Enhancing Online STEM Education: Impacts of Pre-Released Exam Materials and Remote Proctoring

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Abstract

Student attrition in online courses remains a significant concern, particularly in STEM disciplines. Common pedagogical practices in STEM, such as timed, high-stakes "traditional" exams, may contribute to attrition by adversely affecting cognitive development, student attitudes toward their discipline, and various aspects of motivation. I hypothesized that the pre-release of exam materials could mitigate such undesirable effects of exams. To test this, I investigated the effect of pre-released exam materials on student outcomes in an upper-division online biology course, focusing on exam performance and impacts to student attitudes and motivational factors. Results indicated that in comparison to a traditional exam system, the pre-release of exam materials did not significantly improve student exam performance, attitudes, or motivation, nor did it affect the achievement gap associated with lower socioeconomic status (SES). However, student responses to a qualitative survey suggested a trend for unique benefits of pre-released exam materials, including reduced anxiety and an enhanced focus on core concepts. This implies that pre-released exam materials have the potential to improve the qualitative test-taking experience of online STEM students without disadvantaging students from lower SES backgrounds. In addition to the above, I found that remote proctoring significantly penalized exam performance, with more pronounced effects for students from lower SES backgrounds. Nevertheless, proctoring requirements maintained favorable student attitudes, with all attitude categories remaining expert-like only under proctored conditions. These findings suggest that remote proctoring in online STEM courses can have complex and multi-faceted effects that warrant further investigation.

Keywords: Achievement gap, attitudes, grades, motivation, online education, exams, remote proctors, socioeconomic status, STEM, test anxiety

Introduction

Online education continues to grow at a rapid pace. However, student attrition rates from online learning environments remain a concern, particularly in online Science, Technology, Engineering and Mathematics (STEM) courses. High attrition not only limits the sustainability of online STEM programs but also disproportionately impacts historically underrepresented groups, exacerbating existing inequities. Addressing these challenges requires innovative pedagogical

approaches that enhance academic performance, discipline-related attitudes, and motivational beliefs—all key factors for online STEM student success and retention.

One promising strategy is the pre-release of exam materials. Students in a face-to-face introductory STEM course self-reported that the pre-release of exam materials helped them to focus their studying on key concepts, promoted deeper critical thinking, and reduced test-taking anxiety (Wiggins et al., 2023). The current study aims to investigate whether implementing a pre-released exam delivery system in an online biology course can similarly enhance outcomes, and whether effects are equitable across diverse student groups.

Literature Review

Online learning platforms have transformed higher education, becoming a core mode of instruction at most colleges and universities. Post-secondary institutions use online learning platforms to enhance financial sustainability and reach a broader, more diverse pool of students. For students, online learning offers the benefits of flexibility, convenience, and affordability (Shay & Rees, 2004). However, student attrition in online learning environments remains a concern, as dropout rates often exceed those in traditional classroom settings (Bawa, 2016; Shaikh & Asif, 2022; Xavier & Meneses, 2020). STEM courses experience particularly high attrition rates (Wladis et al., 2014). This not only limits the successful growth of online STEM programs but also negatively impacts the well-being of students who do not persist (Xavier & Meneses, 2020). Furthermore, remote STEM education disproportionately challenges historically underrepresented students (Barber et al., 2021). Consequently, the continued expansion of online STEM education could exacerbate the existing high attrition rates in underrepresented groups (Crisp et al., 2009, Estrada et al., 2016), potentially deepening social inequities and detracting from impactful and innovative STEM work through loss of diversity (Barber et al., 2020; Hofstra et al., 2020).

Although no single factor fully predicts student attrition from an online course, instructional strategies play a key role in students' success (Muljana & Luo, 2019). For example, instructors' ability to spark intellectual curiosity and appropriately challenge students is linked to improved retention; online learners tend to report greater satisfaction and demonstrate greater persistence when engaged with rigorous and relevant content (Artino & Stephens, 2009; Muljana & Luo, 2019; Shaikh & Asif, 2022). In support, instructional practices that foster higher-order learning in face-to-face courses improve student performance (Haak et al., 2011; Stanger-Hall, 2012).

Online student retention is influenced not only by engagement in higher-order learning but also by socio-psychological factors that contribute to learning readiness, such as discipline-related attitudes and components relating to motivation, academic self-efficacy, and self-determination (Bawa 2016; Muljana & Luo, 2019; Shaikh & Asif, 2022; Xavier & Meneses, 2020). Thus, enhancing attitudes and motivational beliefs in online learners may improve academic success (Artino & Stephens, 2009; Cho & Shen, 2013; Chung et al., 2022; but see Walker et al., 2024). Supporting this, studies of face-to-face students show a strong correlation between socio-psychological factors and achievement (Burtner, 2005; Oseguera et al., 2019; Perkins et al., 2005), with evidence suggesting that participation in a single STEM course can

impact socio-psychological factors (e.g., Cleveland et al., 2017; Liu et al., 2022; Stanger-Hall, 2012).

While online STEM faculty who emphasize higher-order learning and foster positive motivational beliefs in their students have the potential to address the ongoing issue of attrition, certain pedagogical practices like timed, high-stakes traditional exams may undermine these efforts. In most STEM courses, exams are the primary assessments of learning. Typically, students first see exam questions during a testing period with time constraints, requiring students to rapidly process instructions, question texts, and any accompanying figures or tables. Moreover, these timed exams often constitute a significant portion of the course grade, determining whether students pass or fail. Such traditional characteristics of STEM exams pose at least four challenges for online students, particularly when students are from historically underrepresented groups.

First, traditional STEM exams favor simpler, lower Bloom's-level questions due to time constraints, encouraging rote memorization rather than deep, critical thinking (Black & Wiliam, 2010; Jensen et al., 2014; Stanger-Hall, 2012). For online students, who may already feel less connected to the discipline (Delahunty et al., 2014; Selco & Habbak, 2021), this focus on surface-level learning can hinder engagement and development of mature, discipline-specific thinking. Effects may be especially harmful for historically marginalized students, who need to counter social stereotypes regarding their pursuit of a STEM career.

Second, the high-stakes nature of traditional STEM exams often generates counterproductive anxiety which can hinder memory and learning, weaken exam performance, and erode students' STEM identity (Seipp, 1991; Vogel & Schwabe, 2016). This anxiety may be particularly detrimental to online students, who already feel a reduced sense of community (Delahunty et al., 2014; Selco & Habbak, 2021), as well as to underrepresented students, who face additional cognitive loads related to stereotype threat and systemic inequities (Ballen et al., 2017; Cohen et al., 2006; Putwain, 2008; Salehi et al., 2019).

Third, students who receive poor scores on traditional STEM exams often attribute their poor performance to external factors, such as "tricky" questions or an "unfair" exam. Such excuses are especially common in students with low motivation, a group that includes many online students (Stark, 2019). Such perceptions can lead students to adopt a defeatist attitude and take the naïve stance that they cannot do much to improve their academic standing (Black & Wiliam, 2010).

Fourth, traditional STEM exams often impose strict time limits while not accounting for language challenges, which may disproportionally penalize non-native speakers and students for whom the "language of college" was less prevalent in their upbringing, such as students from low-income or first-generation backgrounds. This inability of traditional exams to separate language difficulty from content mastery can exacerbate achievement gaps.

These identified issues with traditional STEM exams can increase attrition rates, especially in online settings, as well as perpetuate demographic achievement gaps (Salehi et al., 2019; Stanger-Hall, 2012). An assessment system that incorporates the pre-release of exam

materials may offer a promising solution (Johnson & Crisp, 2009; Wiggins et al., 2023). In this system, students are given access to certain textual and visual components (e.g., scenarios, tables, or graphs) before the exam. This approach is widely utilized in K-12 education and is likely to translate well to college environments (Johnson & Crisp, 2009; Pellegrino et al., 2001; Wiggins, 1998).

In response to the four specific challenges associated with traditional STEM exams discussed above, an assessment system that incorporates the pre-release of textual and visual information (hereafter referred to as "pre-released exams") could: (1) facilitate the inclusion of higher Bloom's-level questions that promote deeper conceptual thinking and strengthen students' connection to the discipline (Jensen et al., 2014; Stanger-Hall, 2012); (2) reduce unproductive anxiety, especially important for online and underrepresented students (Ballen et al., 2017; Cohen et al., 2006; Jegede & Kirkwood, 1994; Putwain, 2008); (3) enhance student "buy-in" for assessment accuracy that can foster motivation, encourage responsible learning behaviors, and improve future performance (Brazeal & Couch, 2017); and (4) promote equitable comprehension of exam materials, particularly under narrow time constraints.

A recent study of face-to-face students in a large introductory biology course supports these benefits: students reported positive impacts of pre-released exam questions on their understanding of study priorities, depth of thinking, and test-taking anxiety (Wiggins et al., 2023). Students also expressed a strong preference for exam questions with pre-released material. Importantly, pre-released materials did not worsen demographic achievement gaps.

Building on this evidence, I hypothesized that integrating a pre-released exam system into online STEM education would significantly enhance learner outcomes in an equitable manner by fostering higher-order cognitive thinking and key socio-psychological factors, such as mature attitudes toward the discipline and increased learner motivation.

To test this hypothesis, I examined the effect of pre-released exam questions on student exam performance in six sections of an asynchronous, upper-division online biology course. I assigned pre-released exams versus traditional exams at the section-level. Additionally, I examined the effects of pre-released exams on socio-psychological factors relevant to online learner success and retention, including attitudes toward the discipline, motivational beliefs, and qualitative experiences with exams, while also collecting demographic data to assess equity.

In sum, I addressed the following research questions (RQs) in my study:

- **RQ1**: Do pre-released exams improve exam performance and socio-psychological factors relevant to the success of online STEM students?

- **RQ2**: Do pre-released exams help reduce disparities in educational outcomes for students historically underrepresented in STEM?

I initiated this study during the COVID-19 pandemic and could not use on-site proctoring centers for exams as planned, because these centers were closed. Midway through the study, I implemented a remote online proctoring system provided by my institution, creating a natural experiment in which earlier course sections operated without proctors, while later sections included proctoring requirements. As a result, I included "proctoring requirements" as a potential

explanatory factor in all statistical analyses, enabling me to additionally assess the effect of remote proctors on online learner outcomes. Findings from this part of the study add to the growing body of literature on the use of remote proctors in distance education (Harmon et al., 2008; Daffin & Jones, 2018; Wuthisatian, 2020). Accordingly, my study also addressed a third research question:

- **RQ3**: How do remote online proctors influence exam performance and key socio-psychological factors in online STEM students?

In sum, my study aims to advance understanding regarding the impact of assessment practices in online STEM education and to identify strategies that foster equitable academic success and retention.

Methods

Context

I conducted my study at a Research 1 (R1) university in the Pacific Northwest, USA. I collected data from an asynchronous upper-division online biology course which focuses on the sub-disciplines of molecular genetics, transmission genetics, and quantitative genetics. This course is a core requirement for online Zoology majors and includes on-campus Biology and Zoology majors. Additionally, this course attracts post-baccalaureate students who are fulfilling prerequisites for professional programs. Each section spans 11 weeks and consistently reaches its enrollment capacity of 60 students.

For all sections of this course, I served as the principal instructor; I am a woman with a PhD in Zoology and over a decade of experience teaching college-level courses. In 2018, prior to the commencement of this study, I applied for and received Quality Matters (QM) certification for this course. QM certification serves as an internationally recognized standard that acknowledges courses that provide high-quality online learning experiences and adhere to rigorous QM course design criteria.

Exams

Each section of the course included three timed online exams (Figure 1), which I administered remotely. I permitted students to use their notes and a calculator during the exams but instructed them to complete the exams individually and refrain from sharing answers. Students signed an academic integrity statement at the start of each exam affirming their intent to follow these instructions and comply with our institution's Student Code of Conduct.

Figure 1

Timeline of Research Flow and Data Collection
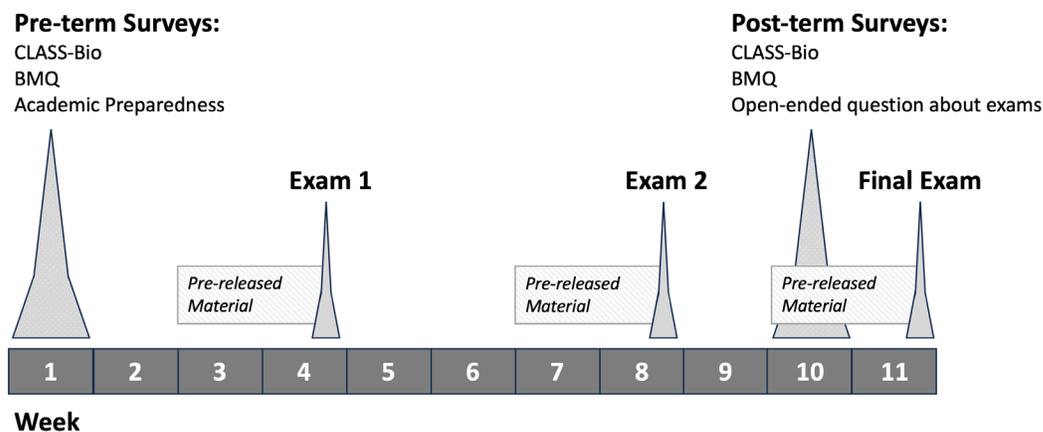
Note. The listed surveys and three exams were delivered for all sections. In the sections assigned to the pre-released exam treatment, exam material was shared with students 13 days prior to the start of each test-taking period. CLASS–Bio: Colorado Learning Attitudes in Science Survey–Biology. BMQ: Science Motivation Questionnaire II-Biology.

I included a combination of question formats in exams, including constructed-response questions (short answer, fill-in-the-blank, and short essay) and restricted-response questions (multiple choice, multiple select, true/false, and matching). I graded all exam questions.

To limit the use of unauthorized resources during remote exams, I utilized topic-specific question bins. For each assessed topic, I had the learning management software randomly draw one question from its respective topic bin for each student. The assessed topics for all three exams remained consistent throughout the study, with the third (final) exam being comprehensive.

To help students prepare for exams, I provided a comprehensive list of measurable weekly learning outcomes in advance of each exam. These outcomes outlined the skills, abilities, and knowledge that students might be expected to demonstrate.

Performance on Exams

The learning management system randomly drew exam questions from topic-specific bins for each student, resulting in unique subsets of questions on each student's exam. This randomization made direct comparisons of overall exam performance among students challenging. However, I repeated three exam questions for every student across all sections of the course (see Appendix A). These questions targeted learning goals traditionally emphasized in undergraduate genetics courses, focusing on: (1) linkage and gene mapping, (2) transcription and translation, and (3) genomics. The average score on these three repeated questions demonstrated a strong positive correlation with the average score on the three exams, as shown by the Pearson product-moment correlation coefficient, $r(171) = .67$, $p < .001$. Based on this strong correlation,

I used the average score on these three repeated questions as a proxy for overall course exam performance.

Proctoring Requirements

I conducted this study from Winter 2021 through Summer 2022. Initially, I planned to utilize physical on-site proctoring centers to administer the online exams. However, due to COVID-19 restrictions, these centers were unavailable at the start of the study. As a result, I conducted online exams for the first four investigated sections of the course remotely without proctoring.

During the latter part of the study, my institution adopted use of an automated remote proctoring system, Proctorio. This system records a student's exam session by accessing their webcam, screen, and microphone, enabling instructor review. I delivered online exams in the final two sections of the study—one section utilizing pre-released exams and the other using traditional exams—through this automated remote proctoring system (Figure 2).

Figure 2

The 2 x 2 Study Design: Exam Treatment and Proctoring Conditions Across Sections
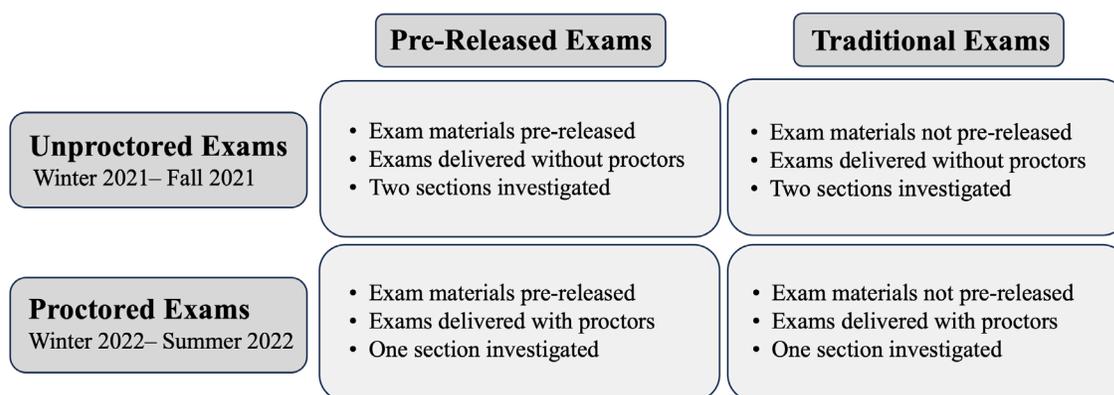
Note. Except for exam treatment and proctoring conditions, all course elements were kept identical across the six investigated sections.

Treatment Conditions: Pre-Released vs. Traditional Exams

I used a quasi-experimental design to investigate whether the pre-release of exam materials improves outcomes for online biology students. Due to ethical considerations, I could not assign students within a single course section to different treatment groups, as the treatment condition was likely to influence student outcomes. Instead, I assigned treatment at the section level, so that all students within a given section experienced the same exam system – either pre-released or traditional exams.

To minimize confounding variables, I included multiple course sections in this study and randomized exam treatment across terms. Specifically, I ran three sections using pre-released exams and three using traditional exams. Given the incorporation of proctoring requirements only in the later sections, this resulted in a 2 x 2 study design (Figure 2). Except for exam

treatment and proctoring requirements, I kept all course elements identical across the six investigated sections. To isolate the effects of treatment, I used an interrupted time series design (with surveys delivered in a pre/post manner) and included incoming student preparation as a covariate in statistical tests (see details below).

Under the pre-released exam system, an instructor shares portions of exam materials with students ahead of the actual test-taking period. Instructors can choose to pre-release exam material in various ways and to different degrees (see Wiggins et al., 2023). In the present study, I disclosed both the point value (e.g., "4 pts") and general topic (e.g., "Genetic Linkage Maps") for 100% of exam questions in sections utilizing pre-released exams. Additionally, I provided incomplete textual and/or visual information (e.g., scenarios, tables, or figures; see example in Figure 3) for 50% of exam questions. This included the three repeated exam questions used in this study as a proxy for exam performance (see the pre-released materials for these questions in Appendix B). I shared exam materials with students 13 days prior to the start of each test-taking period with the intent to clearly communicate the core concepts for which I would hold students responsible and to help students work through complex information ahead of the actual exam.

Figure 3

Example of Pre-Released Materials for an Exam Question

Question 3   0 pts

Topic 13: Genetic Linkage Maps (4 pts)

In a species of insect, the genes: *b* (black body), *pr* (purple eyes), and *c* (curved wings) are linked. You have been tasked to map these genes.

First, you decide to create triple heterozygotes. To this end, you cross a true-breeding *b, pr, c* female with a true-breeding wildtype male. You then conduct a testcross with one of the female triple heterozygotes to obtain [...more information about the results of the testcross will be revealed on the exam...].

Phenotype			Offspring number
pr	+	+	[# will be revealed on the exam]
+	b	c	[# will be revealed on the exam]
+	+	c	[# will be revealed on the exam]
pr	b	+	[# will be revealed on the exam]
+	+	+	[# will be revealed on the exam]
pr	b	c	[# will be revealed on the exam]
+	b	+	[# will be revealed on the exam]
pr	+	c	[# will be revealed on the exam]

Calculate the following distances (in map units):

1. The distance between genes *pr* and *b*: [   ] map units

2. The distance between genes *b* and *c*: [   ] map units

To encourage students to engage with pre-released exam materials in advance of exams, I incorporated a free-writing exercise (graded) into the course. I asked students to: (1) access the pre-released exam information via a link provided in the assignment prompt, (2) select one pre-released exam question, and (3) submit a free-writing response outlining their studying strategy for that question. As I determined in preliminary research, incorporating such a free-writing exercise into course design effectively motivates student interaction with pre-released exam materials. This approach to assessment is unfamiliar to most students, so many will not access pre-released materials unless prompted to do so through a point-based mechanism.

In sections using traditional exams, I assigned students a similar free-writing exercise. However, instead of focusing on pre-released materials, the exercise required students to reflect on and strategize their study approach based on weekly learning outcomes that I provided as a downloadable PDF link within the assignment prompt.

Student Participants

Students enrolled in the course had previously completed at least three introductory biology courses as prerequisites. An upper-division cell and molecular biology course was recommended but not required.

For each section of the course, over 65% of enrolled students consented to share their course data. The consenting students included undergraduate and graduate students, students of various socioeconomic status (SES), and students of various ethnic/racial and gender identities (see Table 1). I collected these demographic data using a 13-question multiple-choice survey (see Appendix C) while providing students with the option to opt out of any question.

Table 1

Demographic Data of Consenting Students

Category	% of students
Class standing	
Freshman	0.0 %
Sophomore	6.3 %
Junior	32.0 %
Senior	44.2 %
Graduate student	17.5 %
Socioeconomic status (SES)	
Higher SES	63.8 %
Lower SES	36.2 %
Racial/ethnic identity	
White or Caucasian	68.6 %
Asian	14.2 %
Latinx/Hispanic	10.3 %
Black/African American	1.5 %
Other	5.4 %

Gender identity	
Woman; or *cis*-gender woman	74.4 %
Man; or *cis*-gender man	19.7 %
Other	5.9 %

Note. Percentages are based on students who opted to answer survey questions.

All activities associated with this study were approved by the Human Research Protection Program (HRPP) and Institutional Review Board (IRB) at my institution's Research Office (study number: IRB-2020-0813).

Survey Instruments

Attitude shift (CLASS-Bio)

I used the Colorado Learning Attitudes in Science Survey—Biology (CLASS-Bio; Semsar et al., 2011) to quantitatively assess whether pre-released exams improved my students' attitudes toward the biological sciences. This survey consists of 31 Likert-item questions that I administered in a pre/post manner (Figure 1). The survey questions measure the extent to which students agree with experts on seven broad constructs relating to biology: "Real World Connection," "Enjoyment (Personal Interest)," "Problem-Solving: Reasoning," "Problem-Solving: Synthesis & Application," "Problem-Solving: Strategies," "Problem-Solving: Effort," and "Conceptual Connections/Memorization." Previous studies have successfully used the CLASS-Bio to examine how pedagogical strategies impact shifts in these seven constructs (e.g., Cleveland et al., 2017).

Motivation shift (BMQ)

I used the Science Motivation Questionnaire II-Biology © Shawn M. Glynn (BMQ; Glynn et al., 2011) to quantitatively examine whether pre-released exams improve the broad concept of motivation in my students. The BMQ consists of 25 Likert-item questions that I administered in a pre/post manner (Figure 1). The survey questions assess students' career motivation, grade motivation, intrinsic motivation, self-efficacy, and self-determination. Researchers have used the BMQ in biology contexts to measure differences in motivation between groups (Campos-Sánchez et al., 2014), as well as to assess longitudinal changes in motivation within a group (Cleveland et al., 2017).

Academic preparedness

Academic preparedness can strongly influence the performance of students in STEM (Salehi et al., 2020). To capture an aspect of academic preparedness in the present study, I asked students to complete a concept survey at the start of the course (see Figure 1) consisting of 10 multiple-choice questions (see Appendix D) related to content covered in the course. I based this pre-term concept survey on 10 questions from the Genetics Concept Assessment (GCA; Smith et al., 2008), which is designed to measure learning goals traditionally associated with undergraduate genetics courses. Preliminary data suggested that these 10 specific questions appropriately challenged my incoming students, without being too easy or too difficult.

I included an attention check question in each survey to identify students who were not responding carefully or honestly. I only retained student answers if they answered the attention check questions correctly.

Qualitative Survey Question: The Exam Experience

Given the positive feedback from students regarding pre-released exams at a different R1 institution (Wiggins et al., 2023), I hypothesized that a pre-released exam system would also be viewed favorably by my students. To gain a qualitative understanding of my students' exam experiences, I presented the following post-term open-ended survey question (Figure 1): "Did the style of exams in the [identifying word omitted] Genetics course work for you? Why or why not?" Cognitive testing of a similarly worded question by Wiggins et al. (2023) showed no significant confusion or alternative interpretations, suggesting that it is valid for its intended research use. I categorized qualitative responses from my students into one of five major emergent themes and then sub-coded responses as either "positive" or "negative" in relation to student outcomes (see below).

Analysis of Data

I investigated the effects of exam treatment (pre-released vs. traditional exams) on four learner outcomes: (1) exam performance, measured using the three repeated exam questions, (2) shifts in favorable attitudes toward the discipline, measured using the CLASS-Bio, (3) shifts in the broad concept of motivation, measured using the BMQ, and (4) self-reported qualitative experiences with the exam system, measured using the post-term open-ended survey question. In each of these four independent analyses, I included "proctoring" as an additional explanatory factor. Additionally, I included "academic preparedness" (measured using the pre-term concept survey) as a covariate, so that results of all analyses reflect differences in learner outcomes between students with a similar initial understanding of the content.

Students enrolled in the course self-identified with a variety of demographic factors (Table 1) that could influence learner outcomes. Based on past literature, I hypothesized that socioeconomic status (SES; Haak et al., 2011; Wright et al., 2016) might be a particularly strong mediator of the outcomes under investigation. To explore this prediction, I included "student SES" in all analyses as a third explanatory factor. I categorized SES into two levels: (1) higher SES, as represented by students who identified as middle class, upper-middle class, or wealthy, and (2) lower SES, as represented by students who identified as lower class or working class. Student SES was associated with various other demographic statistics, which suggests strong differences in cognitive loads between the higher and lower SES groups (Figure 4).

Figure 4

Self-Reported Data of Higher and Lower Socioeconomic Status (SES) Students
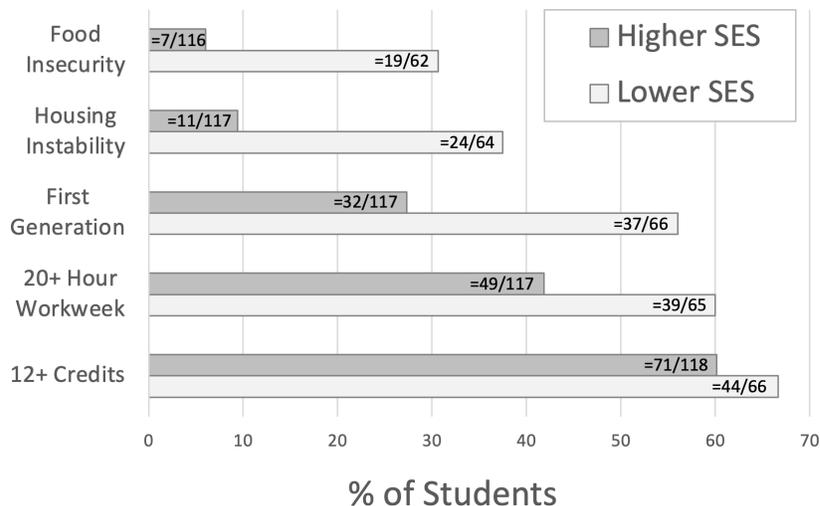
Note. Shown are the % of higher and lower SES students who identified with food insecurity over the past year, housing instability over the past year, first-generation status, a workweek of 20 or more hours, and a course load of 12 or more credits. Percentages are based on students who opted to answer survey questions. Sample size is shown.

Higher and lower SES students also showed significant differences in academic preparedness, as determined by the pre-term concept survey (*t*-test: $t(166) = 2.63$, $p = .009$, $d = 0.42$). Average scores on this survey were 47.1% ± 1.9% (± SEM) for higher SES students and 39.2% ± 2.3% for lower SES students.

In addition to SES, gender identity may have influenced the investigated outcomes (Ballen et al., 2017; Eddy et al., 2014). However, the low sample size of students who identified as a "man" (19.7% of students) constrained the investigation of gender-related effects. Therefore, I performed final statistical analyses on students who identified as a "woman" or "man," but without including a gender-identity term. The omission of a gender identity term is unlikely to have caused bias in the results; a chi-square test of independence indicated that the proportion of students identifying as a "woman" or "man" was not significantly different between the pre-released and traditional exam treatment groups ($X^2(1, N = 173) = 0.03$, $p = .86$), between the proctored and unproctored exam groups ($X^2(1, N = 173) = 0.36$, $p = .55$), or between the lower and higher SES groups ($X^2(1, N = 173) = 2.84$, $p = .09$). I did not include students with other gender identities in the final data analyses (or students who chose not to share their gender identities) due to the extremely low sample size for these groups, which prevented statistical checks for equal representation between groups.

For the analysis of each separate learner outcome, I only considered students with a complete set of variables for that outcome. I conducted analyses using the R statistical package (freely available at http://www.r-project.org/).

Attitude shift (CLASS-Bio)

I collapsed CLASS-Bio scores from the original 5-point scale to a normalized 3-point scale (Semsar et al., 2011), with the three points on the scale representing: (1) a response *analogous* to the consensus response of experts, (2) a *neutral* response neither analogous nor opposite to the consensus response of experts, and (3) a response *opposite* to the consensus response of experts.

For each attitude category in the CLASS-Bio survey (i.e., "Real World Connection," "Enjoyment," "Problem-Solving: Reasoning," "Problem-Solving: Synthesis & Application," "Problem-Solving: Strategies," "Problem-Solving: Effort," and "Conceptual Connections/Memorization") I calculated a % favorable response score for each student on both the pre-term and post-term CLASS-Bio surveys. I based this % favorable response score on the number of statements for which the student provided a response analogous to the consensus response of experts (in other words, when the student gave an expert-like response). To assess shifts (increase or decrease) in the % favorable response score, I calculated the difference between the post-term and pre-term % favorable response scores for each attitude category for each student.

Motivation shift (BMQ)

For each "motivation" category in the BMQ survey (i.e., career motivation, grade motivation, intrinsic motivation, self-efficacy, and self-determination), I determined the normalized change in % "motivation" for each student. First, I summed each student's raw scores for questions in each motivation category separately for the pre-term and post-term BMQs. Next, I calculated the student's % motivation score in each category by dividing the summed raw score by the maximum possible raw score for that category. Finally, I calculated each student's normalized change in % motivation for each category using the formula: [100 * (post-course % motivation score—pre-course % motivation score)/ (100—pre-course % motivation score)].

Qualitative exam experience

I categorized qualitative responses to the open-ended survey question about exams according to themes that emerged from past investigations of student experiences with the pre-released exam system (Wiggins et al., 2023). Although six exam-related themes were originally identified by Wiggins et al. (2023), I found one of these themes irrelevant to the present study (my course did not include a student feedback phase, making the "Collaboration" theme irrelevant), and another theme was mentioned by only 11 students (i.e., "Language of Exam"). Thus, I categorized feedback from my students into only four specific themes: (1) "Helped with Anxiety" (e.g., helping with anxiety or confidence), (2) "Direction to Core Concepts" (e.g., knowing what to study), (3) "Deepening Thought" (e.g., ability to think critically and apply knowledge), and (4) "Authentic Engagement" (e.g., feeling trust/connection to exams). To capture feedback that did not fit into these themes, I also included a fifth category: (5) "Other." This category consisted of comments relating to any of the following: "Language of Exam" (e.g., ability to understand exam questions), other specific comments about exams (unrelated to the previous themes), or unspecific comments about exams (e.g., an answer of "Yes" or "No" to the question: "Did the style of exams in the [identifying word omitted] Genetics course work for you? Why or why not?").

In many cases, an individual student provided feedback that touched on more than one of the identified themes. In such instances, I recorded all relevant themes. I excluded comments unrelated to exams from the analysis.

After categorizing feedback into major themes, I sub-coded each response as being "positive" (100% beneficial) or "negative" (100% detrimental) in relation to student outcomes. I based this sub-coding on educational best practices (see Wiggins et al., 2023), rather than on students' subjective opinions or enjoyment. For example, I coded the response: "Exams were challenging but doable" as having a "positive" impact within the "Deepening Thought" and "Authentic Engagement" themes.

I coded blindly (please see the coding key in Appendix E). A second individual (also an academic faculty member at my R1 institution) independently coded 20% of the blinded responses and achieved a percent agreement statistic of .86.

I calculated a net feedback score for each student's experience with each major theme by taking the difference between the student's "positive" and "negative" experiences for that theme. For example, if a student indicated that their experience with the theme of "Deepening thought" was entirely "positive," I assigned this student a net feedback score of +100% for that theme. If the student indicated an entirely "negative" experience, I assigned a net feedback score of -100%. If a student indicated both "positive" and "negative" experiences for a theme, I assigned a net feedback score of 0% (neutral) for that theme. I considered students who did not comment on a theme to also be neutral for that theme.

Results

Performance on Exams

I conducted a three-way analysis of covariance (ANCOVA) to investigate how exam treatment, proctoring requirements, and student SES influenced student performance on exam questions. I included the covariate, content-specific academic preparedness, in the model to account for differences in initial understanding of course content. Student performance on exam questions had a significant positive correlation with this covariate ($F(1, 158) = 26.08$, $p < .001$), supporting previous studies that highlight incoming preparation as a key determinant of academic performance (Salehi et al., 2020).

The ANCOVA model revealed no significant difference in student performance between pre-released and traditional exams ($F(1, 158) = 0.003$, $p = .95$). This suggests that, when students were exposed to different exam treatment conditions but had similar proctoring requirements, SES, and academic preparedness, there was no significant difference in their exam performance. The average scores (± SEM) for pre-released and traditional exam groups were 74.9% ± 2.6% and 72.1% ± 2.6%, respectively.

In contrast to the lack of a significant exam-treatment effect, proctoring significantly influenced student performance on exam questions ($F(1, 158) = 10.57$, $p = .001$). The average scores on exam questions for proctored vs. unproctored exams were 66.1% ± 3.2% and 77.6% ±

2.2%, respectively (Figure 5). The standardized effect size, measured by Cohen's *d*, was .49. This indicates that proctoring decreased student scores on exam questions by 0.49 of a standard deviation, which corresponds to a reduction of 11.8%.

Figure 5

Effect of Exam Treatment, Proctoring, and Socioeconomic Status (SES) on Exam Performance
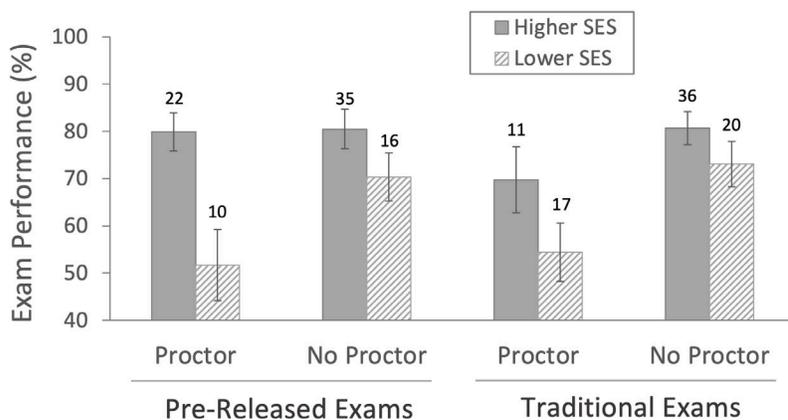
Note. Exam performance is shown for higher and lower SES students taking pre-released and traditional exams under proctored and unproctored conditions. Exam performance was not significantly affected by exam treatment. However, proctoring and SES significantly affected exam performance and exhibited a significant interaction. Sample size is shown. Error bars represent SEM.

SES also significantly affected student performance on exam questions ($F(1, 158) = 10.21$, $p = .002$; Figure 5). Notably, the effects of SES remained significant even after I accounted for academic preparedness (included as a covariate). Average scores on exam questions for students identifying as higher SES vs. lower SES were 79.3% ± 2.2% and 64.0% ± 3.0%, respectively. The standardized effect size was $d = .67$, indicating that being in the lower SES group decreased student scores on exam questions by 0.67 of a standard deviation, which corresponds to a reduction of 16.1%.

The model also showed that the interaction between SES and proctoring was significant ($F(1, 158) = 4.78$, $p = .030$; Figure 5), suggesting that proctoring requirements exacerbated the achievement gap between SES groups.

All other interactions between factors were nonsignificant (with $p > .30$).

Attitude Shift (CLASS-Bio)

I conducted a multivariate analysis of covariance (MANCOVA) to examine shifts in % favorable response scores for the seven CLASS-Bio attitude categories as a group. The covariate, academic preparedness, did not significantly affect shifts in % favorable response scores ($V = 0.05$, $F(7, 157) = 1.14$, $p = .34$).

This MANCOVA model showed that exam treatment did not produce a significant multivariate effect on shifts in % favorable response scores ($V = 0.06$, $F(7, 157) = 1.40$, $p = .21$).

In other words, the pattern of change in expert-like attitudes was similar between students who took pre-released exams and those who took traditional exams.

In contrast, I observed a significant multivariate effect in response to proctoring: the way in which % favorable response scores changed across the seven attitude categories as a group differed for students who took proctored exams vs. unproctored exams ($V = 0.11$, $F(7, 157) = 2.59$, $p = .015$). Visual inspection of the data (Figure 6) showed that students taking proctored exams maintained % favorable response scores for all seven attitude categories, with standard errors that included the tendency of no shift (i.e., a shift of 0%). In comparison, students who took unproctored exams experienced an overall negative shift in % favorable response scores for four of the seven attitude categories: "Problem-Solving: Effort," "Problem-Solving: Reasoning," "Problem-Solving: Synthesis & Application," and "Conceptual Connections/Memorization."

I found no significant multivariate effect of student SES on % favorable response scores ($V = 0.03$, $F(7, 157) = 0.76$, $p = .62$). Additionally, all interactions between factors were nonsignificant ($p > .12$).

Figure 6

Effect of Proctoring on Shifts in % Favorable Attitude Scores
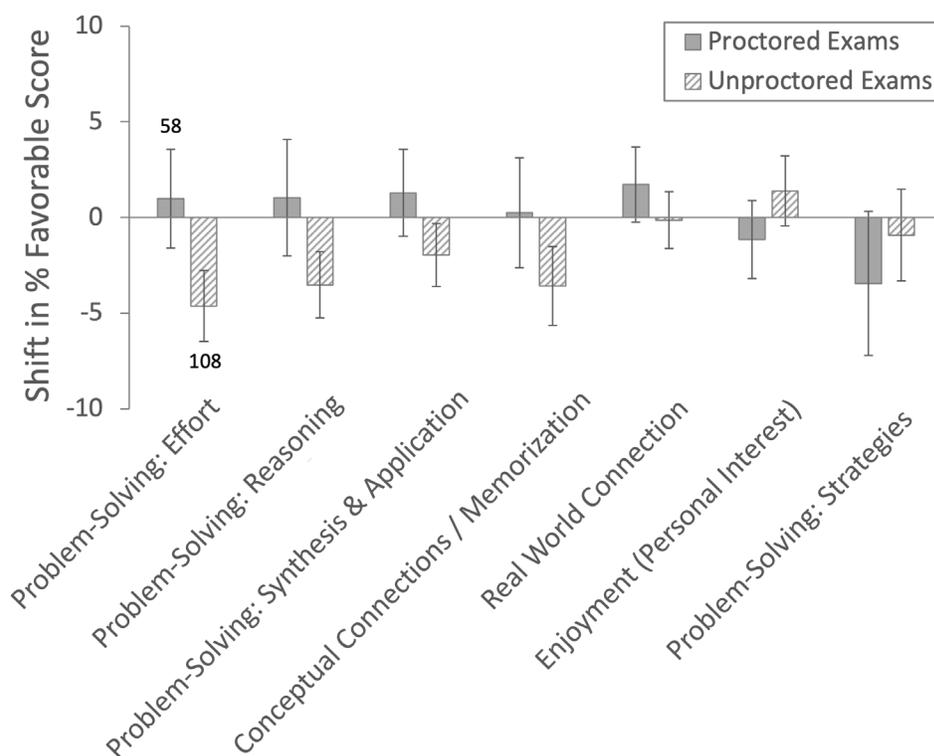
Note. Shift in % favorable scores of proctored and unproctored students are shown for the seven attitude categories measured by the Colorado Learning Attitudes in Science Survey – Biology. Proctoring significantly affected shifts in % favorable response scores. Sample size is shown. Error bars represent SEM.

Motivation Shift (BMQ)

I conducted a MANCOVA to examine the normalized change in % motivation scores across the five BMQ categories. The covariate, academic preparedness, did not significantly affect the normalized change in % motivation scores ($V = 0.04$, $F(5, 156) = 1.37$, $p = .24$). The model also found that exam treatment did not produce a significant multivariate effect ($V = 0.02$, $F(5, 156) = 0.61$, $p = .69$). Furthermore, this model found no significant multivariate effects for proctoring requirements ($V = 0.009$, $F(5, 156) = 0.27$, $p = .93$) or student SES ($V = 0.02$, $F(5, 156) = 0.71$, $p = .62$). All interactions between factors were nonsignificant ($p > .23$).

Qualitative Exam Experience

I conducted a MANCOVA to examine the net feedback scores of students on the open-ended survey question for all five major exam themes as a group. The covariate, academic preparedness, showed a significant positive correlation with net feedback scores ($V = 0.09$, $F(5, 156) = 3.17$, $p = .009$), suggesting that a stronger initial understanding of content led to a better qualitative exam experience.

This MANCOVA model revealed a nonsignificant trend in effect of exam treatment on net feedback scores ($V = 0.06$, $F(5, 156) = 2.03$, $p = .078$). In other words, with similar academic preparedness, students tended to rate their exam experiences differently under pre-released versus traditional exams. Visual inspection of the data indicated that for pre-released exams, average net feedback scores were positive for all five investigated themes (Figure 7). For traditional exams, average net feedback scores were positive for most themes, but appeared reduced for the theme of "Direction to Core Concepts" and were negative for the theme of "Helped with Anxiety."

Figure 7

Effect of Exam Treatment on the Qualitative Exam Experience
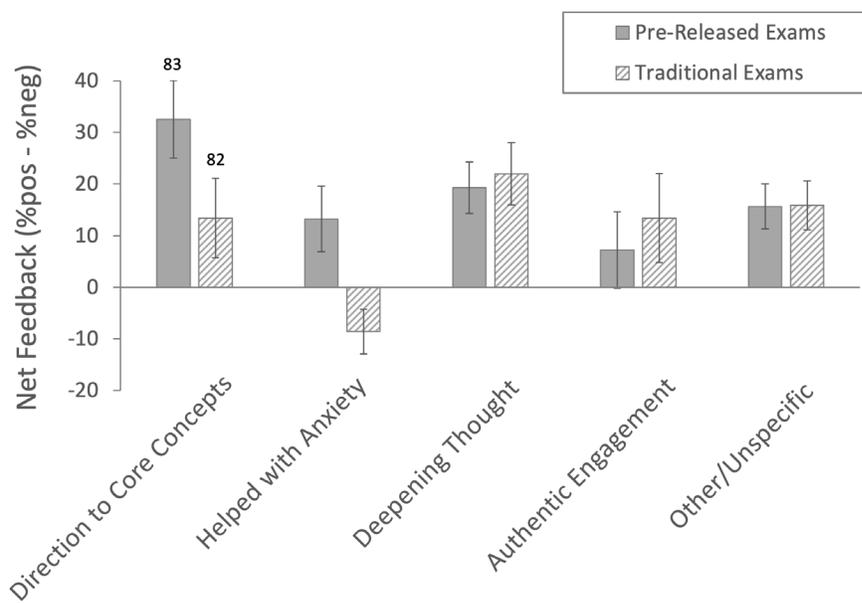
Note. Net feedback scores of students taking pre-released and traditional exams are shown for the five major themes captured by the open-ended survey question about exams. I found a trend for effects of exam treatment. Sample size is shown. Error bars represent SEM.

I found no significant multivariate effect on net feedback scores in response to proctoring requirements ($V = 0.02$, $F(5, 156) = 0.47$, $p = .80$) or student SES ($V = 0.02$, $F(5, 156) = 0.51$, $p = .77$). Additionally, all interactions between factors were nonsignificant ($p > .2$).

Discussion

Student attrition in online courses remains a significant concern, particularly in STEM disciplines. Common pedagogical practices in STEM, such as timed, high-stakes traditional exams may contribute to attrition by adversely affecting cognitive development, student attitudes toward their discipline, and various aspects of motivation. I hypothesized that the pre-release of exam materials could mitigate such undesirable effects. To investigate this hypothesis, I examined how the pre-release of exam materials impacted students in my upper-division online biology course, focusing on the following outcomes: performance on exam questions, attitudes about the biological sciences, motivational beliefs, and self-reported qualitative experiences with the exam system.

Pre-Released Exams Do Not Improve Exam Performance

I found that the pre-release of exam materials did not improve the exam performance of my upper-division online biology students. Given that pre-released materials allowed students to review parts of exam questions ahead of the actual test-taking period, this result was surprising. It suggests that, despite the well-documented challenges that online students face in managing time for college commitments (Shaikh & Asif, 2022; Xavier & Meneses, 2020), they may not have taken full advantage of pre-released materials to anticipate exam content. Instead, students may have primarily used pre-released materials to familiarize themselves with general exam structure (e.g., question number) in efforts to reduce test anxiety (discussed below). Notably, I included point-based assignments to force student engagement with pre-released exam materials, which counters the possibility that most students did not access these resources.

Pre-Released Exams Do Not Rescue SES-related Achievement Gaps

Past studies found that traditional exams in STEM are associated with an achievement penalty for students from economically disadvantaged backgrounds (Haak et al., 2011; Wiggins et al., 2023; Wright et al., 2016). My results confirm that low SES correlates with penalties for exam performance in online STEM students: students who self-identified as working/lower class displayed significantly lower scores on exam questions compared to middle/upper class students. This achievement penalty may relate to differences in content-specific academic preparedness: my lower SES students scored more poorly on a pre-term concept survey covering learning goals traditionally ascribed to undergraduate genetics courses. Past studies confirm that the underperformance of disadvantaged groups in STEM strongly relates to poorer incoming preparation (Salehi et al., 2020). Poorer preparation might arise, for example, due to limited educational resources in lower-income neighborhoods.

However, my analyses also indicate that the achievement gap related to SES persisted even after controlling for differences in academic preparedness. This suggests that the effects of

incoming preparation may be exacerbated by other SES-associated factors (see Figure 4). For example, my lower SES students reported having a longer work week, which could have limited the time they could dedicate toward studying. Additionally, my lower SES students included a higher proportion of first-generation students, who often face family obligations and caregiving responsibilities that compete with their time and attention for college (Richardson & Skinner, 1992). Finally, my lower SES students were experiencing relatively greater cognitive loads (e.g., housing instability, food insecurity), which may have made them particularly sensitive to the additional cognitive demands of high-stakes exam questions (Portela-Parra & Leung, 2019).

I had originally hypothesized that the pre-release of exam materials could reduce SES-related disparities in achievement by, for example, engaging students in more efficient and cognitively-active studying behaviors (Haak et al., 2011; Stanger-Hall, 2012; Theobald et al., 2020), by reducing test anxiety that disproportionately affects minoritized and disadvantaged students (Putwain, 2008), and/or by supporting a more equitable understanding of complex questions across diverse student groups. However, my implementation of pre-released exams did not overcome SES-related performance gaps; I found similar SES-related penalties under the pre-released and traditional exam systems (see Figure 5). This mirrors results from a face-to-face introductory biology classroom that also found no SES-related effects of pre-released exams (Wiggins et al. 2023).

Given these results, alternative interventions are necessary to address SES-related performance gaps among STEM students. Support measures for at-risk students might include orientations covering topics related to learning strategies, time management, and self-efficacy (Hattie et al., 1996; Muljana & Luo, 2019; Shaikh & Asif, 2022; Tuckman & Kennedy, 2011). Support measures could also include course-level changes, such as the use of multiple, lower-stakes assessments—each requiring less preparatory time and reducing information overload—to reward students who engage in consistent, ongoing learning and practice (Cotner & Ballen, 2017; Haak et al., 2011). Self-affirmation interventions may also help to reduce demographic achievement gaps (Cohen et al., 2006; Harackiewicz et al., 2014), as they may directly address the perceived "fairness" of an exam (Good et al., 2008; Spencer et al., 1999).

Pre-Released Exams Do Not Benefit Attitudes or Motivation

The success of online students is tied to behavioral and psychological characteristics such as clear goals, motivation, academic self-efficacy, and self-determination (Cho & Shen, 2013; Muljana & Luo, 2019; Shaikh & Asif, 2022). However, students enrolled in STEM courses often show negative attitude shifts toward their discipline and a decline in various components related to self-regulated learning (Cleveland et al., 2017; Perkins et al., 2005; Redish et al., 1998; Semsar et al., 2011). I had hypothesized that these important socio-psychological factors might be bolstered in online learners through an assessment system that incorporates the pre-release of exam materials, because such a system could provide a more positive assessment experience and instill students with greater confidence in their academic abilities (Johnson & Crisp, 2009). However, my data indicate that pre-released and traditional exams similarly affected student attitudes and motivational beliefs. Taken together, these results suggest that a pre-released exam system is unlikely to yield significant benefits for the success of online STEM students by improving key socio-psychological factors.

Trend for a Unique Experience Under Pre-Released Exams

Qualitative feedback from a post-term open-ended survey question indicated that, when I took academic preparedness into account, there was a trend (nonsignificant) for exam treatment to affect the student exam experience. Under pre-released exams, student net feedback scores regarding exams were positive for all investigated themes. In contrast, under the traditional exam system, net feedback scores appeared reduced for the theme of "Direction to Core Concepts" and showed a negative trend for the theme of "Helped with Anxiety" (see Figure 7). Taken together with the significant effects of pre-released exams on student feedback in a face-to-face introductory biology course (Wiggins et al., 2023), the trends in my study corroborate the idea that pre-released exams may offer benefits for efficient studying and the reduction of test-taking anxiety, as predicted by Johnson and Crisp (2009).

The present study and Wiggins et al. (2023) show discrepancies in significance levels regarding student-reported benefits of pre-released exams. These may have resulted from differences in experimental design. For example, each exam in the single course section examined by Wiggins et al. included both pre-released and traditional questions, making it difficult to isolate effects of a pre-released exam system. Additionally, Wiggins et al. (2023) did not account for academic preparedness in their analysis, potentially introducing bias due to differences in students' initial understanding of course content.

Discrepancies in results between the present study and Wiggins et al. (2023) may also reflect course-level differences. Wiggins et al. (2023) investigated pre-released exams in a face-to-face introductory course, whereas I examined effects in an online upper-division course. Face-to-face and introductory students display lower levels of learning autonomy and may perceive pre-released materials as more helpful for determining what to study. Additionally, students in introductory courses are less familiar with college-level exams, so they may experience greater relief from test-taking anxiety after seeing parts of exams in advance. Thus, benefits of pre-released exams might depend on course level and learning modality.

Nevertheless, despite discrepancies in the degree to which pre-released exams may improve the qualitative exam experience for STEM students, both the results from my study and Wiggins et al. (2023) agree that student feedback for pre-released exam questions does not depend on student SES, suggesting that the experience with pre-released exams is equitable across socioeconomic groups in both online and face-to-face learning contexts.

Proctoring Decreases Exam Scores While Maintaining Mature Attitudes

As a result of the COVID-19 pandemic, I was initially unable to run course sections with proctors as planned. However, midway through the study, my institution adopted a remote online proctoring system, at which point I was able to implement this proctoring system for the remaining sections of my course (Figure 2). This required me to include "proctoring" as an explanatory factor in all statistical analyses, allowing me to coincidentally examine the effect of remote online proctors on learner outcomes of interest.

Student performance on exam questions was significantly lower when remote online proctors were present, as noted in previous research (Daffin & Jones, 2018). This correlation between proctoring and lower assessment scores is unlikely to be a pandemic-related effect

because I introduced proctoring requirements only toward the tail end of the pandemic. Instead, I suggest that remote proctors decreased exam scores due to increased test-taking anxiety or restrictions on academic dishonesty.

Regarding the former, past studies have shown that remote online proctoring can negatively affect the exam performance of students with high trait test anxiety (Woldeab & Brothen, 2019). In corroboration, I observed that proctors imposed greater penalties on the exam scores of lower SES students, who may have been experiencing heightened test anxiety due to increased cognitive loads.

However, high trait test anxiety alone is unlikely to explain the observed negative effect of proctoring on exam performance. Responses to the open-ended survey question indicated that the qualitative exam experience, which included the theme "Helped with Anxiety," was similar for proctored and unproctored students. Thus, I propose that remote proctors also contributed to lower exam scores by restricting students' ability to share answers and/or use unauthorized resources (Harmon et al., 2008; Daffin & Jones, 2018). In support of this, students from unproctored sections of my course frequently uploaded exam questions to education technology platforms like Chegg.com, which provides students with answers to homework/exam questions in real time for a fee.

Interestingly, proctoring not only affected performance on exam questions but also significantly influenced students' attitudes toward their discipline. Students taking proctored exams maintained expert-like attitudes across all investigated categories. However, students who took unproctored exams showed noticeable declines in some attitude categories, including those related to problem-solving and conceptual connections in the field of biology (see Figure 6). I attribute these declines to a more relaxed studying approach and limited mastery of the content. Unproctored students knew they could access unauthorized resources during exams to help with questions. Thus, my data suggest that authentic engagement with course content is essential for building and maintaining mature attitudes toward STEM, such as through the practice of higher-order cognitive skills and acquisition of a deep conceptual understanding of the material (Jensen et al., 2014; Stanger-Hall, 2012).

Limitations

I employed a quasi-experimental design in this study, aiming to establish a cause-and-effect relationship based on exam treatment condition. Due to ethical considerations, I was unable to randomly assign participants within a given section to the treatment or control group. However, to minimize confounding variables, I ran multiple course sections and randomized the assignment of treatment conditions to each section. Additionally, I used an interrupted time-series design to isolate the effect of exam treatment on non-cognitive factors and included incoming preparedness as a covariate in all statistical analyses.

I conducted this research within my own courses, which could raise ethical concerns and introduce bias. To mitigate these issues, I asked a neutral third party to recruit students for the study. This party did not grant me access to student participation data until I had submitted final course grades. Furthermore, I anonymized all data prior to analysis.

My results and interpretations apply most directly to students who identified as a "woman" or "man." Due to low sample size, I did not include students who identified as a non-traditional gender or did not disclose their gender. Additionally, because this study was limited to students in my upper-division genetics course, results may have limited generalizability.

Conclusions and Implications

Pre-Released Exams

In conclusion, I found that the pre-release of exam information in my upper-division online biology course did not improve student performance on exam questions. Additionally, pre-released exams did not enhance favorable, expert-like attitudes toward the discipline and did not improve motivational components related to learning. On the positive side, the pre-release of exam materials did not exacerbate SES-related achievement gaps. Also, qualitative feedback indicated that students may have perceived pre-released exams as beneficial for reducing test-taking anxiety and for providing clearer direction to assessed concepts.

These findings have several implications for educators. My data suggest that the pre-released exam system could be used to improve the qualitative test-taking experience for online STEM students without disadvantaging students from lower SES backgrounds. In fact, the pre-release of exam material may increase the authenticity of exams, as this approach mirrors how students would interact with material in a real-life STEM career (Johnson & Crisp, 2009). Additionally, pre-released exam materials would allow educators to address the logistical constraints of timed exams and enable the inclusion of more higher-order Bloom's questions that enhance development of critical thinking (Jensen et al., 2014; Stanger-Hall, 2012).

Remote Online Proctors

With respect to proctoring requirements, remote online proctors negatively affected exam scores, with a more pronounced penalty for students of lower SES. Nevertheless, proctoring maintained favorable student attitudes toward the biological sciences, with scores in all attitude categories remaining expert-like only under proctored conditions. In contrast, in the *absence* of proctors, scores in four attitude categories declined.

My findings regarding the effect of remote online proctors carry important implications both for educators and researchers. For educators, the disproportionate SES-related penalties of remote online proctors suggest that proctoring should be implemented with caution, especially in the absence of additional support for at-risk students. However, removing proctoring requirements altogether may lead to academic misconduct and a decline in favorable student attitudes, potentially affecting overall academic success and retention (Perkins et al. 2005). As a compromise, educators might consider implementing proctoring requirements alongside more frequent, lower-stakes assessments that carry minimal risk and require less preparatory time from students (Cotner & Ballen, 2017; Haak et al., 2011).

For researchers, my findings suggest that further study of remote online proctoring is necessary, including its impact on cheating behaviors (e.g., use of tools like ChatGPT), cognitive learning outcomes, and socio-psychological factors affecting student success and retention. Research should also explore whether students with high levels of trait test anxiety are

disproportionately disadvantaged by remote proctoring (Woldeab & Brothen, 2019), and whether underrepresented demographic groups face heightened risks under these conditions. Students already experiencing high cognitive loads or stereotype threat may be particularly vulnerable to proctoring-related anxiety (Beasley & Fisher, 2012; Cohen et al. 2006).

Author Note

I have no known conflict of interest to disclose.

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Appendix A

Repeated Exam Questions Across All Sections

All investigated sections included the following three exam questions. Given the strong positive correlation between the average score on these repeated questions and the average score on the three exams, I used the average score on these repeated questions as a proxy for overall exam performance.

Shown below is a double-stranded **DNA sequence**.

    5' - ATGTCTGTATAACCA - 3'

    3' - TACAGACATATTGGT - 5'

In this DNA sequence, transcription happens from left to right to produce an **RNA transcript**.

What is the identity and order of the **amino acids** specified by this RNA transcript?

Please use abbreviations for amino acids and separate with hyphens, e.g., Leu-Leu-Gly.

Second letter

First letter	U	C	A	G	Third letter
U	UUU UUC }Phe UUA UUG }Leu	UCU UCC UCA UCG }Ser	UAU UAC }Tyr UAA Stop UAG Stop	UGU UGC }Cys UGA Stop UGG Trp	U C A G
C	CUU CUC CUA CUG }Leu	CCU CCC CCA CCG }Pro	CAU CAC }His CAA CAG }Gln	CGU CGC CGA CGG }Arg	U C A G
A	AUU AUC }Ile AUA AUG Met	ACU ACC ACA ACG }Thr	AAU AAC }Asn AAA AAG }Lys	AGU AGC }Ser AGA AGG }Arg	U C A G
G	GUU GUC GUA GUG }Val	GCU GCC GCA GCG }Ala	GAU GAC }Asp GAA GAG }Glu	GGU GGC GGA GGG }Gly	U C A G

[Students enter their short answer here]

In a species of insect, the genes: *b* (black body), *pr* (purple eyes), and *c* (curved wings) are linked. You have been tasked to map these genes.

First, you decide to create triple heterozygotes. To this end, you cross a true-breeding *b, pr, c* female with a true-breeding wildtype male. You then conduct a testcross with one of the female triple heterozygotes to obtain 1000 F2 offspring. You divide these F2's into 8 phenotypic classes, as shown in the table below.

Based on the results in this table, you decide that genes must occur in this order: *pr-b-c*. (Thus, data in the table shows the **correct** gene order.)

Phenotype			Offspring number
pr	+	+	43
+	*b*	*c*	37
+	+	*c*	89
pr	*b*	+	81
+	+	+	360
pr	*b*	*c*	370
+	*b*	+	9
pr	+	*c*	11

Calculate the following distances (in map units):

    1. The distance between genes *pr* and *b*: [Students enter a numerical value here] map units

    2. The distance between genes *b* and *c*: [Students enter a numerical value here] map units

Indicate the field of study in each scenario below. [Students are provided with 2 scenarios from the list below and choose an answer from a drop-down menu: Metagenomics, Structural genomics, Comparative genomics, Functional genomics, Proteomics, or Transcriptome analysis].

1. Compares genomes of organisms; found that the DNA sequence of chimpanzees (*Pan troglodytes*) and humans differs by less than 2%.

2. Examines genetic material recovered directly from environmental samples; could investigate the diversity and relative abundance of microbes found in a river receiving drainage from surface coal mining.

3. Uses data from genomic projects to describe gene functions; for example, a nucleotide sequence can be used to predict the existence of a zinc-finger motif within a gene product, allowing researchers to categorize this gene product as a DNA-binding protein.

4. Examines the proteins expressed by a cell or tissue at a specific time point; anticipated to be helpful for the prescription of personalized drugs.

5. Attempts to find genomic structures; for example, a gene in the genome of a newly identified bacterial strain would be found using computational biology programs that look for the presence of a start codon.

6. Deals with the set of all mRNAs that are produced at a certain time-point; could find the mRNA profile that typifies early embryonic development.

Appendix B

Pre-Released Material for the Three Repeated Exam Questions

I provided these pre-released materials for the three repeated questions (used as a proxy for overall exam performance) during terms with pre-released exams. Pre-released materials were shared with students 13 days prior to the start of each test-taking period.

Topic 21: Genetic Code (4 pts)

Shown below is a double-stranded **DNA sequence**.

5' - [The bases in this strand of DNA will be revealed on the exam] - 3'

3' - [The bases in this strand of DNA will be revealed on the exam] - 5'

In this DNA sequence, transcription happens from left to right to produce an **RNA transcript**.

What is the identity and order of the **amino acids** specified by this RNA transcript?

Please use abbreviations for amino acids and separate with hyphens, e.g., Leu-Leu-Gly.

Topic 13: Genetic Linkage Maps (4 pts)

In a species of insect, the genes: *b* (black body), *pr* (purple eyes), and *c* (curved wings) are linked. You have been tasked to map these genes.

First, you decide to create triple heterozygotes. To this end, you cross a true-breeding *b, pr, c* female with a true-breeding wildtype male. You then conduct a testcross with one of the female triple heterozygotes to obtain [...more information about the results of the testcross will be revealed on the exam...].

Phenotype			Offspring number
pr	+	+	[# will be revealed on the exam]
+	*b*	*c*	[# will be revealed on the exam]
+	+	*c*	[# will be revealed on the exam]
pr	*b*	+	[# will be revealed on the exam]
+	+	+	[# will be revealed on the exam]
pr	*b*	*c*	[# will be revealed on the exam]
+	*b*	+	[# will be revealed on the exam]
pr	+	*c*	[# will be revealed on the exam]

Calculate the following distances (in map units):

  1. The distance between genes *pr* and *b*: [answer1] map units

  2. The distance between genes *b* and *c*: [answer2] map units

Topic 31: Genomics (4 pts)

Indicate the field of study in each scenario below.

1. [The description of a specific field will be revealed on the exam]. [answer1]

2. [The description of a specific field will be revealed on the exam]. [answer2]

Appendix C

Demographic Survey

This demographic survey was posed to students during Week 3 of each course section. I used data from this survey to categorize students according to socioeconomic status (SES): (1) higher SES students – those identifying as middle class, upper-middle class, or wealthy, and (2) lower SES students – those identifying as lower class or working class. Survey data was also used to investigate factors that are associated with student SES (e.g., food insecurity over the past year, housing instability over the past year, etc.).

If you have given consent for your information to be used in the educational research study, all data on this questionnaire will be kept confidential by assigning a random code to the data. Only your Instructor (the Primary Investigator of the study) will have access to your identity. Analysis of the data will be done on an anonymous data set. Data will be used in research to improve future science courses at [identifying word omitted] and beyond.

Specifically, your answers will help us determine whether this course is equitable to students with different racial, ethnic, and socioeconomic backgrounds; diverse cultural and language perspectives; and varied physical abilities and life challenges.

Regardless of your participation in the educational research study, you will receive full credit for this questionnaire if you answer all questions; you will have the choice to opt-out of each question. This questionnaire should take you 6-8 min to complete. Thanks for your participation!

1. What best describes your current academic class standing? (Check one)
   - 1st-year
   - Sophomore
   - Junior
   - Senior
   - Non-degree seeking graduate student (post-bacc student)
   - Student in a graduate or professional degree program
   - Other
   - I prefer not to answer

2. How many credit hours are you taking this term? (Check one)
   - 4-8 credit hours
   - 9-11 credit hours
   - 12 credit hours or more
   - I prefer not to answer

3. If you took a break from academics prior to enrolling in [identifying word omitted], how many years ago were you last enrolled in a college-level course? (Check one)

- Less than 1 year ago
- 1-2 years ago
- 3 years ago or more
- This question does not apply to me; I have been continuously enrolled in courses since I started college/university
- I prefer not to answer

4. Are you currently employed (do you have a job that pays wages/salary)? (Check one)
- Yes, 20 hours or more each week
- Yes, 19 hours or less each week
- Not at the present time
- I prefer not to answer

5. Have one or more of your parents/guardians completed a Bachelor's degree or higher? (Check one)
- Yes
- No
- I prefer not to answer

6. Is English your first language (i.e., mother tongue)? (Check one)
- Yes
- No
- I prefer not to answer

7. In what language do you find it easiest to communicate? (Check one)
- English
- A language other than English
- I communicate equally well in English and in another/other language(s)
- I prefer not to answer

8. Over the past year, have you experienced food insecurity (disruption of food intake because of lack of resources)? (Check one)
- Yes
- No
- I prefer not to answer

9. Over the past year, have you experienced housing instability (difficulty in paying rent, frequent moves, overcrowded living conditions, doubling up with friends/relatives, lacking a regular nighttime residence)? (Check one)
- Yes
- No
- I prefer not to answer

10. How would you describe your socioeconomic status? (Check one)
- Wealthy
- Upper-middle class

- Middle class
- Working class
- Lower class
- I prefer not to answer

11. Do you identify as a person with a disability? Do you have any long-lasting or chronic conditions (physical, visual, auditory, cognitive/mental, emotional, or other) that substantially limit one or more of your major life activities (your ability to see, hear, or speak; to learn, remember, or concentrate)? (Check one)
- Yes
- No
- I prefer not to answer

12. With what racial/ethnic identity do you most closely identify? (Check one)
- White or Caucasian
- Hispanic, Latinix, or Spanish Origin
- Black or African-American
- Asian
- Native American or Alaska Native or Indigenous or First Nations
- Hawaiian Native or other Pacific Islander
- Middle Eastern
- Other race, ethnicity, or origin
- I prefer not to answer

13. What term best describes your gender or gender identity? (Check one)
- Woman; or Cisgender woman
- Man; or Cisgender man
- Transgender woman
- Transgender man
- Non-binary; or Gender non-conforming; or Gender queer
- Intersex or other related terms
- Two-spirited (a person who has both a masculine and a feminine spirit; used by some First Nations people to describe their sexual, gender and/or spiritual identity)
- Other
- I prefer not to answer

Appendix D

# Pre-Term Concept Survey Used to Assess Incoming Preparedness of Students

I based this pre-term concept survey on questions found in the Genetics Concept Assessment (GCA; Smith et al., 2008), which consists of 25 multiple-choice questions covering nine broad learning goals commonly associated with undergraduate genetics courses. For ease of delivery, I reduced the number of questions to 10, basing this decision on relevance to course content and preliminary data indicating that these 10 questions appropriately challenged my students. To prevent students from easily looking up answers, I also modified the wording of these questions, as the actual GCA questions and answers are freely available online.

Please answer the questions in this start-of-term knowledge assessment. This survey is designed to help your instructor assess your current understanding of genetics. You will receive full credit for this assessment if you answer all questions to the best of your ability.

This survey should take you 15-20 min to complete.

Thanks for your participation! Your answers will be very helpful in designing a more effective curriculum.

1. This germline cell contains two pairs of chromosomes on which are shown two different genes. One gene locus has the alleles G and g; and the other gene locus has the alleles T and t.
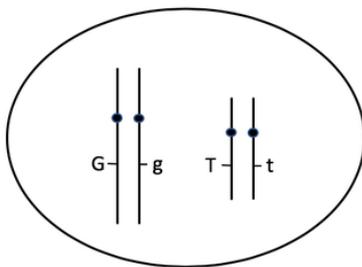
If this germline cell divides <u>normally</u> to produce sperm, what are the possible sperm genotypes?
- G, g, T, t
- Gg, Gg, Tt, Tt
- GT, gt, Gt, gT
- Gg, Tt, GT, gt, Gt, gT

2. If a single DNA base change of a G to a C occurs and then is copied during DNA replication, is this change necessarily a mutation?
- Yes, it is a change in the DNA sequence
- Yes, if the base change occurs in a gamete (sperm or egg cell); otherwise no

- Yes, if the base change occurs in the coding part of a gene; otherwise no
- Yes, if the base change occurs in the coding part of a gene and alters the amino acid sequence of a protein; otherwise no
- Yes, if the base change alters the appearance of the organism (phenotype); otherwise no

3. A tumor suppressor gene is located on chromosome 3 in humans; four different alleles for this gene have been identified. What is the maximum number of alleles that a single normal individual can have for this gene?
- 1
- 2
- 3
- 4

4. Two labs independently discover a wingless strain of *Drosophila*. Both wingless strains are due to a point mutation. You cross a mutant fly from one wingless strain to a mutant fly from the second wingless strain and find that *none* of their offspring are wingless. What can you conclude about the two mutant strains of flies?
- The two strains have mutations in the same DNA base position within a particular gene
- The two strains have mutations in the same gene, but not necessarily the same DNA base position
- The two strains have mutations in two different genes

5. Two genes are located on the same chromosome in *Drosophila*. (In other words, the genes are linked). A particular female fly is heterozygous at both gene loci, with the allele arrangement within a chromosome pair shown below. (Researchers do not know the exact position of the genes on this chromosome pair, as indicated by the dashed lines.)
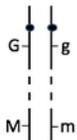
The female fly from above mates with a male fly in which the chromosome pair looks like this:
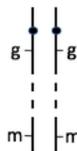
What is the likelihood that this mating will produce offspring with a chromosome pair that looks like this?
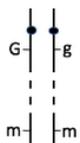

- Not likely, because the G and m alleles are not on the same chromosome in either parent

- Very likely, because the random assortment of chromosomes during cell division to make sperm or eggs allows for the mixing of all alleles
- More likely if the two genes are very close together on the chromosome
- More likely if the two genes are not very close together on the chromosome

6. In humans, which cells have a gene with instructions that determine the shape of the earlobe?
- Cells in the ear
- Cells in the heart
- Gametes (sperm and egg)
- Cells in the ear and gametes
- All of the above

7. A woman is a carrier for Bumpy-foot disorder (Bb) and Helicopter-head syndrome (Hh). The genes involved in both disorders are located on chromosome 11. What representations of this woman's genotype (labelled #1, #2, and #3) could be correct?
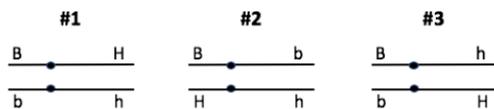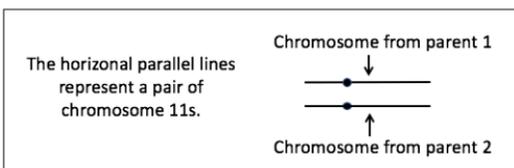
- #1 only
- #2 only
- # 3 only
- #1 and #3 only
- #1, #2, and #3

8. A young woman develops a benign skin tumor that does not spread to any other tissues; the mutation responsible for the tumor arose in a single skin cell. If the woman and her male partner (with no skin tumors) have children after the woman's skin tumor diagnosis, what statement is true?
- All of the woman's children will inherit the mutation
- All of the woman's children will inherit the mutation if the mutation is dominant
- Some of the woman's children may inherit the mutation depending on which of her chromosomes they inherit
- None of the woman's children will inherit the mutation

9. Your lab identifies a human gene that seems to play a role in cystic fibrosis. Because the DNA sequence of this gene is similar to that of a known mouse gene, you suspect the two genes are evolutionarily related. You determine and compare the DNA sequences, the predicted mRNA sequences, and the predicted amino acid sequences corresponding to the two genes.
You would expect to find the greatest sequence similarity from comparisons of the two:
- DNA sequences

- RNA sequences
- Amino acid sequences
- All three comparisons are likely to show the same degree of sequence similarity

10. Somatic body cells in the king cricket have 18 pairs of chromosomes. You have discovered another similar looking species of cricket (which you call the prince cricket) that has only 10 pairs of chromosomes in its body cells. What can you conclude?
- The king cricket has a larger genome than the prince cricket
- The king cricket has more genes than the prince cricket
- The king cricket evolved from the prince cricket
- All of the above
- There is not enough information to make any of the above conclusions

Thanks for participating in this start-of-term survey!

Appendix E

Coding Key for Categorizing Qualitative Student Responses to Exams

I categorized students' qualitative responses regarding their exam experience into five major emergent themes and then sub-coded these responses as being either 'positive' or 'negative' in relation to student outcomes. This sub-coding was based on educational best-practices (see Wiggins et al., 2023), rather than students' subjective opinions or enjoyment.

In response to the question: "Did the style of exams in the [identifying word omitted] course work for you? Why or why not?"			
Theme:	Sub-coding:	Positive Examples:	Negative Examples:
Theme #1: Helped with Anxiety	Helped/positive: Student felt that exams **decreased anxiety** or helped with **confidence** going into the exam (Harmed/negative: Student explains that exams induced anxiety/worry or that exams were "nerve-wracking;" student was overconfident going into exams)	• "They took the test anxiety out of the equation…" • "…helped me picture what I would be looking at on the exam so that when the tests did come around they weren't so daunting…" • "It made taking the test less scary…" • "…the spread and nature of the questions was enough to provide a lot of comfort psychologically…" • "Rather than stressing over whether I am interpreting a question right, I can focus on actually solving the problem..." • "It made me feel much more confident…"	• "Test anxiety hasn't helped…" • "I break out in hives on these exams and experience tunnel vision from the stress…" • …"my grade was impacted by my nervousness…" • "…unnecessarily nerve-wracking." • "I'm worried about the final…" • "…left me feeling both overconfident and a little unprepared…"
Theme #2: Direction to Core Concepts	Helped/positive: Student could understand what content was going to be on exams and how to **study**; student claims that exams were based on **course**	• "It helped…focus my studying..." • "…helpful in preparing for the appropriate exam format and selecting learning outcomes on which to focus." • "…I liked how [the instructor] gave us the	• "The style of exams where the questions are half published prior to the graded exam was probably not the best for me because while it was useful to study for some of the questions it left me at a loss on what else to focus on to prepare for the rest of the

	content; student felt *prepared* for exams (Harmed/negative: Student did not know what content would be on exams or how they should have studied; student felt unprepared for exams; student claims that exams were outside of the scope of course material)	opportunity to know the topics and styles of questions that would be on the exams…" • "…[the exams] were representative of course material." • "…the questions aligned with the study guides/learning outcomes…" • "Yes they did as they helped me put together the knowledge I have gained in this class…"	exam. [It] left me feeling…a little unprepared for the exam." • "…I did not find the early released part of the exam helpful in my studying." • "I…found it difficult to understand the expectations for the exams…I watched every lecture video while taking notes, did the homework and discussions but, did not perform as well as I had liked for how much time I put into studying." • "Sometimes I feel like there is so much material that I studied not on the test." • "I found the exams…not in sync with the textbook/lectures."
Theme #3: Deepening Thought	Helped/positive: Student could *think critically* and *apply* knowledge; questions reflected *understanding* rather than memorization; student references *enjoyment*, interest, or being *positively challenged* (Harmed/negative: Student complains that exams were too simple and based on regurgitation or memorization; student references simply looking up	• "…the actual exams were challenging but doable." • "…helped me put together the knowledge I have gained in this class..." • "…I think they truly tested our knowledge and in order to get in that A range you had to know further then your notes, but it would not be impossible." • "…I was able to put stuff into my own words… you gave students a chance to explain their answer…" • "Utilizing a creative question made by students in the exam provides me to think of the same topic in a different way." • "…the student questions section is not only fun but also encouraging and rewarding."	• "I honestly thought they could have been a bit more challenging... the multiple choice questions felt too simple…" • "I think [the style of exams] made the course too easy." • "It makes it seem as though we're still stuck in the days of rote memorization…" • "They took the test anxiety out of the equation knowing that we are able to use our resources if a question trumps us" • "On the test itself, I easily had enough time to look up the answers I did not know, because it was an open note format." • "I had a really hard time with the exams in this class. Learning facts and regurgitating the information

	answers; student explains that they did not enjoy exams)	• "…it tested my skills by not only seeing what I remembered but by making me do problems…" • "…I wish that there were some more questions on the exam that involved general recall of facts rather than complex understanding of the material…"	has never been very easy for me."
Theme #4: Authentic Engagement	Helped/positive: Student feels exam questions were *fair*, effective, "doable," manageable, not impossible; student indicates that there was a ***good balance*** of question types; student expresses ***trust*** in exams as assessments of knowledge; ***connection*** to exams (Harmed/negative: Student explains that exam questions were unfair; student claims that exams were unnecessarily difficult, overly challenging, or impossible; student explains that not enough time was given for	• "…the actual exams were challenging but doable." • "The exams felt fair and I like that it wasn't all one huge exam for all topics covered." • "…I didn't feel like the exams were meant to be needlessly tricky…" • "It wasn't intimidating and we did not have to provide huge answers for short-answer questions." • "…in order to get in that A range you had to know further then your notes, but it would not be impossible." • "I really like having a combination of multiple choice and short answer because I feel like that's a good way to cover a variety of problem solving skills." • "I…enjoyed being able to explain some reasoning in the short answer problems rather than all multiple choice with a "Sorry you got it wrong good day"." • "…they worked well because even when	• "The exams…had way too many subjective grades." • "I felt the exams were very difficult." • "I have ADHD and typical test structure is very hard for me to do well on. However, that is just how tests are for me and it is a part of academia…." • "I wish there had been more essay questions... multiple choice can be extremely difficult in biology (at least for me). Leaving open ended questions is usually more helpful for me to explain my knowledge." • "…we don't usually get partial credit simply because we cannot show our work." • "…the select all that apply questions aren't really helpful, especially when you lose all credit if you miss one or pick one wrong answer." • "I would have liked to have more questions on the exams... Each question had such a high point value that if I missed one question my grade would decrease by a significant amount."

	completion of exam; lack of trust in exams as true assessments of knowledge)	answering [a] question wrong for example a math problem, [partial] points are still given out when the instructor knows you were on the right path.” • “I always felt I had enough time to really think about the questions...” • “Of all the styles seen throughout the last year, it is the closest one to real life…”	• “…I feel I would benefit from more time so that I can focus on the question I am completing without having to worry about rushing to the next question.” • “I feel like weekly exams would have been easier rather than having two large exams and a final.” • “I had some Canvas issues that caused me problems with the exams…”
Theme #5: Other e.g., Language of Exam	Helped/positive: Student could understand what was necessary to do in order to answer the questions; questions were ***well-written;*** student could ***understand instructions*** (Harmed/negative: Questions were not well-written or student could not understand instructions)	• "… questions and formatting were clear and concise, making it easier to understand what the question was truly asking…” • “I had no issues with the composition or organization of the exams.” • “…exams were well crafted.”	• “The first exam I struggled with small misunderstandings that I missed when reading the exam…” • “…I read the instructions for a question too quickly and I missed an important part…” • “The first exam had a weird student-written question with a mythological creature that made it more difficult for me to understand what the question was asking.”
Theme #5: Other e.g., Specific comment about exams (unrelating to previous categories)	Student's positive comment about exams does not relate to one of the categories above (Student's negative comment about exams does not relate to one	• “Some aspects worked for me, such as…the Canvas format because I am used to using that platform.”	• “I had some wildly unexpected issues on my second exam that really upset me. It wasn't the actual style of the exam, it was connection issues and a monitor issue.” • “I had some Canvas issues that caused me problems with the exams…”

	of the categories above)		
Theme #5: Other e.g., Unspecific comment about exams	Student's positive comment about exams is unspecific (Student's negative comment about exams is unspecific)	• "I personally was fine with the style of exams." • "Yes they were good..." • "The exam style worked well for me..."	• "The style of the exams were sometimes difficult for me…" • "The style did not really work for me." • "No…"