83.358$, $p < .001$, $\eta_p^2 = .109$) but no effect of COVID-19 ($F(1, 2662) = 0.051$, $p = .821$, $\eta_p^2 = .002$) and no significant interaction ($F(2, 2662) = 1.13$, $p = 0.323$, $\eta_p^2 = .001$). A post-hoc Tukey HSD indicated participants who were enrolled at the UC institution, in-person or fully remote, had significantly lower beliefs in the role of memorization when compared to both CSU ($p < .001$) and CCC ($p < .001$) students (see Figure 1).

Figure 1

Memorization Beliefs by COVID-19 (in-person, remote) and Institution (CCC, CSU, UC)



Note. A jitter plot showing strength of belief in memorization before and after COVID-19 declaration (i.e., in-person & fully remote instruction) as well as across 3 types of institutions (i.e., CCC, CSU, UC).

The Relationship Between Memorization Beliefs and Performance

So far, we have seen that memorization beliefs differ across institutions but were unchanged over the declaration of the pandemic. We want to lay bare our assumptions about the

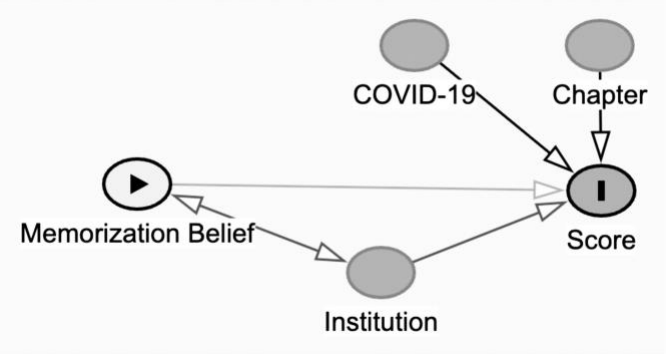
underlying causal relationships between memorization, institution, COVID-19 (e.g. in-person versus fully remote instruction), and scores on review questions before embarking on the analysis of those scores. We will use a directed acyclic graph (DAG) in order to make those assumptions explicit. We want to note that our analysis as well as the use of our DAG will not necessarily confirm nor disconfirm our causal assumptions (Cinelli et al., 2022)—but being explicit about them will help us explain the predictor variables included in our model.

Figure 2 shows the DAG that represents the following causal assumptions: Based on prior research, we assume that students' beliefs about memorization are formed during their long experience in the institution of school (K-12) and are relatively enduring. Although our measurement of memorization occurred relatively early in college (e.g., the introductory statistics course is often a prerequisite for other courses or a GE course), it did *not* occur before college began. Nevertheless, we assume that memorization beliefs are relatively stable and presumably affect learning performance (see the arrow to score in Figure 2) and affect which college students end up at (e.g., selective to less selective, see the arrow to institution). However, it is also plausible that the institution they attend, the instruction they receive, and the peers they are around may also impact memorization beliefs. A bidirectional causal relationship between memorization beliefs and institution may exist. This assumption requires further research outside the scope of the data we have gathered.

Being at particular institutions may also affect students' scores as their courses, instructors, and social settings differ (represented in the arrow from institution to score). We had believed that the COVID-19 declaration would have changed memorization beliefs but found that it was not a significant factor (thus there is no arrow between COVID-19 and memorization belief score). However, we assume that COVID-19 may have had an impact on learning performance (see the arrow between COVID-19 and score). Further, we believe that differences between chapters result in different scores (arrow between chapter and score), such that later chapters are more difficult compared to earlier chapters as the material becomes more complex.

Figure 2

Directed Acyclic Graph (DAG)



Note. The figure highlights the causal assumptions between memorization beliefs, institution, COVID-19, chapter, and score on review questions.

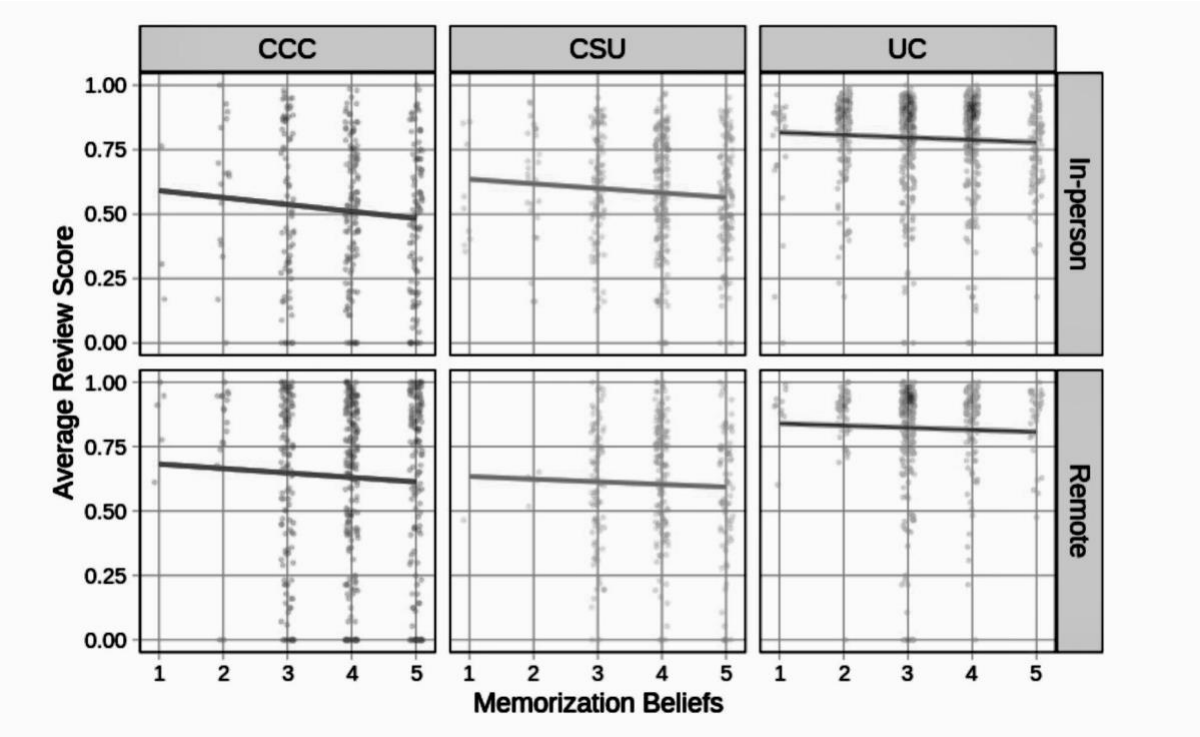
Our primary interest in this study is in examining the relationship between memorization and score on the review questions. We included institution, COVID-19, and chapter in a model to predict score on the review questions. Thus, the full model is specified as follows:

$$Score_{ij} = \beta_0 + \beta_1 Mem_i + \beta_2 COVID_i + \beta_{3k} School_{ik} + \alpha_j Ch_j + Subj_i + \epsilon_{ij}$$

Within this equation, *i* represents each individual subject, while *j* represents each time point, specifically each set of chapter review questions for a total of four. $Score_{ij}$ is each subject's score on one of the four sets of chapter review questions. Mem_i represents each individual's memorization belief score, and $COVID_i$ represents whether each subject took the course before or after the COVID-19 declaration. $School_{ik}$ represents the institution in which the subject (*i*) is enrolled, and *k* represents which of three institutions (UC, CSU, or CCC). Both the $COVID_i$ and $School_{ik}$ variables are dummy coded. Ch_j represents which specific chapter's score is being measured. Moreover, α represents the coefficients for within-subject variables, while β represents the coefficients for between-subject variables. Lastly, $Subj_i$ is the random effect of the individual subject, and ϵ_i is the residual. This model is equivalent to a mixed repeated measures ANOVA with memorization score as a covariate; COVID and institution as between-subject factors, and chapter as a within-subject variable with no interactions specified (see Figure 3).

Figure 3

The Relationship Between Memorization Beliefs, Performance, COVID-19, & Institution



Note. The figure highlights the negative relationship between Memorization Beliefs and Performance (averaged across chapters), while taking into consideration Institution (i.e., CCC, CSU, UC) and COVID-19 (i.e., in-person, remote).

By fitting and testing this model in R, we found significant effects of memorization beliefs ($F(1, 2610) = 115.783$, $p < .001$, $\eta_p^2 = .042$) and institution ($F(2, 2610) = 235.831$, $p < .001$, $\eta_p^2 = .153$), but no effect for COVID-19 ($F(1, 2610) = 2.327$, $p = .127$, $\eta_p^2 = .001$). Lastly, chapter was also a significant within-subject factor ($F(3, 8053) = 327.232$, $p < .001$, $\eta_p^2 = .109$).

The effect of memorization beliefs was negative (b = -.015) such that the model adjusts performance downward for every one unit increase in memorization. We performed pairwise comparisons between institutions using estimated marginal means. Although the CSU outperformed CCC by .018, this difference was not significant ($p = .315$). Additionally, UC outperformed CCC by .223 ($p < .001$) and the CSU by .205 ($p < .001$). Furthermore, as chapters progressed, scores declined (e.g., students scored significantly higher on Chapters 1 than 2 and all differences were significant, ps < .001).

Discussion

Summary of Findings and Implications

Past research on memorization as a learning strategy has highlighted that reliance on memorization is maladaptive, leading to lower performance (House, 2006; Lin & Tai, 2015; Schoenfeld, 1989), less confidence (Wheeler & Montgomery, 2009), and a lower likelihood of engaging in productive struggle (Phelps-Gregory et al., 2020). The current study sought to explore this relationship further in the larger context in which a student learns. To our knowledge, this is the first study that has explored memorization beliefs and performance across COVID-19 (i.e., in-person instruction & fully remote instruction) as well as across the different types of institution (e.g., segments of California Master Plan for Higher Education).

As we predicted, students from less selective institutions (i.e., CSU and CCC) professed stronger beliefs in the role of memorization in learning than students from a more selective institution (i.e., UC). Interestingly, there were no differences in these memorization beliefs before and after the declaration of the COVID-19 pandemic in any of the campuses we studied. Like prior research, we found that lower memorization belief scores predicted better performance on end of chapter review questions. Additionally, the UC institution significantly outperformed both the CSU and CCC institutions, and as chapters progressed, performance on end of chapter review questions significantly decreased.

The negative relationship between memorization beliefs and performance is striking given the longitudinal nature of this study. For at least four chapters, the effect holds up, indicating that students who strongly believe the course will require lots of memorization performed poorly relative to students that do not hold that belief, regardless of their academic institution or whether the course was in-person or fully remote. Why does this belief have this predictive power? Perhaps, believing that the course requires memorization either leads to maladaptive learning strategies or is a reflection of the strategies they have used so far in math courses. For example, relying on memorization may lead students to try and memorize individual formulas, code, or definitions rather than understand how they fit together or make connections between concepts in the course. Students may have also attempted to memorize in prior math courses leading to brittle knowledge, thus leaving them ill-prepared for this college level

statistics course. Whether memorization beliefs are an indication of poor learning strategies or deficiencies in prior learning, these beliefs can serve as a clue to the variety of learning experiences students may have even when they are all in the same course.

Our study attempted to go beyond the beliefs inside students' heads to consider the wider context: both the context of an unprecedented global pandemic and the institutional contexts that students learn in. We had expected that the COVID-19 pandemic would have had a significant influence on students' beliefs about memorization and on their performance, such that untimed, open textbook, open note, and open Internet assignments and exams would create less of a need to memorize as well as higher performance (Er et al., 2021; Nickerson & Shea, 2020), but this was not the case. It is possible that exams were rendered "easier" with these more open features, and the real-world difficulties of the COVID-19 pandemic may have impacted student learning and/or motivation. For example, especially for students from lower socioeconomic backgrounds, issues such as the lack of internet access as well as more familial and home responsibilities during the pandemic (Pokhrel & Chhetri, 2021) may have added additional stressors to students' lives. Indeed, additional analysis in our lab has shown that both CCC and CSU students (but not the UC students). experienced an increase in overall anxiety due to the abrupt changes caused by the pandemic. Thus, the easing of policies during the pandemic may have been negated by added real-world difficulties.

Most of the past educational research we have drawn upon (and most research linking attitudes to math performance in general) focuses solely on data from one academic institution. And although it is *de rigueur* to mention the limitations of such data in learning about the experiences of students across a variety of different types of campuses, gathering richer data is often impossible. Thus, part of the innovation of this study is making headway into this type of cross-institutional analysis by utilizing an innovative method of data collection—an interactive textbook—adopted by various instructors at the three segments of California's Master Plan for Higher Education.

Institution is, perhaps, one of the most understudied but important contexts when examining data on student learning. Part of the difficulty is in untangling the chain of causality. Since students are not randomly assigned to institutions, there are many pre-existing differences in ethnic diversity, SES, and geography. There are also vast differences in the type of courses offered, expectations of faculty, and graduation and admission rates, all of which shape a student's learning experience. Memorization (even within an institution) had a negative association with performance but when we zoom out to consider institutional context, we found that the UC institution had lower memorization belief scores as well as higher performance when compared to the CSU and CCC institutions. If we were to have done this study solely focusing on the UC institution, our understanding would have been limited and not representative of many students in California's public system of higher education. Therefore, the issue of memorization may be important at a UC, but perhaps even more critical to CCC and CSU students.

Limitations and Future Directions

Although this study makes innovative strides in examining student learning in richer, more authentic contexts, there are several limitations to consider. First, being in a real class setting limited the survey questions we could reasonably ask students. Thus, our measure of

students' beliefs about memorization was based on one question from the introductory survey inside the *CourseKata Statistics and Data Science* textbook. Future studies should incorporate a measure for beliefs about memorization that are more robust such that we can disentangle students' beliefs about memorization as related to study strategy, domain of mathematics, and perceptions of mastery or fluency. Future studies should also examine students' beliefs in the power of memorization in a way that can distinguish between more enduring beliefs in the power of memorization and beliefs that are contextualized to the class. Despite this very limited measure, this one question regarding students' beliefs about memorization was a significant predictor of student performance months later across a variety of contexts. This study can establish the initial importance of *memorization beliefs* as a robust construct, but we need more research to unpack what exactly is the mechanism that links these beliefs with academic outcomes.

Another limitation of this study is the generalizability of our results. Although this is one of the first studies to examine these rigorously, using the same materials in a longitudinal manner, in different institutions of higher education, there is large variation in these different segments of California's Master Plan for Higher Education. Future research would gather data from a greater variety of institutions, for example from multiple community colleges or CSUs, and attempt to understand how much of these differences can be explained by selection alone (e.g., differences in students accepted into the institution) versus other behaviors, habits, and contextual forces. As more UC, CSU, and CCC institutions adopt this new and innovative way to learn statistics, future studies can use a multilevel modeling approach. This would enable us to further see differences at the institutional level and gain a better understanding of how educational contexts can predict students' attitudes, beliefs, and learning.

Also, although one strength of this research is that these effects were found in performance on real coursework completed over weeks of instruction, these effects were specific to a statistics learning context in a very particular textbook. Whether beliefs about memorization are negatively associated with a broader range of learning outcomes remains to be seen. Future studies should investigate whether the relationship between beliefs about memorization and performance exists in other subject domains.

As in much of educational research, we want to know the causal underpinnings of academic outcomes. We provided a directed acyclic graph in order to lay bare our assumptions of underlying causal relationships between memorization, institution, COVID-19, and scores. However, this study was correlational in nature, thus, it may be beneficial if future studies can produce experimental designs to figure out the causal relationship between memorization beliefs and academic performance. For example, if an intervention can help students shift their mindset away from memorization and more towards making connections across concepts, would that lead to better scores or different behaviors in the textbook?

Another direction for future studies can include tracking different cohorts as the situation with COVID-19 continues to evolve. In this data, COVID-19 is split into two groups: in-person instruction and fully remote instruction. As the world shifts and re-organizes to provide more hybrid, or more in-person options, we can continue to examine different ways these modalities impact student behavior or selection. Will students who ascribe to different beliefs opt for more

online or in-person options? If students fully return to their campuses for in-person instruction, will they exhibit different behaviors than those "in-person" students who took the class before they knew of hybrid or remote learning options? Will learning trajectories be more similar to the original in-person instruction or more similar to the fully remote instruction? Popular press suggests that the COVID-19 pandemic has permanently changed education. There is worry that many students will have to play catch-up with the return to in-person instruction (Bombardieri, 2021). Moreover, George et al. (2021) suggests there may be an enduring impact on students' mental health and that schools may have difficulty keeping up. In addition, there is concern that "distance learning will reinforce teaching and learning approaches that we know do not work well" (Winthrop, 2020, para. 3). All of these worries indicate that student learning has changed, and we may never view education the same way we did before the COVID-19 pandemic. As educators, it is our duty to guide and teach students, so it is imperative that we investigate these conjectures with data in order to better prepare all current and future educators for the educational changes that are occurring around us.

Conclusion

As educators and researchers, we want students to learn and master course content to the best of their ability. In order to do so, we must recognize the power of institutional context and realize that institutions of higher education are made up of communities of students with similar beliefs and similar levels of academic achievement. Knowing this will help us understand how students react to disruptive social changes such as a pandemic but also to help forge a way towards an educational system that works for all students.

Declarations

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The authors have no conflicts of interest to disclose.

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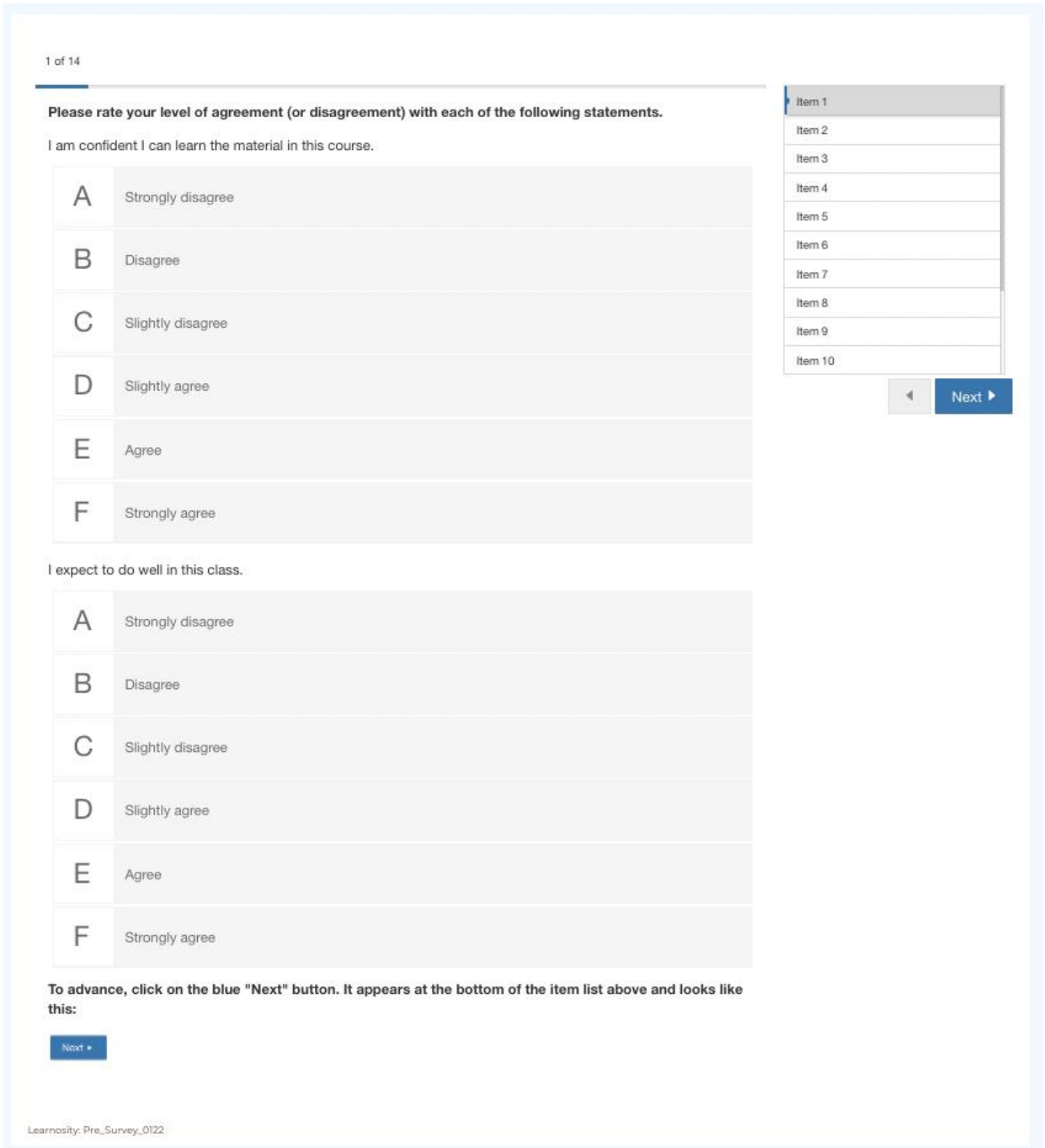
Appendix A
14-item Pre-Survey



What I'm going to learn in this class will be useful.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

What I'm going to learn in this class will be useful in the future.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Good grades in this class will improve my job and career chances.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

What I'm learning in this class will be relevant to my everyday life.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Item 1
Item 2
Item 3
Item 4
Item 5
Item 6
Item 7
Item 8
Item 9
Item 10
◀ Next ▶

I think this class will be interesting.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

I will like this class.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

This class is important to me personally.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Performing well in this class is important to me.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

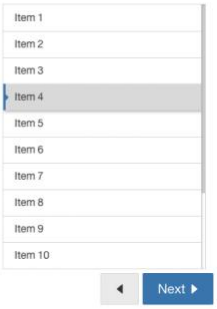
Item 1
Item 2
Item 3
Item 4
Item 5
Item 6
Item 7
Item 8
Item 9
Item 10

Next

4 of 14

In general, I tend to feel very anxious about mathematics.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree



When I think about this course, I'm concerned that... (If you have no concerns you may simply write "none").

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Learnosity: Pre_Survey_0122

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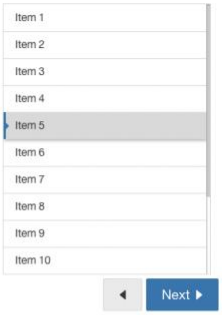
I think I will have to give up too much to do well in this class.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree



I think this course is going to be too stressful for me.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Learnosity: Pre_Survey_0122

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I feel like this school is a good fit for me.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Sometimes I feel that I belong at this school, and sometimes I feel that I don't belong at this school.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Item 5
Item 6
Item 7
Item 8
Item 9
Item 10
Item 11
Item 12
Item 13
Item 14

◀ Next ▶

B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Learnosity: Pre_Survey_0122

You can learn new things, but you can't really change your basic math ability.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

My math ability is something about me that I can't change very much.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Item 5
Item 6
Item 7
Item 8
Item 9
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Item 11
Item 12
Item 13
Item 14

Next

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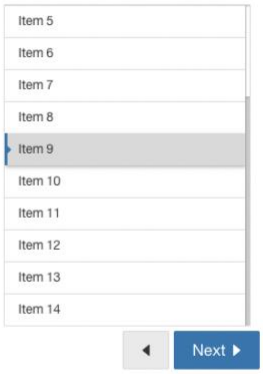
How confident are you in your R skills?

A	Not at all confident
B	Only a little confident
C	Somewhat confident
D	Mostly confident
E	Completely confident



Learnosity: Pre_Survey_0122

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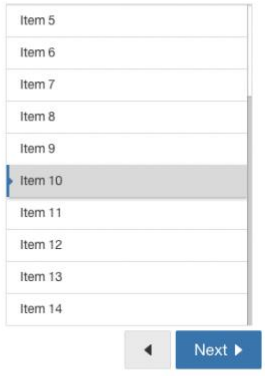
I expect this course will require a lot of memorization.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree



Learnosity: Pre_Survey_0122

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In this course, you will use R (a programming language) to analyze data. How do you feel about this?

A	Strongly negative
B	Negative
C	Somewhat negative
D	Somewhat positive
E	Positive
F	Strongly positive

I think statistics and data science is interesting.

A	Strongly disagree
B	Disagree
C	Slightly disagree
D	Slightly agree
E	Agree
F	Strongly agree

Item 5
Item 6
Item 7
Item 8
Item 9
Item 10
Item 11
Item 12
Item 13
Item 14
Next

12 of 14

Now just a few demographic questions. Your answers to these questions, as with all your answers on this survey, are kept confidential. Although we hope that you'll respond, you may skip questions you do not wish to answer.

What best describes your gender?

A	Male
B	Female
C	Non-binary
D	Prefer to self-describe

If you indicated that you prefer to self-describe your gender, how do you describe yourself?

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Which of the following categories describe you? If you'd like to use more than one category or if you'd like to use a category not provided, please select "prefer to self-describe" and answer the next question.

A	**American Indian or Alaska Native** (Examples include Navajo Nation, Blackfeet Tribe, Mayan, Aztec, Nome Eskimo Community, etc)
B	**Asian or Asian Am.** (Examples include Asian American, Chinese, Fillipino, Asian Indian, Vietnamese, Korean, etc.)
C	**Black or African Am.** (Examples include African American, Jamaican, Haitian, Nigerian, Ethiopian, Somalian, etc.)
D	**Hispanic, Latino, or Spanish Origin** (Examples include Mexican or Mexican American, Puerto Rican, Cuban, Salvadorian, Dominican, Columbian, etc.)
E	**Middle Eastern or North African** (Examples include Lebanese, Iranian, Egyptian, Syrian, Moroccan, Algerian, etc.)
F	**Native Hawaiian or Pacific Islander** (Examples include Native Hawaiian, Samoan, Chamorro, Tongan, Fijian, Marshalese, etc)
G	**White** (Examples include German, Irish, English, French, Norwegian, etc.)
H	Prefer to self-describe my race, ethnicity, or national origin

If you prefer to self-describe your race, identity, or national origin, how do you describe yourself?

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What's your year in school?

A	Freshman
B	Sophomore
C	Junior
D	Senior
E	Other

What's your age, in years?

Approximately how many hours per week do you work at paid employment?

A	I don't currently have paid employment.
B	1-10 hours per week
C	11-20 hours per week
D	21-30 hours per week
E	31-40 hours per week
F	40+ hours per week

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What is your cumulative GPA at this school?

A	below 2.00
B	2.00-2.49
C	2.50-2.99
D	3.00-3.49
E	3.50-4.00
F	I don't have a GPA yet because I'm a new student.

Do you commute more than 30 minutes each way to attend this school?

A	Yes
B	No

Is English your most proficient language?

A	Yes
B	No

If you indicated that English is not your most proficient language, what is your primary language?

To the best of your knowledge, what is the HIGHEST level of education earned by your mother?

A	I do not know/uncertain
B	Elementary or Middle School
C	Some High School
D	High School Graduate
E	Post High School Vocational Training
F	Some College
G	Associate's Degree
H	Bachelor's Degree
I	Post Graduate Degree (Master's, Doctorate, etc.)

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If you are NOT taking this course through a college or university, please skip the remaining questions and click the SUBMIT button to the right. Otherwise, please complete this last page of questions.

Which of the following describes you?

A	I am a community college student
B	I am a student at a four year university and transferred from a community college
C	I am at a four year university and began here as a freshman
D	None of the above

Did you graduate high school in the U.S.?

A	Yes
B	No

If you did not graduate high school in the U.S., in what country did you graduate high school?

What is your major?

How would you describe your current financial circumstances, in general.

A	I cannot make ends meet.
B	I am barely making it.
C	I am breaking even.
D	I have extra money after paying the bills.
E	I do not have to worry about money.

Which of the following courses have you successfully completed? (Check all that apply)

A	AP Calculus in high school
B	Calculus in college
C	AP Statistics in high school
D	A different statistics course (besides this one) in college