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Improving Student Success by Incorporating Instant-Feedback Questions and Increased Proctoring in Online Science and Mathematics Courses

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Abstract: Introductory courses in mathematics and physical sciences are challenging for students and often have lower success rates than other comparable courses. In online courses, this is compounded by students employing surface learning strategies. Furthermore, it has been shown that students often do not utilize learning materials that are provided in the structured course modules, such as lecture videos. To combat this problem, we have implemented two different solutions to improve student engagement and retention of knowledge in courses in general chemistry and precalculus. First, using the Quick Check tool in our learning management system (LMS), we have incorporated auto-graded questions that students answer directly after viewing the course materials. These aim to promote the viewing of course materials beyond homework and quizzes, including engagement with course lecture videos. Second, using an online proctoring option integrated into our LMS, we have moved to increase the extent to which exams are proctored. This encourages students to engage in more frequent reinforcement prior to exams as they will not be able to access external information sources. We show that these measures led to greater improvement in student performance between the midterm and final exam, particularly on application questions. However, the incorporation of Quick Check questions reduced student performance on formative assessments particularly on more challenging topics. The implications are discussed in terms of cognitive load theory.

Keywords: mathematics education, science education, online education, proctoring, engagement, cognitive load.

Online education has become an increasingly important part of the higher education landscape, with significant proliferation of online courses and degree programs at all levels from a large range of higher education institutions. This has provided greater learning opportunities for students who require a more flexible format for their learning, particularly nontraditional students with work and/or family commitments. However, questions have been raised regarding the rigor and the academic integrity of online education (Singh & Hurley, 2017), particularly given the issues associated with students using unauthorized help on assessments (Wachenheim, 2009). Furthermore, from a pedagogical perspective, B. W. Brown and Liedholm (2002) showed that students in online courses performed worse on more complex questions than students taking those courses in traditional face-to-face classes.

Another challenge is that the application of technology in education—and educational approaches in general—is a *wicked problem*, that is, one without a well-defined solution (Koehler & Mishra, 2008). It is also well-accepted that science, technology, engineering, and mathematics (STEM) education poses particular challenges in online education, as seen in a qualitative study by Smith et al. (2003) where instructors teaching mathematics online were less satisfied with the experience than those teaching other disciplines, partly due to technical challenges. Furthermore, students must be motivated to access course materials and seek help from instructors, which is less critical for face-to-face classes (Trenholm et al., 2016).

It has been shown that online instruction leads to lower learning gains for higher order learning outcomes, such as analysis and evaluation, as compared to face-to-face instruction, although this is not true for lower level outcomes such as those associated with recall and comprehension (B. W. Brown & Liedholm, 2002; Ross & Bell, 2007). As higher order skills are commonly required in STEM courses (see the textbook analysis for general chemistry by Dávila & Talanquer, 2010), this represents a significant challenge for online courses in mathematics and science, which have demonstrated relatively low success rates compared to their face-to-face counterparts (Xu & Jaggars, 2011). This is particularly important for lower performing students, as Lu and Lemonde (2013) have found that lower-performing statistics students perform better in a face-to-face environment than an online environment; this contrast in performance between learning environments was not observed for high-performing students.

Challenges When Encouraging Deep Rather Than Surface Learning

Since Biggs's (1987) seminal work, there has been significant discussion of how students perform differentially according to whether they take a deep (attempting to generalize and make connections between different types of work) or a surface (use of rote memorization and achieving tasks based on simple reproduction and replication) approach. Students' use of deep learning strategies has been correlated with student performance in chemistry (Bunce et al., 2017; Lastusaari et al., 2019) and mathematics (Rekabdar & Soleymani, 2010). This is supported by Renkl's (1997) finding that students who are able to generalize what they learn from presented examples to principles required to solve associated problems, rather than simply following the example passively, have greater overall learning gains. In addition, surface learning approaches are detrimental to the longer term success of students given that they have been shown to lead to fragmented views of subject matter (Crawford et al., 1998; Lastusaari et al., 2016). Addressing these concerns is particularly important for educators working at institutions with high proportions of first-generation students, since parents' education level is correlated with the use of surface learning approaches (Biggs, 1987). Given the preponderance of application and analysis levels of learning outcomes assessed in typical general chemistry (Dávila & Talanquer, 2010) and college algebra (Mesa et al., 2012) courses, as well as the observation that students employing surface learning strategies tend to perform disproportionately poorer on applied questions versus factual questions (Yonker, 2011), it is particularly important to foster self-regulated learning that steers students away from surface learning approaches.

From the perspective of Johnstone's theory of information processing (Johnstone & Kellett, 1980), it is not surprising that students engage in surface learning approaches. Introductory science and mathematics courses have significant cognitive loads due to the amount of content incorporated, the significant amount of jargon used, and the large number of interconnections required to solve problems, as well as the need to relate concepts between different levels of abstraction (Johnstone, 1991, 2010). Biggs (1987) has stated that students who find themselves overwhelmed with the material are prone to engage in the use of surface learning strategies, and he urged instructors to minimize this load accordingly.

Challenges When Encouraging Deep Learning in Online Education

Disengagement has been shown to be correlated with decreased performance (Cho & Shen, 2013). Yet it is more challenging to motivate students to self-regulate into engagement with deep learning strategies in online versus traditional education. First, students must "opt in" to engage in the course rather than "opt out" (Trenholm et al., 2016), but as noted above, students who become overwhelmed are more likely to fall back to a surface learning approach. This includes disengaging from course material, as seen in the significant proportion of students who fail to view assigned online instructional videos (Law, 2019; Ross & Bell, 2007). Second, students are more apt to simply choose to withdraw or stop attending an online course compared to a face-to-face course (Ashby et al., 2011; Ferguson, 2020).

Given the inherent increase in the extraneous cognitive load – cognitive load not directly aligned with the expected learning outcomes – that is required of students when technology is used in the classroom (Law, 2019), it is no surprise that students are likely to use surface learning approaches in online courses. For nontraditional students in particular, the increased cognitive load is exacerbated by the large number of outside commitments they frequently face (Kara et al., 2019; Romero & Barberà, 2011) in addition to often high course loads.

Modulating Student Behavior Using Affordances of Learning Management Systems and Other Resources

It is therefore imperative in the development of introductory STEM education that instructors consider tools within their institution's learning management system (LMS) that can encourage students to engage with the course materials. While some of these tools have been described previously (Law, 2019), in this article we focus on investigating how instant-feedback questions and the increased use of test security measures improve student success.

The use of instant-feedback questions. The use of online video-based instruction has been widely reported in the literature (Harwood & McMahon, 1997; Law, 2019; Pölloth et al., 2019). From the perspective of cognitive load theory (Sweller et al., 1998), instructional videos are particularly valuable in STEM education because by prompting the use of both visual and auditory processors of working memory, they can reduce split attention and redundancy effects, leading to a reduction in the extraneous cognitive load associated with learning (Chen & Wu, 2015; Sweller et al., 1998). In addition, instructional videos model expert approaches to solving problems that are difficult for students to visualize and generalize; this ability to visualize and generalize expert problem-solving strategies has been shown to correlate with students' learning gains (Renkl, 1997).

Unfortunately, students often fail to view assigned videos that are part of a course; without any instant-feedback tools, each instructional video in a chemistry course, for instance, typically accumulated approximately 0.2 views per student in the course (Law, 2019), while students viewed on average 68% of the lecture recordings in an upper level quality management course (Ross & Bell, 2007). Such viewing has, however, been shown to improve student learning (Ross & Bell, 2007).

To encourage students to engage productively with the course material and to provide students with formative assessment and feedback, we have incorporated instant-feedback questions into some class sections of our precalculus and chemistry courses, embedded both in videos and at the bottom of the module pages in the LMS. These questions become part of the students' experience of the course; they are designed to guide students into following the course as opposed to superficially attempting to complete the homework assignments in a scattershot manner, including via the use of solutions that can be found on the internet.

The incorporation of additional proctored exams. Until recently, there have been no tools that allowed online proctoring of exams. As a result, in online courses most instructors have used unproctored assessments. It has been shown in multiple studies that unproctored exams suffer from significant inflation of scores due to students using books or internet-based resources (Alessio et al., 2017; Carstairs & Myors, 2009; Daffin & Jones, 2018; Harmon & Lambrinos, 2008), including student-collected banks of questions from pre-exam tests (Wachenheim, 2009).

Historically, the only way this could be prevented was by requiring students to take exams under the supervision of a proctor. In the context of an online course where most students did not reside in the local area, this required them to make their own arrangements to secure the services of a testing center or another approved proctor. This posed not only a practical challenge for students who may not have had resources or connections available to them in their community but also possibly significant up-front costs. Finally, given that exams must be taken when the testing facility or proctor is available, this can present a scheduling challenge for students who work or have other commitments during the day. For these practical reasons, typically we have not required students to have more than two proctored exams per course; additional exams in the course, as well as quizzes, were typically unproctored.

More recently, particularly with the proliferation of webcam technology and greater bandwidth available to students, online proctoring services, such as ProctorU or Examity, that can be integrated into an LMS have become available (Rios & Liu, 2017). These services seek to replicate the function of an in-person proctor by verifying identity via inspection of a government-issued photo identification as well as through monitoring of the environment of the student through screen sharing and webcam services.

However, proctoring methods can be used for more than simply deriving greater test security. It has been reported that with the incorporation of proctored quizzes, the use of practice quizzes and page views increased in a medical terminology course (Wellman & Marcinkiewicz, 2004). We further hypothesized that since the ad hoc retrieval of answers and other information from the internet and other resources tends to reflect surface-level rather than deep learning strategies, proctored exams should encourage greater retention of knowledge by encouraging students not to rely on these strategies. We therefore compared student engagement performance in different courses as a function of the intensity of test security.

Methods

Institutional Context

This study was conducted at an independently accredited, 4-year regional campus of a statewide public university system in a rural area, with no university housing provided at this campus. The student body consists of students with a relatively low socioeconomic status and relatively large proportions of first generation and nontraditional students. Most students on the campus, including a large proportion of science students, take online courses as part of their degree program, including a completely online mathematics program.

Courses Studied

We studied two gateway courses aimed at students in science and mathematics. The first of these is a precalculus course (N = 225), in which 42% of students were mathematics majors and 15% were science (biological sciences and biochemistry) majors. The second course is a first-semester general chemistry course (N = 105) for science and premed (i.e., health professional) majors; 58% of students enrolled in this course were science majors. For both courses, approximately 20% of the student body were nondegree students, many visiting students from other campuses of the university system and other institutions taking an occasional course. We have included most class sections since the university began using the Canvas LMS for these courses (from fall 2015 and spring 2015, respectively, for precalculus and chemistry, through fall 2019), except for chemistry in spring 2016, which was omitted because the Zaption video response system was used that semester, which would have confounded these data. In addition, due to a significant curriculum change independent of the variables studied, in fall 2018, data for the precalculus course are presented separately for classes offered before and after this semester.

Course delivery. Both courses were delivered in a fully online, asynchronous format through the Canvas LMS. While course designs vary in detail, each course is based around a series of weekly modules with course materials delivered through a mixture of reading assignments, instructional videos, and occasional use of simulations and other interactive materials. Each course includes asynchronous discussions of various types between students using the discussion forum tool in Canvas. The overall course design in these courses has been previously described (Law & Wilson, 2017).

Instructional videos. Instructional videos were recorded by the course coordinator for each course primarily for use in the relevant course. Videos were typically 3–10 min long in chemistry and approximately 5–30 min long in mathematics. Most videos included an exposition of a specific concept along with associated worked-out examples using screencasting software, and most were produced using a tablet PC with a digitizer pen, although in chemistry some videos featured experimental demonstrations by the course coordinator. In addition, a select number of videos from the textbook publisher and elsewhere were referenced; these formed a relatively small proportion of videos incorporated into the course design.

Course assessment. For each course, assessment was based on a mixture of homework, forum discussions, quizzes, and exams. Homework was primarily administered using commercial, online homework systems (WebAssign (Cengage) or MyMathLab (Pearson) in precalculus; Sapling Learning (MacMillan) or Mastering Chemistry (Pearson) in chemistry) In precalculus, some homework problems in each section required students to submit hand-graded solutions. In chemistry, additional problems for students to submit worked-out solutions were assigned to be submitted on Canvas.

For each course, regular, timed quizzes and exams were delivered via either Canvas or the abovementioned online homework platforms. Quizzes were not subject to special security measures. For each class section, at least two exams were proctored; other exams could be assigned without additional security measures. In this study, we focused on comparing students' scores only on quizzes and proctored exams, as unproctored exams tend to have significantly higher scores, likely due to the use of outside resources (Alessio et al., 2017; Carstairs & Myors, 2009; Wachenheim, 2009).

Using Add-Ons to the LMS to Facilitate Course Changes

Prior to 2016, there were relatively few tools available within the LMS to provide test proctoring in an online setting or to provide instant, formative feedback within the context of a module page. This was remedied by the incorporation of two embedded services in Canvas: (a) an online proctoring service to facilitate proctoring of every exam; and (b) the Quick Check tool, an instant-feedback system coupled to module pages. In this study, we explored how these affected student learning.

Enabling increased exam proctoring using online proctoring services. Our university's adoption of the Examity online proctoring service for online courses, which reduced logistical challenges and student cost associated with taking proctored exams, meant that we were able to proctor all instead only some of the exams for more recent sections of these courses.

Embedding of self-assessment questions with instructional content. Beginning in spring 2017, we used the Quick Check tool (https://github.com/IUeDS/quickcheck; Figure 1) in precalculus to embed auto-graded, instant-feedback questions at the end of content pages in the online course material for online instruction. Feedback was provided to students after each question and included guidance on topics to review if they made a mistake. Infinite attempts were allowed for each set of questions, but students were required to repeat the entire set each time.

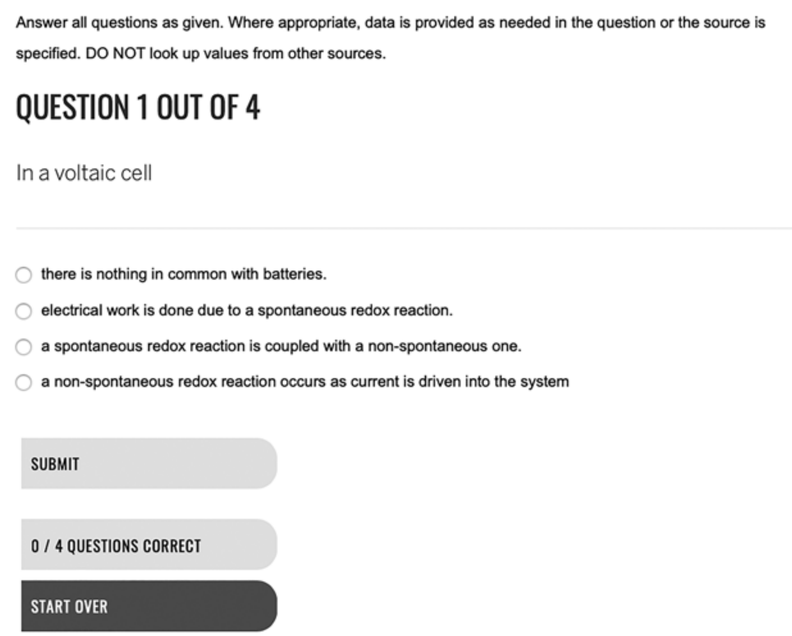

Figure 1. A question delivered using the Quick Check tool embedded in Canvas. The tool was designed by eLearning Design and Services/University Information Technology Services, Indiana University. From "The Right-Tech Approach for Integrating Technology into Teaching and Learning," by Y. K. Law, in T. Gupta & R. E. Belford (Eds.), Technology integration in chemistry education and research (TICER) (pp. 209–232), 2019, American Chemical Society. Copyright 2019 by American Chemical Society. Reprinted with permission.

Data Collection

Data were collected from institutional data systems both in aggregate and for each student from each course section as described above. The study was reviewed and certified as exempt by the Indiana University Institutional Review Board. As described above, due to the significant curriculum change in fall 2018 to the precalculus course involving significant changes in course assessment content (but not methodology), we decided to treat the course before and after these changes as two separate courses for the purpose of this study. This also removes issues of confounding in the multivariate analysis, as all sections using the pre-2018 curriculum did not proctor all exams, while all those using the new curriculum adopted in 2018 included the use of the Quick Check tool.

Aggregate data. Enrollment in each section, aggregate course grade distribution, and student major information were obtained from the Indiana University student information system. Page views each week were obtained through the original analytics tools built into Canvas. The page views per student were calculated based on the number of students with transcript entries; this excludes students who have dropped the course in the first week of classes. To account for differences in length of course and missing data entries, we calculated the number of views per student in each week based on the entries present and summed for the overall course.

Student scores and response data. For each student, we recorded their scores for each assignment from Canvas. Because of how record keeping was completed, students with a score of zero were assumed to have not completed the assignment; it was very rare for students to have recorded a score of zero if they had attempted the assignment and it was common practice for instructors to record a "hard" zero for missing assignments. Unless otherwise specified, all cases that contained missing score entries were not included in the average score of a given assignment in order to assess the effect of mastery as opposed to completion of a given assignment.

In addition, for chemistry, selected final exam questions common across most semesters were analyzed. For exam questions that were omitted for certain semesters, we used logistic regression to impute missing values using MICE 3.9.0 (van Buuren & Groothuis-Oudshoorn, 2011) in R.

Results

Effects of Quick Check and Proctoring Practices on Course Success Rates

As seen in Table 1, there was no statistical difference in student success or completion rates associated with changes in proctoring approaches. Similarly, we did not observe a difference in student success rates when instant-feedback questions were included, although the number of students who withdrew appears to have increased when the Quick Check tool was incorporated (Table 2). While this is a measure of overall course completion, we note that this is not, alone, a reliable measure of student learning or engagement.

Table 1. Student grade distributions as a function of exam proctoring. DFW refers to the proportion of students who scored a D, F, or withdrew from the course with a transcript notation. W refers to the proportion of students who withdrew from the course.

Variable	Some exams proctored	All exams proctored	χ^2 (1)	*p*
Precalculus (fall 2018 – fall 2020)				
DFW (%)	47	41	0.26	0.61
W (%)	16	9	0.85	0.36
N	51	43		
General Chemistry				
DFW (%)	33	23	1.24	0.26
W (%)	7	9	0.16	0.69
N	42	64		

Table 2. Student grade distributions with and without using Quick Check in precalculus classes, fall 2015 through summer 2018. DFW refers to the proportion of students who scored a D, F, or withdrew from the course with a transcript notation. W refers to the proportion of students who withdrew from the course.

Variable	Without Quick Check	With Quick Check	χ^2 (1)	*p*
DFW (%)	38	43	0.24	0.62
W (%)	0	11	—	
N	37	94		

Student Engagement With Course Material Is Modulated by the Incorporation of Both Proctored Exams and the Quick Check Tool

While there is no clear, quantitative measure of student engagement, one crude measure is the average number of page views per student in a course. It should be noted that materials external to the LMS, such as homework submitted on online platforms, are not included here. Instructor activity on the LMS, however, was counted in the average page views per student.[1]

In precalculus, the number of page views over the course (for sections beginning fall 2018) increased from 1,629 to 2,203 when proctoring of all exams became required; similarly, in chemistry, the number of page views per student increased from 1,350 to 2,068 when all exams were proctored. The smaller increase in precalculus was partly due to lost entries in the page views in the last 4 weeks of fall 2019. This suggests that the requirement for students to take all exams under proctored conditions increased the extent of student engagement with course materials, as reported previously by Wellman and Marcinkewicz (2004).

To examine whether this effect was associated with last-minute studying activity prior to exams, we compared the weekly page views per student in chemistry and precalculus courses as a function of proctoring approach. Figure 2 shows that for both courses, the increase in page views when all exams were proctored seems to have occurred throughout the course rather than just during the midterm weeks, although for chemistry the increase was more toward the beginning of the course. This suggests that course engagement increased throughout the semester with the incorporation of Quick Check.

Similarly, as could be expected because students were required to view course pages after the incorporation of Quick Check, the total number of page views per student increased from 808 to 1,053 for precalculus sections offered between fall 2015 and summer 2018. This is in line with our previously reported observation that video playbacks increased with the use of same-page embedded questions using either Quick Check or Top Hat (Law, 2019).

[1] In Canvas, the New Analytics tool available since the beginning of 2019 has resolved this issue by counting page views made only by students in the course. This was, however, not appropriate for our study since this option was not available for courses predating the launch of this tool.

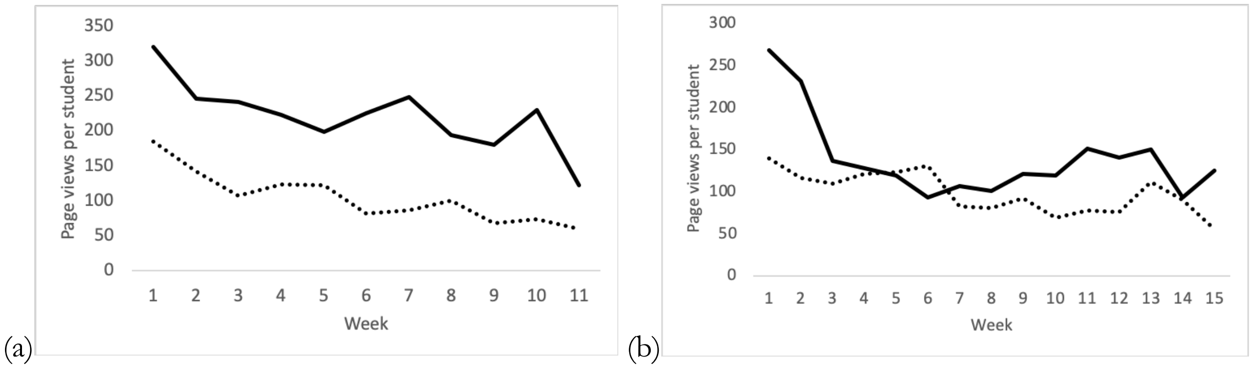

Figure 2. The weekly page views per student without instant-feedback questions for full semesters of (a) precalculus (spring 2016-summer 2018; first 11 weeks only) and (b) chemistry. The solid line indicates sections with all exams proctored and dotted lines indicate sections with some exams proctored.

Proctoring Appears to Improve Student Performance on Final Exams but Not Continuously Assessed Work

In both chemistry and precalculus there was a rather large improvement in the change in student score between the midterm and final exam (Figure 3) when all exams, as opposed to only some exams, were proctored. This change is statistically significant in chemistry ($t = 2.93$, $df = 71.2$, $p = .0046$); however, it is just beyond the range of statistical significance at the 0.05 level for precalculus ($t = 1.89$, $df = 52.6$, $p = .064$). What is notable is that changes in exam scores are relatively large for the final exam but not for the midterm exam (Table 3). However, no significant differences were found in aggregate homework or quiz scores.

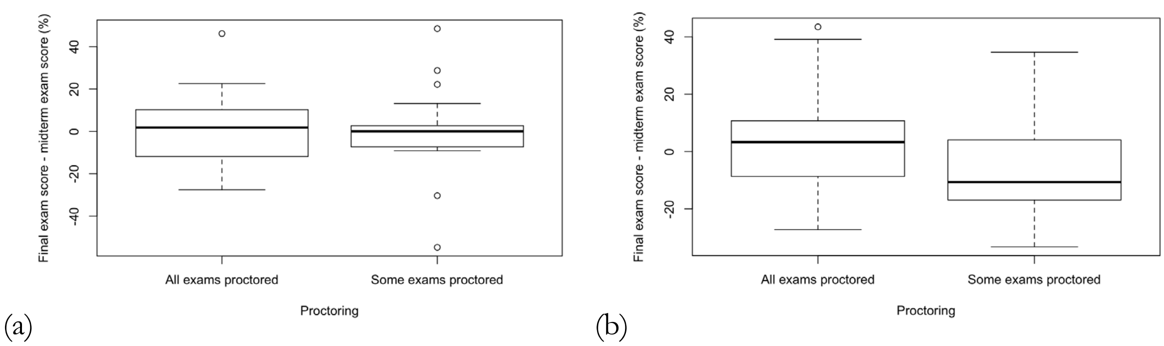

Figure 3. The distribution in the difference in exam scores between the final and midterm exams for students taking (a) precalculus (fall 2018 – fall 2020) and (b) general chemistry as a function of proctoring arrangements. The whiskers indicate the overall range of cases except for outliers indicated by circles.

To obtain a better understanding of how students performed differently on different topics and question types, we examined student performance on selected exam questions in chemistry that were common or similar across the semesters. This selection of questions relates to the application and analysis levels of Bloom's taxonomy, as expected from typical textbook questions (Dávila & Talanquer, 2010). However, the subset of questions with statistically significant improved responses with all exams being proctored tended to be on the application level of Bloom's taxonomy (Figure 4). In contrast, the two questions on the distribution of molecular speeds and periodic trends, which lie on the recall and understanding levels of Bloom's taxonomy, did not yield a significant difference in student performance as a result of proctoring practices.

Table 3. Average scores of students (%) on midterm and final exams as a function of proctoring arrangements.

Exam	Precalculus		Chemistry	
	All exams proctored	Some exams proctored	All exams proctored	Some exams proctored
Midterm	79	77	45	46
Final	85	77	63	51

Note. Only the difference in scores for the chemistry final is statistically significant, $t = 3.14$, $df = 71.1$, $p = .002$.

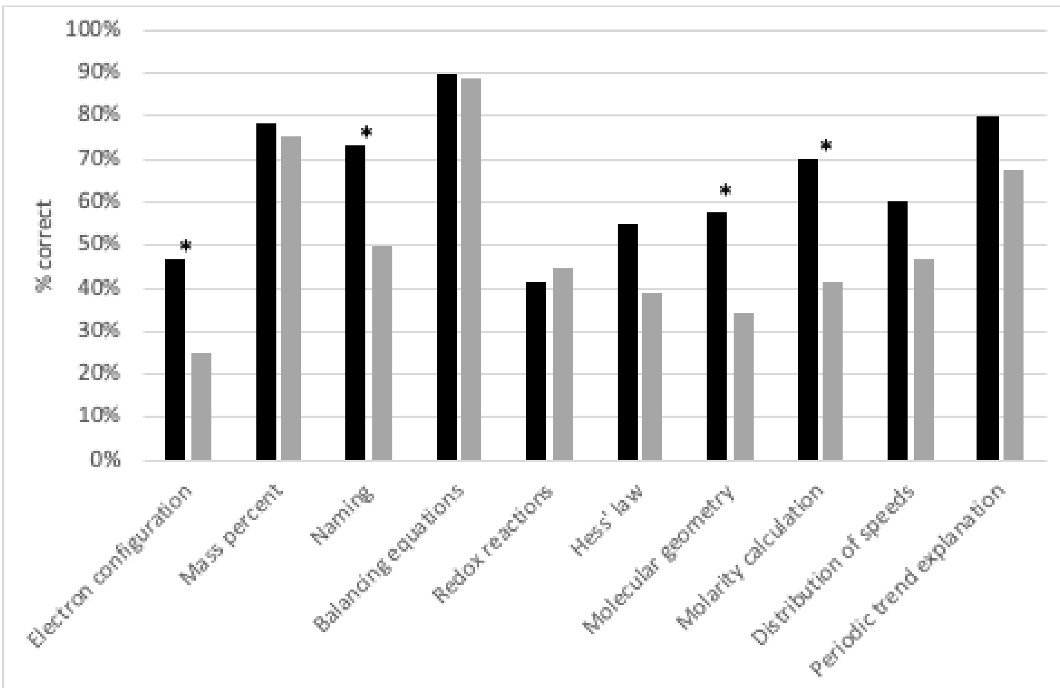

Figure 4. The proportion of students responding correctly to chemistry exam questions depending on whether all exams (black) or only some of the exams (gray) were proctored. * p < .05.

Using Quick Check Decreases Student Performance in Continuously Assessed Work but Increases Student Learning Improvement Between Exams

While there was no statistically significant difference in the aggregate homework and quiz scores in precalculus, most quiz and homework scores were lower for sections using the Quick Check instant-feedback system (Figure 5). Furthermore, topics for which a significant difference was observed tended to be those involving mathematically more complex concepts such as polynomials and systems of equations.

There was no statistically significant difference in student scores on midterm and final exams between students who used and did not use Quick Check. However, there was a statistically significant difference in the improvement of student scores between the midterm and final exam scores, $t = 2.25$, $df = 85.6$, $p = .027$ (Figure 6).

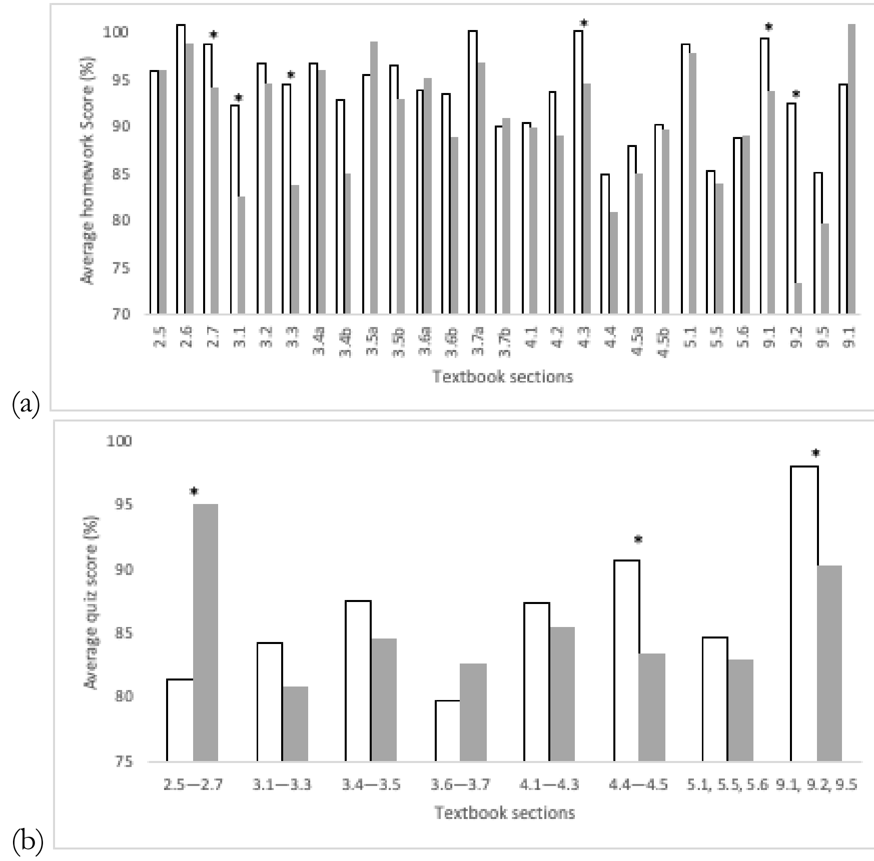

Figure 5. Average scores on homework assignments and quizzes in precalculus (fall 2015 through summer 2018) as a function of whether Quick Check questions were used (gray) or not (white). The textbook references refer to the textbook used (Swokowski & Cole, 2012). * $p < .05$.

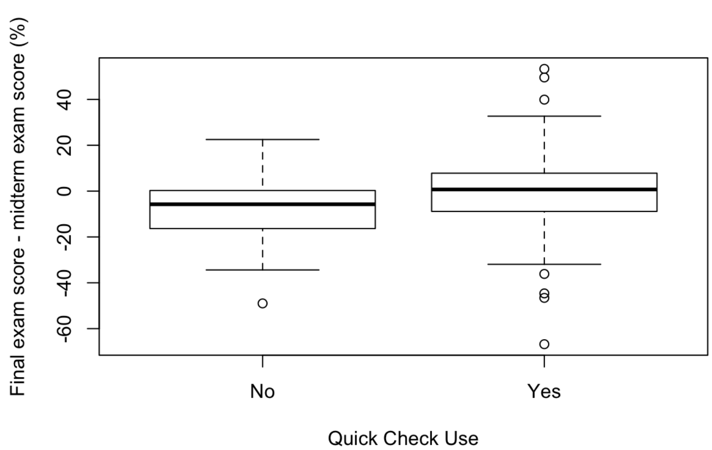

Figure 6. The distribution in the change in exam score between the midterm exam and the final exam for students taking precalculus (fall 2015 through summer 2018) as a function of the use of Quick Check. The whiskers indicate the overall range of cases except for outliers indicated by circles.

Discussion

As reported previously (Law, 2019; Wellman & Marcinkiewicz, 2004), both the incorporation of increased proctoring arrangements and the incorporation of Quick Check increased the number of page views of materials posted to the LMS. These results suggest that there was greater access to online course materials.

These measures, however, do not appear to have significantly improved students' performance on formative assessments. We believe that this was due to students' tendency when completing formative assessments to refer to their textbooks as well as other resources, including online sites such as Chegg.com which have worked solutions as examined previously by Palazzo et al (2010). This is corroborated by students' comments in face-to-face courses, where all quizzes and exams are proctored, that they attempt online homework problems by referring to study materials for similar questions from which they can craft an answer without generalizing their learning. Intriguingly, students' progression (as measured by the withdrawal rate) as well as performance in formative assessments decreased when Quick Check questions were implemented, particularly for mathematically more challenging topics. We believe that this was due to an increase in students' cognitive load when Quick Check questions were incorporated, given that their inclusion was not associated with a decrease in workload in another realm. Using Johnstone's theory of information processing (Johnstone, 1991, 1997; Johnstone & Kellett, 1980) coupled with Sweller's cognitive load theory (Sweller et al., 1998; van Merriënboer & Ayres, 2005), we can explain this by recognizing that the incorporation of Quick Check increased the extrinsic cognitive load, which led to cognitive overload particularly for more challenging topics, thus decreasing students' performance on formative assessments and on students' mastery of learning outcomes in general. The design of Quick Check, with infinite attempts, is also conducive to students solving problems in a nonproductive manner, similar to what Kortemeyer (2015) observed for online homework systems. As a result, students' immediate learning gains may have decreased with the use of this tool. This lends support for applying the right-tech approach (Law, 2019) which calls for rationalizing the technology used to support student learning.

These measures, however, yielded improved learning gains between the midterm and final exams. For Quick Check, while there was an increased extrinsic cognitive load, the requirement for students to engage with course materials also increased students' germane cognitive load and increased transfer of information into long-term memory. This appears to have improved students' learning gains between exams. We suggest that the increased use of proctored assessments, which prevent students from using online resources and other assistance that circumvents authentic problem solving (Alessio et al., 2017; Daffin & Jones, 2018), will promote more self-regulated learning. The fact that students' lower level learning outcomes appear to have been affected less than higher level learning outcomes suggests the greater use of deep or strategic learning strategies as opposed to surface learning strategies (Yonker, 2011).

These results are encouraging and suggest that students are prompted to engage in self-regulated learning by increasing test security measures. However, this study is limited in that we did not directly examine students' study strategies, course engagement, or performance in online courses using survey instruments that provide measures of learning approaches (S. Brown et al., 2015; Lastusaari et al., 2016), so we have no direct measure of whether these pedagogical approaches led to students' use of deep learning strategies instead of surface learning strategies, or of student course engagement (Nasir et al., 2020). Student surveys and viewing patterns of instructional videos could be analyzed to better evaluate student engagement. Such studies will provide a better picture of how test security measures modulate students' engagement and learning approaches that lead to improved self-regulated learning.

Conclusions

We conclude that the incorporation of instant-feedback questions and increased test security led to increased students' use of the LMS as well as learning between the midterm and final exams, particularly for application-level questions. However, students' performance on formative assessments did not improve. This supports our previous assertion that the adoption of instructional technologies may decrease student learning due to an increase in extraneous cognitive load. Future studies should incorporate explorations of how student learning approaches and more direct measures of student engagement change over the course of a semester as a function of the pedagogical approaches studied in this work.

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