Continuity of Instruction, Cognitive Load, and the Middle Years Slump

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Introduction

Similar to other institutions of higher education, The Citadel 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, including civil/construction, mechanical, and electrical/computer engineering, 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. In this paper, we explore the potential impacts of this disruption on perceived workload, which is considered a surrogate for cognitive load.

We hypothesize that students may have experienced more and different sources of cognitive load between face-to-face and emergency online modalities. We further propose that sources of intrinsic and extraneous load, and the remaining capacity for knowledge assimilation, may differ between academic classes. At The Citadel, and many other institutions, the types and difficulty of engineering courses differ by academic year. Perhaps differences in cognitive load existed before the pandemic? Or perhaps different engineering courses were better suited for an emergency online modality?

Cognitive Load Theory

Cognitive Load Theory (CLT) characterizes learning as assimilation of knowledge into one's long-term memory. However, it is our short-term (working) memory that first processes information. If the cognitive load (or mental effort) associated with a task exceeds short-term processing capacity, then learning cannot occur [1, 2]. Three sources of cognitive load can impact learners [1-4]. Intrinsic cognitive load is the effort required to learn a specific topic. For example, the mental effort required to learn in an introductory engineering course may be lower than that required to learn in an engineering science or design-based course. Extraneous cognitive load is experienced based on inappropriate methods or excess information that make learning unnecessarily difficulty. Indeed, some students may have perceived that the sudden online modality made learning engineering more difficult than the traditional face-to-face modality due to new distractions at home or the digital presentation of information. Finally, germane cognitive load is associated with permanently assimilating information into long-term memory. Engineering curricula are interconnected networks of classes that build on prior prerequisites. It is essential that students have sufficient capacity to accommodate germane load so that they can carry knowledge and skills forward to future engineering classes.

Engineering Coursework by Academic Class

Mechanical engineering majors across class years were enrolled in ten required engineering courses and two engineering electives during the spring semester in which the course delivery transition took place (Table 1). Freshmen were only taking one introductory MATLAB class. Sophomores were enrolled in foundational engineering-related courses that are not specific to mechanical engineering. Juniors were in the midst of foundational mechanical engineering coursework, including thermodynamics, fluid mechanics, machine design, and numerical methods. Seniors in the spring are only required to take one class, Capstone Design II. However, they are also enrolled in two MECH-specific electives of their choosing, often related to focus areas like manufacturing, mechatronics, advanced materials, or aerospace.

Table 1. Typical engineering coursework for mechanical engineers.

Freshmen	Sophomore	Junior	Senior
Computer Apps	Circuits	Thermofluids II	Capstone Design II
	Dynamics	Machine Design	2 MECH electives
	Mechanics of Materials	Modeling/Analysis II	
		Computational Methods	
		System Design	

The quantity and types of engineering courses that civil and construction students were taking during the rapid transition to emergency online learning varied by academic class (Table 2). Freshmen were engaged in only two introductory engineering classes. Sophomores were engaged in foundational civil engineering courses and a related lab. Junior civil engineering students were engaged in a variety of courses focused on the civil engineering sub-disciplines, including Highway Engineering which typically has one of the most challenging design projects outside of Capstone Design. Senior civil engineering students were engaged in three design-based classes and a related lab. Junior and senior construction engineering students were engaging in four major-focused courses.

Table 2. Typical engineering coursework for civil and construction engineers.

Freshmen	Sophomore	Junior[1]	Senior
Engr Drawing	Geospatial Representation	Highway Engr	Geotech II Engr
Computer Apps	Geomatics Lab	Asphalt/Concrete Lab	Geotech Lab
	Statics	Intro to Env Engr	Steel Design
		Structural Analysis	Capstone Design II
		Hydraulics, Hydrology	

[1]Construction Engr students typically take Resource Estimating, Construction Engr Equipment, Structural Analysis, and Soils/Foundations in the junior year; [2]Construction Engr students typically take Capstone II, Practicum, Mechanical/Electrical Systems, and Facilitates Operation/Maintenance in the senior year.

Study Overview

We conducted a study to explore perceived workload, as a surrogate for cognitive load, and student preparation for online self-directed learning among engineering students at The Citadel at key points during the pandemic. Students reflected on their face-to-face and emergency online engineering courses using the NASA Task Load Index (TLX), a rigorously-developed instrument for measuring perceived workload. The following questions were addressed:

1. How did perceived workload and sources of workload associated with face-to-face engineering courses vary across academic classes prior to the pandemic?
2. To what extent did the mid-semester shift to an online modality impact perceived workload and sources of workload for each academic class?
3. Which academic classes, if any, may have been disproportionately impacted by the mid-semester shift in modality?

Our study may yield important insights for future online engineering instruction, both planned and unplanned. Ensuring manageable cognitive load is essential for supporting deep, long-lasting learning and transference of skills and knowledge into professional practice.

Methods

Survey Administration

The NASA TLX was used to capture changes in workload across engineering course modalities. The TLX is a rigorously-developed instrument shown to yield valid results for a variety of student and professional populations [5, 6]. Workload is assessed across six sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration [6, 7]. Traditionally, participants complete pair-wise comparisons to rate the importance of sub-scales for a specified task; however, several authors have demonstrated that omitting these comparisons yields comparable results [5]. As such, we calculated a Raw TLX score for each participant as the average of scores across all six sub-scales and also examined each sub-scale separately.

During the Spring 2020 semester, participants reflected on the workload associated with their engineering courses before and after the rapid shift to online learning. Prior to their mid-March Spring Break, students engaged in face-to-face engineering courses. Continuity of instruction began after break, which required all courses to switch to an online modality and students to remain at home or leave campus. Within the first week of continuity of instruction, participants completed the NASA TLX based on experiences in their face-to-face engineering courses. After six weeks, students completed the NASA TLX based on their experiences in their emergency online engineering courses.

Participants

Overall, 215 participants completed the TLX for both face-to-face and emergency online courses. Of these participants, 94.4% were male and 78.6% were white, which is representative of the engineering student population at The Citadel. By academic class, 12.1%, 22.3%, 29.3%, and 36.3% of participants were freshmen, sophomores, juniors, and seniors, respectively. By major, 50.7%, 47.9%, and 1.4% of participants were mechanical, civil/construction, and electrical engineers, respectively. Also, 81.4% were cadets engaged in a residential military college experience, 5.1% were active duty or veteran students, and 13.5% were completing a college transfer program.

Data Analysis

Participant responses to the TLX survey included ratings [0-100] for each sub-scale: mental, physical, temporal, effort, frustration, and performance. For each participant and each survey administration (face-to-face and emergency online), a raw TLX score was calculated as the average across all subscales. IBM SPSS 27 was used to conduct all subsequent statistical tests.

Non-parametric tests were used to explore differences in workload and related dimensions, since much of the data was non-normal with unequal error variances. Based on the Shapiro-Wilks test, several TLX sub-scales by academic class yielded non-normal data ($p \leq 0.05$). Also, Levene's Test supported that several TLX sub-scales by academic class exhibited unequal error variances ($p < 0.05$).

TLX scores were studied for the pre-survey (prior to emergency online instruction) to infer whether differences in workload existed across academic classes prior to the pandemic. The Kruskal-Wallis *H* test, a rank-based non-parametric test, was used to identify any differences in sub-scale and raw TLX scores from the face-to-face survey administration. Distribution of TLX scores were similar for all academic classes, as assessed by visual inspection of boxplots. As such, we used the Kruskal-Wallis *H* test to make inferences about differences in medians by academic class [8].

For each academic class, we used the Wilcoxon Signed-Rank, a rank-based non-parametric test, test to identify differences in face-to-face and emergency online raw TLX and sub-scale scores. For all TLX data, difference scores were approximately symmetrically distributed, as assessed by a histogram with superimposed normal curve [9]. In addition to significance levels, we also evaluated effect sizes, calculated as: $z/N^{0.5}$, where N is the total sample size (twice the number of matched pairs) [10]. Since we conducted separate Wilcoxon Signed-Rank tests for each academic class, our analysis does not allow for comparison of the magnitude of changes in workload across modalities between academic classes. SPSS does not provide a non-parametric alternative to a 2x2 mixed Analysis of Variance (ANOVA).

Results

Baseline Workload by Academic Class

Prior to the mid-semester shift to an online modality, freshmen reported lower perceptions of workload for nearly all sources of demand than other academic classes (Table 3). Indeed, freshmen reported lower mental and effort demand, as well as a lower Raw TLX than sophomores. Furthermore, freshmen reported lower temporal, effort, and frustration demand, as well as a lower Raw TLX than juniors. Finally, freshmen reported lower mental demand than seniors.

In contrast, there were almost no differences in workload or sources of demand between non-first-year students prior to the mid-semester shift to an online modality (Table 3). The only exception was lower frustration for seniors, as compared to juniors. Raw TLX, and component mental, physical, temporal, effort, and performance demands, were thus similar for sophomores, juniors, and seniors.

Table 3. Differences in workload measures between academic classes prior to the mid-semester shift to an online modality.

Workload	Academic Class				Kruskal Wallis Test	
Measure	Freshmen	Sophomore	Junior	Senior	$\chi^2(3)$	p
Mental[1]	67.5	80.0	75.0	75.0	18.49	< 0.001**
Physical	20.0	20.0	15.0	17.5	0.909	0.823
Temporal[2]	50.0	65.0	70.0	65.0	12.46	0.006**
Effort[3]	67.5	80.0	80.0	75.0	15.74	0.001**
Frustration[4]	25.0	42.5	60.0	50.0	20.94	< 0.001***
Performance	40.0	50.0	55.0	40.0	1.93	0.587
Raw TLX[5]	50.0	60.8	60.8	55.0	16.09	0.001***

[1]Freshmen < Sophomore (***), Senior (**); [2]Freshmen < Junior (*); [3]Freshmen < Sophomore (**), Junior(*); [4]Freshmen < Junior (***); Senior < Junior (**); [5]Freshmen < Sophomore (*), Junior (**)

Impact of Modality on Workload Measures

Differences in workload measures reported at midterm for face-to-face engineering classes and at the end of the semester for online engineering classes were compared using Wilcoxon Signed Rank Tests for each academic class.

Raw TLX

All academic classes experienced increases in Raw TLX scores after the mid-semester shift in modality (Table 4). Of the 26 freshmen, 21 reported a higher workload during the online portion of their engineering courses, while 5 reported a lower workload. With a large effect size, there was a significant increase in workload for freshmen between the face-to-face (Med = 50.0) and online (Med = 57.5) modalities ($p < 0.001$). Of the 48 sophomores, 37 reported a higher workload during the online portion of their engineering courses, while 9 reported a lower workload. With a large effect size, there was a significant increase in workload for sophomores between the face-to-face (Med = 60.8) and online (Med = 68.3) modalities ($p < 0.001$).

Of the 63 juniors, 45 reported a higher workload during the online portion of their engineering courses, while 17 reported a lower workload (Table 4). With a large effect size, there was a significant increase in workload for juniors between face-to-face (Med = 60.8) and online (Med = 69.2) modalities ($p < 0.001$). Of the 78 seniors, 43 reported a higher workload during the online modality, while 32 reported a lower workload. With a small effect size, there was a significant increase in workload for seniors between face-to-face (Med = 55.0) and online (Med = 60.0) modalities ($p = 0.017$).

Table 4. Impact of mid-semester modality shift on Raw TLX score for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	*z*	*p*	*r*
Freshmen (n = 26)	50.0	57.5	21	5	3.57	< 0.001	0.70
Sophomores (n = 48)	60.8	68.3	37	9	4.30	< 0.001	0.62
Juniors (n = 63)	60.8	69.2	45	17	4.12	< 0.001	0.52
Seniors (n = 78)	55.0	60.0	43	32	2.39	0.017	0.27

[1]Number of students who reported an increase (+) or decrease (-) in mental demand between midterm and final NASA TLX administrations.

Mental Demand

Freshmen and juniors experienced increases in perceived mental demand after the mid-semester shift in modality (Table 5). Of the 26 freshmen, 18 reported a higher mental demand during the online portion of their engineering courses, while 6 reported a lower mental demand. With a medium effect size, there was a significant increase in mental demand for freshmen between face-to-face (Med = 67.5) and online (Med = 70.0) modalities ($p = 0.02$). Of the 63 juniors, 38 reported a higher mental demand during the online portion of their engineering courses, while 12 reported a lower mental demand. With a large effect size, there was a significant increase in mental workload for juniors between the face-to-face (Med = 75.0) and online (Med = 80.0) portions of their engineering courses ($p < 0.001$). No significant change in mental demand was reported for sophomores and seniors.

Table 5. Impact of mid-semester modality shift on mental demand for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	z	*p*	*r*
Freshmen (*n* = 26)	67.5	70.0	18	6	2.33	0.020	0.46
Sophomore (*n* = 48)	80.0	82.5	25	12	1.79	0.073	0.26
Junior (*n* = 63)	75.0	80.0	38	12	3.93	< 0.001	0.50
Senior (*n* = 78)	75.0	80.0	34	30	0.60	0.552	0.07

[1]Number of students who reported an increase (+) or decrease (-) in mental demand between midterm and final NASA TLX administrations

Physical Demand

No class year reported a statistically significant difference in physical demand between face-to-face and online courses (Table 6). In fact, sophomore and junior students perceived no change in physical demand, while freshmen perceived a small decrease and seniors experienced a slight increase. Of note, physical demand was the lowest rated sub-scale across all class years (see Table 3), indicating physical aspects of learning engineering topics contributed least to students' perceived cognitive workload.

Table 6. Impact of mid-semester modality shift on physical demand for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	z	*p*	*r*
Freshmen (*n* = 26)	20.0	10.0	9	10	-0.10	0.919	0.01
Sophomore (*n* = 48)	20.0	20.0	22	16	0.96	0.337	0.14
Junior (*n* = 63)	15.0	15.0	26	27	0.27	0.789	0.03
Senior (*n* = 78)	17.5	20.0	32	36	-0.69	0.489	0.08

[1]Number of students who reported an increase (+) or decrease (-) in physical demand between midterm and final NASA TLX administrations.

Temporal Demand

Sophomores and juniors experienced increases in perceived temporal demand after the mid-semester shift in modality (Table 7). Of the 48 sophomores, 34 reported a higher temporal demand during the online portion of their engineering courses, while 12 reported lower temporal demand. With a medium effect size, there was a significant increase in temporal demand for sophomores between the face-to-face (Med = 65.0) and online (Med = 80.0) modalities (p = 0.001). Of the 63 juniors, 18 reported a higher mental workload during the online portion of their engineering courses, while 9 reported a lower temporal demand. With a medium effect size, there was a significant increase in temporal workload for juniors between the face-to-face (Med = 70.0) and online (Med = 80.0) modalities (p = 0.002). No significant change in temporal demand was reported for freshmen and seniors.

Table 7. Impact of mid-semester modality shift on temporal demand for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	z	*p*	*r*
Freshmen (*n* = 26)	50.0	60.0	15	9	1.46	0.144	0.29
Sophomores (*n* = 48)	65.0	80.0	34	12	3.38	0.001	0.49
Juniors (*n* = 63)	70.0	80.0	18	9	3.14	0.002	0.40
Seniors (*n* = 78)	65.	70.0	42	30	1.01	0.314	0.11

[1]Number of students who reported an increase (+) or decrease (-) in temporal demand between midterm and final NASA TLX administrations

<u>Effort Demand</u>

Sophomores and juniors experienced increases in perceived effort demand after the mid-semester shift in modality (Table 8). Of the 48 sophomores, 24 reported a higher effort during the online portion of their engineering courses, while 13 reported a lower effort. With a medium effect size, there was a significant increase in effort for sophomores between the face-to-face (Med = 80.0) and online (Med = 90.0) modalities (p = 0.013). Of the 63 juniors, 35 reported a higher perceived effort during the online portion of their engineering courses, while 17 reported a lower effort. With a medium effect size, there was a significant increase in effort demand for juniors between the face-to-face (Med = 80.0) and online (Med = 90.0) modalities (p = 0.014). No significant change in effort was reported for freshmen and seniors.

Table 8. Impact of mid-semester modality shift on effort for each academic class.

	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	*z*	*p*	*r*
Freshmen (*n* = 26)	67.5	77.5	15	8	1.90	0.057	0.37
Sophomores (*n* = 48)	80.0	90.0	24	13	2.49	0.013	0.36
Juniors (*n* = 63)	80.0	90.0	35	17	2.46	0.014	0.31
Seniors (*n* = 78)	75.0	80.0	44	29	2.26	0.024	0.26

[1]Number of students who reported an increase (+) or decrease (-) in effort between midterm and final NASA TLX administrations.

<u>Frustration Demand</u>

All academic classes experienced increases in perceived frustration after the mid-semester shift in modality (Table 9). Of the 26 freshmen, 20 reported higher frustration during the online portion of their engineering courses, while 3 reported lower frustration. With a large effect size, there was a significant increase in frustration for freshmen between the face-to-face (Med = 25.0) and online (Med = 57.5) modalities (p = 0.001).

Of the 48 sophomores, 41 reported higher frustration during the online portion of their engineering courses, while 6 reported lower frustration (Table 9). With a large effect size, there was a significant increase in frustration for sophomores between the face-to-face (Med = 42.5) and online (Med = 85.0) modalities (p < 0.001).

Of the 63 juniors, 50 reported higher frustration during the online portion of their engineering courses, while 9 reported lower frustration (Table 9). With a large effect size, there was a significant increase in frustration for juniors between the face-to-face (Med = 60.0) and online (Med = 90.0) modalities (p < 0.001).

Of the 78 seniors, 55 reported higher frustration during the online portion of their engineering courses, while 19 reported lower frustration (Table 9). There was a significant increase (with a large effect size) in frustration for seniors between the face-to-face (Med = 50.0) and online (Medi = 70.0) portions of their engineering courses (p < 0.001, r = 0.61).

Table 9. Impact of mid-semester modality shift on frustration demand for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	*z*	*p*	*r*
Freshmen (n = 26)	25.0	57.5	20	3	3.20	0.001	0.63
Sophomores (n = 48)	42.5	85.0	41	6	5.16	< 0.001	0.74
Juniors (n = 63)	60.0	90.0	50	9	5.45	< 0.001	0.69
Seniors (n = 78)	50.0	70.0	55	19	4.54	< 0.001	0.51

[1]Number of students who reported an increase (+) or decrease (-) in frustration between midterm and final NASA TLX administrations.

Performance Demand

No academic class experienced significant changes in expected performance after the mid-semester shift in modality (Table 10). For freshmen, the effect size was medium despite a significance level above 0.05, which could indicate lack of statistical power. For other academic classes, all effect sizes were small.

Table 10. Impact of mid-semester modality shift on performance demand for each academic class.

Academic Class	Medians		Pair Changes[1]		Wilcoxon Signed Rank Test		
	Mid/F2F	Final/Online	+	-	*z*	*p*	*r*
Freshmen (n = 26)	40.0	67.5	11	7	1.68	0.093	0.33
Sophomore (n = 48)	50.0	67.5	25	19	1.03	0.301	0.15
Junior (n = 63)	55.0	60.0	29	28	0.63	0.532	0.08
Senior (n = 78)	40.0	50.0	37	38	0.40	0.691	0.05

Discussion

How did perceived workload and sources of workload associated with face-to-face engineering courses vary across academic classes prior to the pandemic?

Prior to the pandemic, workload experienced in engineering courses was lowest for freshmen, with few differences among upper-level academic classes (Table 3). Freshmen were only enrolled in up to two introductory-level engineering courses, as compared to multiple engineering courses for upper-level academic classes (Tables 1-2). Interestingly, perceived loads and sources were similar for sophomore, juniors, and seniors, despite differences in coursework, such as fewer engineering courses for sophomores and more design-work for seniors. The only exception is that even before the pandemic, juniors were experiencing more frustration than seniors, perhaps due to their high number of engineering courses and first real exposure to design work. Nevertheless, we conclude that with the exception of freshmen, perceived cognitive load at the midterm of face-to-face engineering classes was very similar across academic classes prior to the pandemic despite differences in type, number, and rigor of engineering courses. Thus, subsequent changes in cognitive workload at the end of the semester (discussed below) were likely caused by the sudden shift to emergency online instruction rather than attributed to difficulty of the subject matter.

To what extent did the mid-semester shift to an online modality impact perceived workload and sources of workload for each academic class?

Freshmen and seniors experienced lower overall workload compared to sophomore and junior students and reported increased workload across the fewest number of sub-scales between face-to-face and emergency online instruction (Table 11). Both groups reported increased frustration with a high effect size. Freshmen reported increased mental demand (medium effect size), while seniors reported increased effort (small effect size). Perhaps it is not surprising that only two workload sub-scales were impacted for freshmen, given their relatively lower perceived workload prior to the pandemic. Seniors, however, were engaged in demanding design-based courses. The shift to an emergency online modality required more effort (and perhaps higher subsequent frustration), but not increased mental or temporal demand. Perhaps seniors, as seasoned engineering students, were best equipped to handle the rapid shift in modality.

Sophomores and juniors experienced higher total workload and increased demand across multiple sub-scales (Table 11). Both groups experienced increased temporal demand and effort (medium effect size), as well as increased frustration (high effect size). Even still, juniors reported higher mental demand (large effect size). Indeed, engineering students in “the middle years” are participating in engineering science courses, beginning major-intensive courses, and often tackling intensive labs and new design challenges. Engineering students often report that the “middle years” include more difficult and time-consuming courses and are a high-stress period of time. Those courses also tend to include more “hands-on” learning and group collaboration, including tasks that may not have translated as well into the online environment, particularly for novices. Characteristics of the learning task and environment are a significant contributor to cognitive load and so perhaps it is not surprising that sophomores and juniors experienced increased demand across multiple sub-scales.

Table 11. Summary of changes in perceived workload and sources of demand experienced within academic classes as a result of the shift from face-to-face to emergency online instruction.

	Freshmen	Sophomores	Juniors	Seniors
Mental	*		***	
Physical				
Temporal		***	**	
Effort		*	*	*
Frustration	***	***	***	***
Performance				
Raw TLX	***	***	***	*

Green = small effect size; Yellow = medium effect size; Orange = large effect size

Which academic classes, if any, may have been disproportionately impacted by the mid-semester shift in modality?

Based on our analysis, we believe that middle-years students, especially juniors, may have been disproportionately impacted by the mid-semester shift in modality. Juniors reported higher demand across four of the six sub-scales, more than any other academic class. Sophomores reported higher demand across three of the six sub-scales, which was second only to juniors. Of note, juniors were the only group to report increased mental demand (with high effect size) between modalities. Indeed, juniors were engaged in the most (and perhaps most rigorous) engineering courses. Both sophomores and juniors reported increased temporal, effort, and frustration demands, which ultimately led to increased total workloads. We believe that freshmen reported increased demand across only two sub-scales due to engagement in only two introductory engineering courses which already rely heavily on computer work due to learning new analysis and drafting software. Seniors, engaged in a similar number and type of engineering courses as sophomores and juniors experienced increased demand across only two sub-scales, which we believe supports that they were better positioned to accommodate the rapid shift in modality.

Conclusions

We conducted a study to explore the impacts of a mid-semester shift in engineering course modality caused by the COVID-19 pandemic on students' perceived workload and sources of demand within academic classes. Workload, a surrogate for cognitive load, was measured using the NASA TLX, which requires students to score their workload across mental, physical, temporal, effort, frustration, and performance sub-scales. The Raw TLX score, a measure of total workload, was calculated as the average across sub-scales. The following conclusions were made based on the results.

1. At midterms (prior to the pandemic), total workload was similar for sophomores, juniors, and seniors, despite being enrolled in different types and numbers of engineering courses. Workload was already lower for freshmen, as compared to upper-level classes, prior to the pandemic.
2. All academic classes reported higher total workload and frustration demand between face-to-face and emergency online instruction. No academic class reported a change in physical (as expected) nor performance demand.
3. Freshmen, who reported lower workload prior to the pandemic, experienced increased workload across only two sub-scales – frustration and mental demand.
4. Sophomores and juniors may have been disproportionally impacted by the shift in modality, as they reported increased workload across three and four dimensions, respectively.
5. Seniors, despite engaging in a similar number and type of engineering courses as sophomores and juniors, only reported increased workload across two sub-scales. We believe that seniors' extensive prior experience as engineering students best equipped them to handle the change in modality.

This study relates to a larger project that is currently underway to explore the interactions between cognitive load experienced in engineering courses during the pandemic and self-directed learning readiness. Our work will provide important insights for using online education to provide continuity of engineering instruction during future crises, whether biological, environmental, or other. While the COVID-19 pandemic is the first disruption of its kind in the United States during the 21st Century, extreme weather events like flooding, tornados, and blizzards are now regular disruptors across the US. Understanding students' experiences and coping with this current shift to online learning could inform strategies employed by higher education institutions to better prepare for future disruptions. Furthermore, we expect that online engineering instruction may remain prevalent after the pandemic. As such, we seek to provide insights for both planned and unplanned online engineering instruction.

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