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Impacts of Emergency Online Instruction on Engineering Students' Perceived Cognitive Load during Learning Assessments

Mary K. Watson[a], Elise Barrella[b], Kevin Skenes[a], Benjamin Kicklighter[a] and Aidan Puzzio[a]
The Citadel - the Military College of South Carolina[a], DfX Consulting LLC[b]
Corresponding Author's Email: elise@dforxconsulting.com

ABSTRACT

CONTEXT

A primarily undergraduate military college shifted from face-to-face instruction to emergency online instruction in Spring 2020 due to the COVID-19 pandemic. We are examining student experiences with the shift using Cognitive Load Theory (CLT), which asserts that learning is hindered when cognitive load overwhelms finite working memory capacity. At the onset of the pandemic, we hypothesized that the need to manage learning in new and changing modalities may increase students' cognitive load and development.

PURPOSE OR GOAL

We seek to triangulate a previous finding that middle-years students experienced more cognitive load demands than either freshmen or seniors during the Spring 2020 semester. In this study, we examine cognitive load experienced by students in sophomore-, junior-, and senior-level civil engineering courses when engaging in various types of summative assessments. Our goal was to understand how academic course level and assessment type (closed-ended vs. open-ended) may have impacted cognitive load among students.

APPROACH OR METHODOLOGY/METHODS

We are engaged in a longitudinal mixed-methods study to explore the impacts of changing modalities on cognitive load and student development during the pandemic. For this study, we measured cognitive load experienced during five assessments administered across civil engineering courses of different academic levels using the NASA Task Load Index (TLX). The TLX is a rigorously-developed instrument that quantifies workload (a surrogate for cognitive load) across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. We used non-parametric analysis to identify differences in cognitive workload by course level and assessment type. We supplemented interpretation of findings through analysis of open-ended questions and focus group transcripts.

ACTUAL OR ANTICIPATED OUTCOMES

Sophomores and juniors experienced summative assessments differently than seniors, a finding that is consistent with our previous publications suggesting that modality changes may have disproportionately impacted middle-years students. Analysis of TLX data showed that sophomores and juniors reported highest time-demand and frustration, respectively, during closed-ended assessments. Open-ended assessments elicited significant frustration among juniors, a trend that was not observed for seniors. Qualitatively, both sophomores and juniors discussed workload-associated aspects of the modality shift more than seniors.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We seek to further understand the unique experiences of middle-years students as a means for developing recommendations for managing cognitive load during online engineering courses – whether planned or unplanned.

KEYWORDS

Online learning, cognitive load, COVID-19

Introduction

During the Spring 2020 semester, The Citadel (a public, teaching-focused, military institution in the Southeastern United States) shifted to an emergency online modality to protect the campus community's health and well-being during the COVID-19 pandemic. Prior to the pandemic, all undergraduate engineering programs at The Citadel were administered solely through face-to-face instruction. As such, the mandatory transformation to online instruction was an unprecedented disruption to our model for student learning and development. The pandemic's impact on course modalities persisted past the Spring 2020 semester, as most courses during the subsequent academic year used a hybrid modality.

We have been engaged in a project to understand the impacts of pandemic-induced modality shifts on Citadel engineering students' cognitive load and self-directed learning readiness. Our inquiry into cognitive load changes has been guided by Cognitive Load Theory, which characterizes learning as assimilation of knowledge into one's long-term memory after preliminary processing by short-term (working memory). If the cognitive load associated with a task exceeds short-term processing capacity, then learning cannot occur (Sweller, 2011; Paas, et al., 2003). At the onset of the pandemic, we hypothesized that the need to manage learning during changing modalities may increase students' cognitive load and readiness for self-directed learning (McCune et al., 1990), perhaps with interaction between the two.

To test our hypotheses, we administered a multi-part survey to our students twice during Spring 2020. At midterms, students used the NASA Task Load Index (TLX) to reflect on the workload (a surrogate for cognitive load) associated with face-to-face engineering courses. The TLX assesses cognitive workload across six sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart, 2006). At finals, students used the TLX to reflect on load associated with their emergency online engineering courses. Open-ended feedback was also collected at the end of the semester.

To date, our preliminary analyses suggest that cognitive load and self-directed learning readiness indeed increased over the course of emergency online instruction. Interestingly, we have found that students across academic years may have experienced cognitive load differently, with middle-years students (i.e., sophomores and juniors) reporting an increase in more workload sources than either first-year students or seniors (Watson et al., 2021).

The goal of this study to triangulate our finding of increased cognitive load among middle-years students using additional quantitative and qualitative data (Heale & Forbes, 2013). Specifically, we solicited NASA TLX responses from students enrolled in civil engineering courses to understand cognitive workload experienced during a variety of assessments administered across academic levels during emergency online instruction. Also, we present thematic analysis of select open-ended survey responses and focus group transcripts to generate deeper understanding of students' experiences during the modality shift, especially related to their engagement with summative assessments. In this paper, we will address the following research questions: (1) How might assessment type (closed-ended vs. open-ended) have impacted assessment-level workload across academic classes? (2) To what extent, if any, might assessment-level workload have varied across academic classes?

Methods

Target Courses and Assessments

We explored cognitive workload among students as a result of specific assessments in civil engineering courses across academic levels and assessment types (Table 1). At the sophomore level, workload data was collected in Statics and Geomatics courses. In Statics, students reflected on cognitive workload associated with a closed-ended, regular-semester test. In Geomatics, students reflected on cognitive workload associated with a hybrid assessment, which included closed-ended questions and a self-directed project (Brown et al,

2021). At the junior level, workload data was collected in Introduction to Environmental Engineering for a regular-semester test. At the senior level, workload data was collected in Geotechnical Engineering II and Environmental Lab. In Geotechnical Engineering II, students reflected on load associated with a regular-semester test. In Environmental Lab, students reflected on load associated with composition of a comprehensive report.

Table 1: Summary of courses in which students provided assessment-specific workload data.

Course	Assessment Description	Academic Level	Responses (Total Students)
Statics (CIVL 202)	Third (final) regular-semester test, which included closed-ended questions only	Sophomore	23 (50)
Geomatics (CIVL 208)	Third (final) regular-semester test, which included closed-ended questions and an open-ended, self-guided project	Sophomore	25 (44)
Intro to Env Engr (CIVL 322)	Third (final) regular-semester test, which included closed-ended questions only	Junior	27 (34)
Geotech II (CIVL 410)	Third (final) regular-semester test, which included closed-ended questions only	Senior	21 (46)
Env Engr Lab (CIVL 419)	Comprehensive laboratory report	Senior	10 (42)

Workload Data Collection and Analysis

For each target assessment (Table 1), participants reflected on cognitive workload using the NASA TLX (Figure 1). Through Qualtrics, participants were prompted to provide 0-100 ratings for each of the six workload sources/dimensions: mental, physical, temporal, effort, frustration, and performance. We then computed a Raw (average) TLX score for each student and assessment. We omitted pairwise comparisons required to compute the Weighted TLX score, to shorten survey length and encourage participation. Previous studies (e.g., Hart, 2006) comment that raw and weighted scores usually show similar results.

Subsequently, we explored differences in cognitive workload associated with regular-semester tests administered across academic years during emergency online instruction. Raw TLX scores and source dimensions were compared between Statics (sophomore-level course), Introduction to Environmental Engineering (junior-level course), and Geotechnical Engineering II (senior-level course) using Kruskal-Wallis *H* tests (conducted using IBM SPSS Statistics 27). Distributions of workload ratings were similar for all groups, as assessed by visual inspection of boxplots. For significant findings, pairwise comparisons were performed per Dunn's (1964) procedure with Bonferroni corrections for multiple comparisons.

We explored differences in cognitive workload between closed-ended, regular-semester tests and other open-ended assessments. For students who provided workload ratings for closed- and open-ended assessments, we used Wilcoxon Signed Rank tests to compare Raw TLX scores and source dimensions. For workload ratings, difference scores were approximately symmetrically distributed, as determined by a histogram with superimposed normal curve.

Collection and Coding of Student Challenges

We collected and used qualitative data to understand experiences of our engineering students during emergency online instruction (Figure 1). As part of our larger survey, we asked students to respond to the question: "What challenged you most in your online classes this semester?" Two researchers reviewed each open-ended response (n = 277) to identify which dimension(s) of cognitive load, as defined in the NASA TLX instrument, were impacted

by the switch to online learning. An additional code of “general/overall load” was added to capture statements about a change in load that lacked specific language to assign to one of the six dimensions. The researchers tried to assign codes as strictly as possible without reading into student comments; this was particularly challenging for the Frustration dimension, which could be broadly interpreted. They assigned statements to as few codes as possible, but did split up statements to pull out separate challenges that impacted cognitive load. Statements were coded as “none” if they were too vague to determine impact on load.

Focus Group Facilitation and Analysis

During July 2020, three focus groups were conducted via Zoom with engineering students, providing an opportunity to further reflect on their experiences with the switch to online learning (Figure 1). All participants were recruited from the pool of survey respondents. Each session began with a welcome, introductions, and review of guidelines for engaging in the focus group. With participant consent, the sessions were video recorded for purposes of accurately summarizing the focus group discussion and statements made by participants. Focus group questions related to three topics: (1) participants’ experiences with and response to the online learning shift, (2) how others’ responses (e.g., faculty, peers, etc.) helped/hindered their online learning, and (3) participants’ thoughts about the future.

The first focus group included three male, civil engineering majors; two juniors and one sophomore. The second focus group was attended by four male, senior-level participants. Three participants were civil engineering majors, one participant was a mechanical engineering major, and one participant was a veteran. The third focus group was attended by three participants, all women in engineering. Two were junior mechanical engineering majors and the third was a an employed, evening civil engineering student preparing to graduate.

Focus group discussions were summarized by two researchers and were reviewed for themes related to assessment-level experiences. For this paper, we considered overall sentiments of each group and more specifically the reflections of civil engineering students. The majority of focus group participants (7 out of 10) were civil majors and of the civils, all but one participant completed at least one assessment-level survey during the semester.

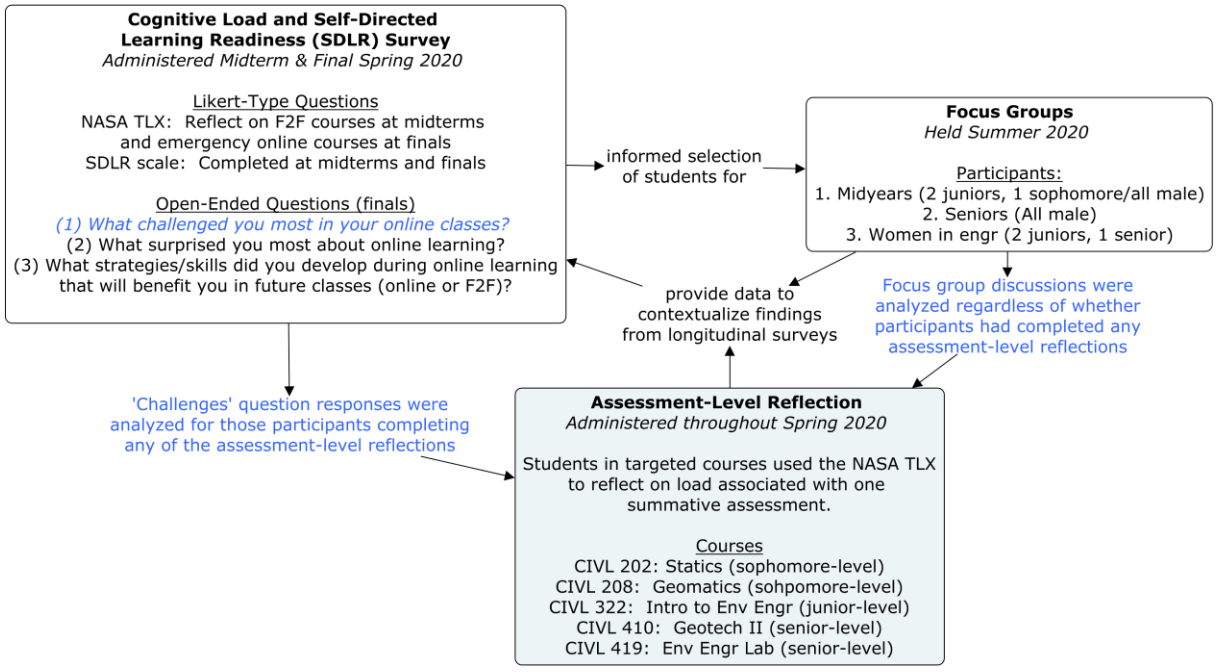

Figure 1. Summary of data sources used to understand student experiences and development during the Spring 2020 semester of the COVID-19 pandemic. Text in blue demonstrates how survey and focus group data are used in the current study to explore assessment-level load.

Results & Discussion

Test-Associated Cognitive Workload

Cognitive workloads (measured as Raw TLX) experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (p = 0.041; Table 2). Post-hoc analysis showed that students enrolled in the sophomore-level Statics course (*Med* = 59.0) experienced more cognitive load than students enrolled in the senior-level Geotechnical Engineering II course (*Med* = 54.5; p = 0.004).

Temporal demand experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (p = 0.005; Table 2). Post-hoc analysis showed that students enrolled in the sophomore-level Statics course (*Med* = 50.0) experienced more temporal demand than students enrolled in the senior-level Geotechnical Engineering II course (*Med* = 20.0; p = 0.004).

Frustration experienced during closed-ended, regular-semester tests were significantly different between students enrolled in courses of differing academic levels (p < 0.001; Table 2). Post-hoc analysis showed that students enrolled in the junior-level Introduction to Environmental Engineering course (*Med* = 80.0) experienced more frustration that students enrolled in either the sophomore-level Statics course (*Med* = 45.0; 0.018) or the senior-level Geotechnical Engineering II course (*Med* = 15.0, p < 0.001).

Other workload sources, including mental, physical, effort, and performance demands experienced during closed-ended, regular-semester tests were not significantly different between students enrolled in courses of differing academic levels (Table 2).

Table 2. Comparing Raw TLX and workload sources associated with closed-ended, regular-semester tests across courses of differing academic levels.

Workload & Source Dimensions	Medians			Kruskal-Wallis *H* tests	
	Statics: Sophomore-Level (n = 23)	Intro to Env Engr: Junior-Level (n = 27)	Geotech II: Senior-Level (n = 21)	*H*(2)	Asymptotic *p*
Mental	75.0	75.0	77.5	00.706	<0.703***
Physical	15.0	05.0	12.5	04.195	<0.123***
Temporal[a]	50.0	45.0	20.0	10.656	<0.005***
Effort	70.0	75.0	70.0	00.678	<0.713***
Frustration[b]	45.0	80.0	15.0	21.074	< 0.001***
Performance	75.0	75.0	82.5	00.072	<0.965***
Cognitive Workload (Raw TLX)[c]	59.0	66.0	54.5	06.381	<0.041***

[a]Soph > Seniors (p = 0.004); [b]Juniors > Soph (p = 0.018); Juniors > Seniors (p < 0.001); [C]Juniors > Seniors (p = 0.036)

Student Challenges by Academic Year

Within our larger survey, 16 of 23 students in the sophomore-level Statics course responded to the open-ended “challenges” question. Most students identified keeping up with the work load (effort) or focusing/avoiding distractions (overall cognitive load) as their biggest challenge. No student called out a specific course or assessment type in their response.

Twenty-three out of twenty-seven junior students who completed an assessment TLX also commented on the most challenging part of online courses. Equal numbers of students (n = 7) identified mental demand due to difficult concepts or overall cognitive load as the biggest challenge that they faced. Two students attributed their challenge to online testing methods. Students who were already struggling with a course before the shift felt that those courses became more difficult, due to the online environment or the course topics. Several juniors

also mentioned difficulty focusing at home as contributing to overall higher load. Three students reported that they did not face cognitive load challenges related to courses.

Fifteen out of twenty-one senior-level students completed an assessment TLX and responded to the open-ended challenges question. Seniors less frequently (n = 3) cited challenges with a specific cognitive load dimension than sophomore or junior students. Seniors more frequently reported challenges unrelated to cognitive load (n = 6) such as adjusting to a new schedule or coordinating schedules with teammates. An equal number of students (n = 6) observed a change in their overall cognitive load.

Sophomore-Level Workload and Challenges with Different Assessments

We compared cognitive workload and workload sources for students who completed reflections on both the project-based assessment and closed-ended assessment in Geomatics and Statics, respectively (Table 3). Of the seven participating students, six reported higher cognitive workload (Raw TLX) when engaging in the project-based Geomatics assessment (Table 3). Indeed, the cognitive workload experienced during the project-based Geomatics assessment was significantly higher than experienced during the closed-ended Statics assessment (p = 0.034). Of the seven participating students, six also reported higher frustration when engaging in the project-based Geomatics assessment (Table 3). Median frustration experienced during the project-based Geomatics assessment was higher than experienced during the closed-ended Statics assessment (p = 0.043).

Based on the seven participating students, no significant differences were found between other workload sources when engaging in the project-based Geomatics assessment, as compared to the closed-ended Statics assessment (Table 3).

Table 3. Matched-pairs comparison (n = 7) of Raw TLX and workload dimensions experienced during open-ended and closed-ended assessments administered in sophomore-level Geomatics and Statics courses.

Workload and Source Dimensions	Medians		Wilcoxon Signed-Rank tests	
	Geomatics: Project-Based Assessment	Statics: Closed-Ended Assessment	z	p
Mental	85.0	75.0	-1.876	0.061
Physical	55.0	20.0	-1.826	0.068
Temporal	75.0	60.0	-1.194	0.233
Effort	85.0	70.0	-1.841	0.066
Frustration	65.0	40.0	-2.028	0.043*
Performance	50.0	65.0	-1.119	0.263
Cognitive Workload (Raw TLX)	81.0	66.0	-2.117	0.034*

Five students completed both sophomore-level course assessments and responded to the larger survey's open-ended prompts. Each student reflected on a different challenge with online learning and none identified particular courses or assessment types in their response.

Senior-Level Workload and Challenges with Different Assessments

We compared Raw TLX and workload sources for students who completed reflections on both the comprehensive laboratory report and closed-ended assessment in Environmental Laboratory and Geotechnical Engineering II, respectively (Table 4).

Of the seven participating students, six reported higher median workload (Raw TLX) when engaging in the report-based assessment (Table 4). Indeed, the cognitive workload experienced during the report-based Environmental Laboratory assessment was significantly

higher than experienced during the closed-ended Geotechnical Engineering II assessment (p = 0.027). Of the seven participants, six reported higher effort when engaging in the report-based assessment (Table 4). Indeed, effort expended during the report-based Environmental Laboratory assessment was significantly higher than experienced during the closed-ended Geotechnical Engineering II assessment (p = 0.026).

Based on the seven participating students, no differences were found between other workload sources for the report-based Environmental Engineering Lab assessment, as compared to the closed-ended Geotechnical Engineering II assessment (Table 4).

Six students completed the TLX for the Environmental Lab and Geotechnical Test and also responded to open-ended questions in the end-of-semester survey. Three students noted that the learning mode (online only) was a challenge for them and two students specifically identified challenges working on teams to complete assessments, which may be reflected in the higher overall cognitive load experienced for the lab report.

Table 4. Matched-pairs comparison (n = 7) of Raw TLX and workload dimensions experienced during open-ended and closed-ended assessments administered in senior-level Environmental Lab and Geotechnical Engineering II courses.

Workload and Source Dimensions	Medians		Wilcoxon Signed-Rank tests	
	Env Lab: Comprehensive Report	Geotechnical Engr II: Closed-Ended Assessment	z	p
Mental	70.0	80.0	-1.063	0.288
Physical	10.0	10.0	-1.131	0.258
Temporal	15.0	10.0	-1.194	0.233
Effort	70.0	65.0	-2.220	0.026*
Frustration	25.0	5.0	-1.472	0.141
Performance	80.0	15.0	-0.272	0.785
Cognitive Workload (Raw TLX)	53.0	41.0	-2.217	0.027*

Focus Group Themes

Across focus groups, participants agreed that the transition was difficult, especially at the beginning. Students faced challenges making the transition, related to technology, scheduling, work load, etc. Student sentiment was mixed, with most students reporting a negative experience with online learning but a couple of students emphasizing positives.

Overall Cognitive Load due to Modality Change

The middle years participants agreed that there was an unpreparedness of the faculty and that the general asynchronous format of classes was not effective. Both factors made it hard for students to keep up with the work. All sophomore and junior participants agreed that keeping a schedule and staying ahead of work was the best advice they could give to students to deal with unforeseen/bad circumstances. Two participants in the middle-years focus group stated that a big challenge related to the shift was lack of structure away from campus. A junior noted that professors held classes in different styles and he had to adjust to each. The seniors agreed that it was an adjustment to shift from relying on professors to learning on their own. As seniors, all of the participants were engaged in courses that required collaboration for assignments. Similar to survey responses, seniors focused on challenges related to coordination/communication rather than greater cognitive load.

Lower Performance Reported by Senior Students

In terms of performance, none of the senior participants felt that their learning improved with online courses, even if their grades did not suffer. Participants noted there was a learning

curve in terms of what professors expected out of assignments (e.g., more multiple- choice questions) and a lack of one-on-one time with professors or quality feedback on assignments. One student said that once he adjusted to new question formats, he felt his abilities were about the same as before. Although professors tried to make sure students' grades did not suffer, he felt that he did not understand the material as well and had more trouble gauging his performance. The evening senior did not feel as challenged to study for open-notes exams; she may have learned more deeply with traditional testing.

Experiences with Different Types of Assessments

For the juniors and seniors, labs and projects (more common during those class years) were the focus of discussion, particularly related to challenges. The virtual labs were a lot different than at school, and many students found it difficult to grasp the concepts without the hands-on portion. Even when a video demonstration was provided, it was not always effective. In some senior labs, professors sent students data and expected them to figure out the calculations and interpretations without having seen/experienced the experiment. One civil lab was extra challenging because the professor was new and did not have the lab solutions done. Civil students felt that they did not learn much in that lab. These experiences may be reflected in the higher effort and overall load reported on the TLX for the environmental lab.

The seniors, in particular, spent a lot of time describing unique challenges that they faced with projects and labs. For capstone projects, many civil students did not have needed software at home. Although capstone faculty tried to keep the same expectations for projects, it was very different to work together from home and complete the same deliverables. The senior evening student was already working on a capstone project in a small class with only two teams, so she had a different experience. Her capstone team was already using technology to connect, so they just added videoconferencing to further facilitate collaboration. Seniors did not express strong negative feelings about tests.

Non-Cognitive Challenges with Online Coursework

Interpersonal and communications challenges were important factors in students' experiences with the switch to online learning. All underclassmen said that their interactions with their classmates changed after the shift to online learning. The sophomore and juniors observed that their peer interaction became more limited in both length of time and amount of different people. The relationships became more transactional, particularly with respect to project work and problem sets. A junior shared that in his projects, instead of all his classmates working together to do the project, they would just divide up the work amongst themselves. Unlike the underclassmen, the civil engineering seniors did not feel that relationships among classmates changed. Two of the participants noted how close and collaborative their class already was and that everyone continued to help each other online, although they admitted that it was not the same experience as being in person. The third civil senior had a different perspective, noting that if they were no longer having class sessions together, he felt that there would be little communication amongst classmates. Students across class years were missing the "socializing" aspects of on-campus life.

Conclusions

We are engaged in a longitudinal study to understand the impacts of pandemic-induced changes in course modality on cognitive load and self-directed learning readiness among engineering students. The purpose of this study was to triangulate our earlier finding that sources of cognitive load may have varied across students from different academic years during the Spring 2020 shift to emergency online instruction. Through analysis of workload data collected for closed-ended and open-ended assessments administered in courses of varying academic levels, as well as thematic analysis of open-ended student feedback and focus group transcripts, we make the following preliminary conclusions:

1. Sophomores and juniors experienced higher and/or more varied sources of cognitive workload related to closed-ended assessments, as evidenced by quantitative TLX ratings and open-ended survey responses.
2. Open-ended assessments elicited higher cognitive workload among both sophomores and seniors, based on quantitative TLX ratings and focus group analysis.
3. Qualitative data analysis supported that the shift to online learning elicited less cognitive workload changes for seniors, as compared to sophomores and juniors.

Limited samples size is a limitation of our study. Participation in target courses (Table 1) with closed-ended assessments was reasonable (46% to 79%) which lends credibility to our finding of higher load among middle-years students during those assessments. Our comparison of assessment types within academic classes is not as strong, since only seven sophomores and seven seniors completed TLX surveys for closed- and open-ended assessments. Also, our findings may not be generalizable to groups beyond our institution.

Ultimately, we have now found through a variety of data sources and analysis approaches that emergency online instruction caused varying types and magnitudes of cognitive load among students from different academic years. We are continuing to explore how increased cognitive load, especially among middle-years students, may have impacted their development and performance during the Spring 2020 semester and beyond.

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