Beyond Continuity of Instruction—Innovating a Geomatics Course Using Problem-based Learning and Open-source Software

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Beyond Continuity of Instruction: Innovating a Geomatics Course Using a Project-Based Approach and Open-Source Software

Abstract

Geomatics, with an emphasis on developing students' competencies in Geographic Information Systems, is a technology-intensive course. During the Spring 2020 semester, The Citadel shifted to online continuity of instruction after midterms due to the COVID-19 pandemic. The Geomatics instructor was faced with ensuring academic continuity and quality without remote student access to licensed GIS software. The instructor pivoted to use of QGIS, an open-source software, and a carefully-scaffolded project to equip students with essential GIS skills. Test 3 included two equally-weighted parts: (1) conceptual GIS questions and (2) a new open-ended project, which required students to use GIS to investigate a real-world scenario. Synchronous and asynchronous support was provided to afford students the flexibility needed to manage home commitments and technology challenges. Nevertheless, students' potential for increased (even unmanageable) cognitive load was high, due to the new modality, pedagogy and software.

We investigated the impacts of the post-pandemic Geomatics course on students' cognitive load and academic performance through the lens of Cognitive Load Theory, which asserts that cognitive overload can hinder learning. Based on students' NASA Task Load Index scores, Test 3 workload was on par with their face-to-face engineering courses and lower than their online engineering courses. We expect that the cognitive load associated with the project and new software was manageable and not a barrier to learning. Performance on the project was substantially higher than on the closed-ended Test 3 questions, which supports that the project-based approach was integral to helping students achieve GIS competencies. Final exam performance was lower than in previous years, which may suggest that the mid-semester modality shift impacted their ability to fully synthesize material from the semester. Future course offerings will use the project to provide students with authentic engagement with GIS and real-world topics, while QGIS will remain an option for remote instruction.

Introduction

At midterms of the Spring 2020 semester, all classes at The Citadel were rapidly transitioned to an emergency online modality due to the COVID-19 pandemic. Prior, all undergraduate engineering courses were administered via face-to-face instruction. Sophomore civil engineering students were enrolled in a Geomatics course, which is the second in a surveying sequence. The Geomatics instructor faced the challenge of developing students' Geographic Information Systems (GIS) competencies without remote access to licensed software. Ultimately, the instructor pivoted to a project-based pedagogy using QGIS (2020), an open-source software. We believe that the unfamiliar online modality, implementation of a pedagogy that required self-directed learning, and introduction of a new software mid-semester could have resulted in increased (even unmanageable) cognitive load for students.

Cognitive Load Theory (CLT) relates cognitive architecture to learning of complex tasks [1, 2].[2] [1]Cognitive load is the amount of mental effort exerted by the working memory to complete a task. The goal of learning is to consolidate information and move it from working to long-term memory for later recall (Figure 1). CLT asserts that working memory has limited capacity for processing new information, while long-term memory has virtually unlimited capacity for storing information [1, 3]. If the cognitive load associated with a task exceeds working memory capacity, then learning is hindered.

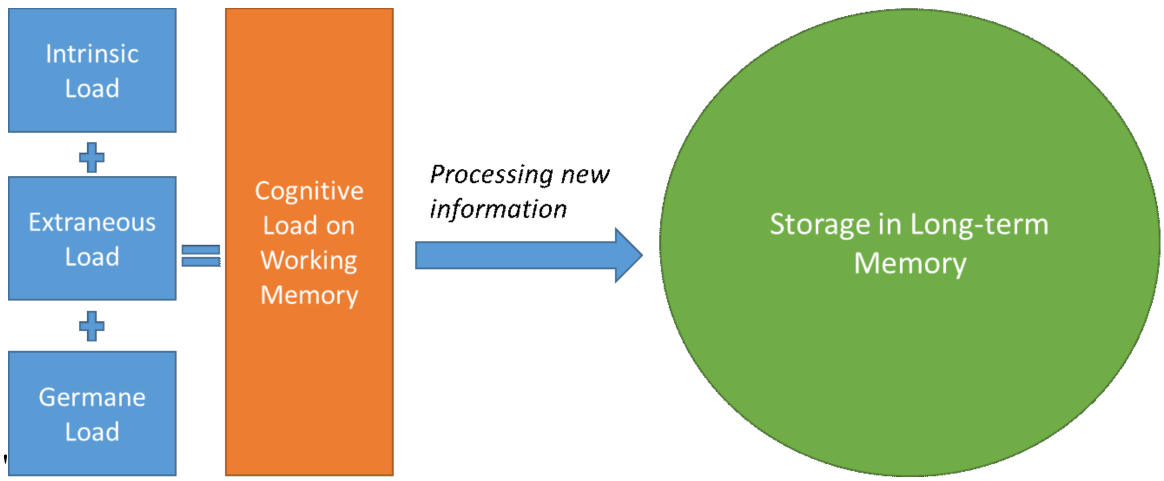

Figure 1. Relationship between sources of cognitive load and a learning process that consolidates new information for storage in long-term memory.

While total load determines the burden on working memory (Figure 1), load source is important. Intrinsic load is related to the difficulty or complexity of the subject matter and learner's prior knowledge. Extraneous load is influenced by design of instructional material and mode and is not necessary for learning the subject. Germane load is caused by the actual learning process, such as interpreting or classifying [3, 4] Effective instructional design limits extraneous load and maximizes germane load associated with mental processes needed for learning [3]. Instructional design can target characteristics of the learning task, the learner, and the learning environment in order to help students manage the limited capacity of working memory [5]. Prior work demonstrated that learning modality does impact cognitive load [4, 6]. For example, Chen and Wu [7] showed higher load with voice-over lectures compared to lecture capture.

We examined students' experiences with the project-based pedagogy and open-source QGIS software through the lens of CLT. In the Geomatics course, students' QGIS project was a major component of their third regular-semester exam. Using the rigorously-developed NASA Task Load Index (TLX), students reflected on perceived workload (an indicator of cognitive load) experienced in their face-to-face engineering courses (through midterms), their emergency online engineering courses (midterms through finals), and their third exam. Based on our data, we explore the following questions: (1) How did cognitive load related to the project compare to students' face-to-face and online classes? (2) How did test/exam performance compare to previous years? We seek to provide insights for improving project delivery and use of QGIS for remote instruction based on available data and instructor reflection.

Course Context

The shift to emergency online learning aligned with a natural break in Geomatics content, which presented an opportunity for innovation (Figure 2). GIS data acquisition, mapping, and analysis were previously practiced through homework using licensed software and assessed via a closed-ended test. In Spring 2020, the instructor implemented a project-based pedagogy with open-source software to complement remote learning and prevent students from becoming passive observers watching demonstrations of inaccessible software. Test 3 included two equally-weighted parts: (1) conceptual GIS questions and (2) a new open-ended project, which required students to use QGIS to investigate a real-world scenario (Table 1).

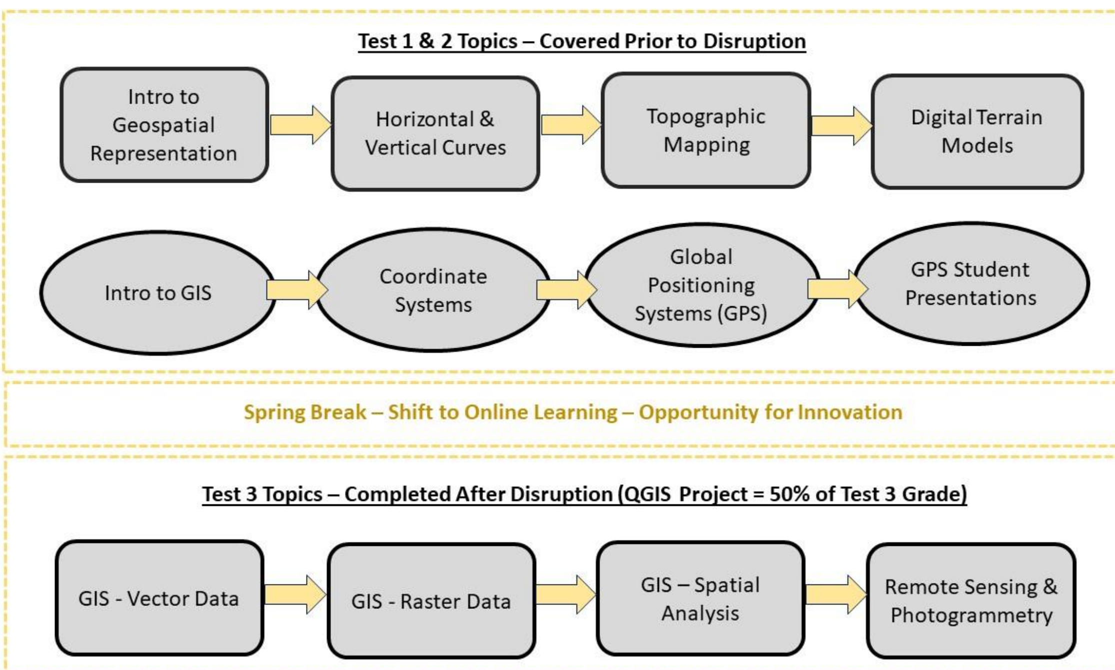

Figure 2. Alignment of Geomatics course topics and summative assessments with the mid-semester shift to online learning caused by COVID-19 in the Spring 2020 semester.

Table 1. Project topics selected by students to analyze using open-source QGIS software.

Crime and law enforcement	Arrests, electronic citations, and field contact (Charleston, SC) Drug crimes compared to poverty (Boston, MA) Gun deaths, unemployment, education, and income (IL)
Wildlife and Species	Shellfish classification, pollution, and population (Charleston, SC) Deer harvest, hog harvest, and population (SC) Wildlife Management Area (WMA) analysis (AR)
Location Suitability	Ideal locations for honeybees (VA) Ideal locations for new apartments (Charleston, SC) Ideal location for new restaurants (Charleston, SC
Land Cover and Environmental	Average temperature compared to land cover in 2010 and 2020 (Taiwan) Chesapeake Bay water quality compared to population (MD, VA) Change detection of wetlands, forests, shoreline etc (Charleston, SC)
Transportation	Road report card grade and vehicle crashes by population (US) Vessel traffic and artificial reef location (VA, DE, NJ, NY) Traffic citations and vehicle crash trends (Charleston, SC
Health	COVID-19 cases and deaths by income (CO) Obesity, income, and Retail Food Environment Index (SC) Proximity to hospitals in rural areas (AL)
Education	School district rating, high school graduation rates, and income (SC)

The instructor was simultaneously learning/teaching with QGIS and striving to meet students' evolving needs, which required on-going project adaptation. Three types of flexible support helped students achieve outcomes and manage load. First, students received instructor feedback on a topic proposal to ensure manageable project scope. Second, the instructor developed 18 QGIS videos and a reference document outlining 38 topics with timestamped locations. The videos and comprehensive documentation provided the instructor with a feasible way to remotely field questions and allowed flexibility for self-directed learning. Third, the instructor provided video conferencing sessions and dedicated six 50-minute synchronous class sessions to real-time troubleshooting. Additionally, there were several advantages of QGIS that may have limited extraneous load (Table 2).

The instructor's pedagogical and software choices allowed for successful coverage of topics and engaged students in self-directed analysis of salient social/political/environmental issues. Asynchronous and synchronous instruction allowed students flexibility to fulfill family commitments, manage differing time zones, and recover from connectivity mishaps, while still receiving scaffolded project support. Overall, 41 of 44 students demonstrated acceptable GIS mastery. Remaining students, while initially engaged, dropped off due to challenges involving family and technology.

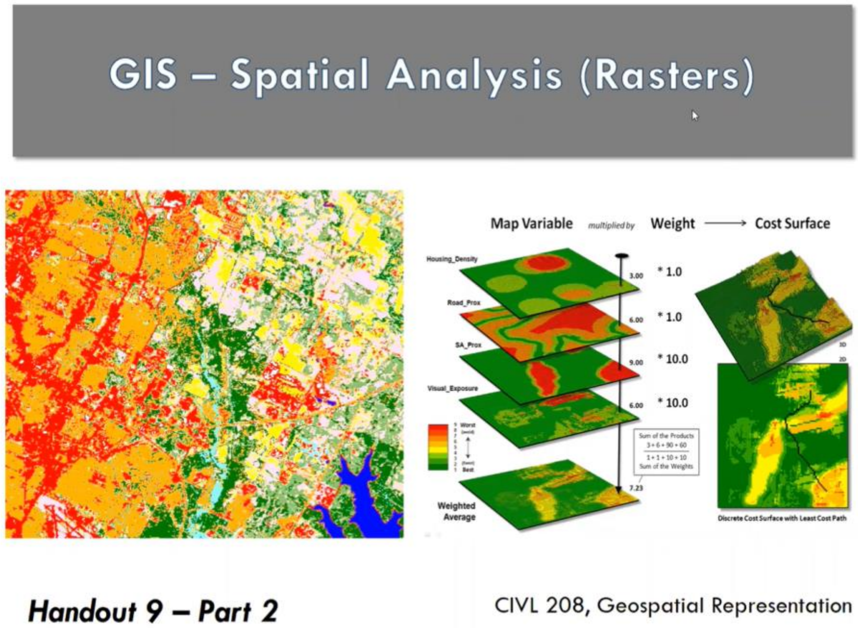

Figure 2. Sample video resource to provide students with asynchronous QGIS support.

Table 2. Advantages and challenges of QGIS software identified for novice users during a Geomatics course transitioning to online instruction.

Advantages	Challenges
Free software and available to Windows and Mac operating systems	Limited time for students to familiarize themselves with software
File management system was intuitive and easy to use	Analysis errors due to students' lack of knowledge on proper analysis settings
Software graphical user interface (GUI) was simple and appealing	Coordinate system issues - some analysis involving files with different coordinate systems produced errors
Many free online resources, videos and community threads for troubleshooting basic analysis processes	Some plug-ins did not have much documentation or instruction for use and hence produced undesirable results when run
Availability of open source plug-ins for a sizeable collection of analysis tools	Large scale analysis (e.g. statewide analysis) posed problematic with computing power and software robustness as possible causes of the software 'crashing' or 'freezing'

Methods

Students in two sections of Geomatics (*N* = 44) were invited to reflect on their workload at key times during continuity of instruction using the rigorously-developed, widely-administered

NASA TLX [8, 9]. The NASA TLX requires participants to rate workload (with a 0-100 score) associated with a particular task along six sub-scales: mental demand, physical demand, temporal demand, performance, effort, and frustration. Students completed the NASA TLX at the mid-term of the Spring 2020 semester based on their experiences in face-to-face engineering courses prior to the pandemic. During continuity of instruction, students again completed the NASA TLX based on their experiences with online Exam 3 of the Geomatics course, which included the QGIS project and traditional closed-ended questions. Finally, students completed the NASA TLX at the end of the Spring 2020 semester based on their experiences in emergency online engineering courses.

For each participant and each survey administration, we computed a Raw TLX score as the average of scores across all six sub-scales. Several studies have reported that the Raw TLX yields similar findings as the Weighted TLX score [10], which is computed based on participants' pair-wise comparisons of sub-scale importance for a specified task. Informed by these prior studies comparing Raw and Weighted scores, pair-wise comparisons were omitted from this study in order to manage the survey length and improve completion rates. Statistical analysis included using matched pairs *t*-tests to compare perceived workload associated with Exam 3 to each face-to-face and online engineering course workloads.

We compared student performance on tests and final exams during the Spring 2020 semester to previous Spring 2019 and Spring 2018 semesters to contextualize impacts of continuity of instruction. We used One-Way Analysis of Variances (ANOVA) to compare grades by year, with Tukey post-hoc tests when appropriate.

Results

Contextualizing Cognitive Load Associated with Test 3

We compared students' perceived workload associated with Test 3 (project + closed-ended questions) to that associated with each their face-to-face and emergency online engineering courses in the Spring 2020 semester. According to NASA TLX scores, overall workload and sources of demand were similar for face-to-face engineering courses and Test 3 (Figure 4A).

In contrast, overall workload and some sources of demand were lower for Test 3, as compared to emergency online engineering courses (Figure 4B). Overall workload was significantly lower for Test 3 (M_{test3} = 57.9), as compared to emergency online courses (M_{online} = 69.7) [$t(18) = -3.78$, $p = 0.001$]. Several sources of demand were also lower for Test 3, as compared to emergency online courses. Physical demand was significantly lower for Test 3 (M_{test3} = 24.2), as compared to emergency online courses (M_{online} = 34.7) [$t(18) = -2.13$, $p = 0.047$]. Temporal demand was significantly lower for Test 3 (M_{test3} = 57.9), as compared to emergency online courses (M_{online} =

73.7) [$t(18) = -2.17$, $p = 0.044$]. Effort was significantly lower for Test 3 ($M_{test3} = 76.8$), as compared to emergency online courses ($M_{online} = 88.2$) [$t(18) = -1.48$, $p = 0.026$]. Frustration was significantly lower for Test 3 ($M_{test3} = 63.2$), as compared to emergency online courses ($M_{online} = 83.7$) [$t(18) = -3.30$, $p = 0.022$].

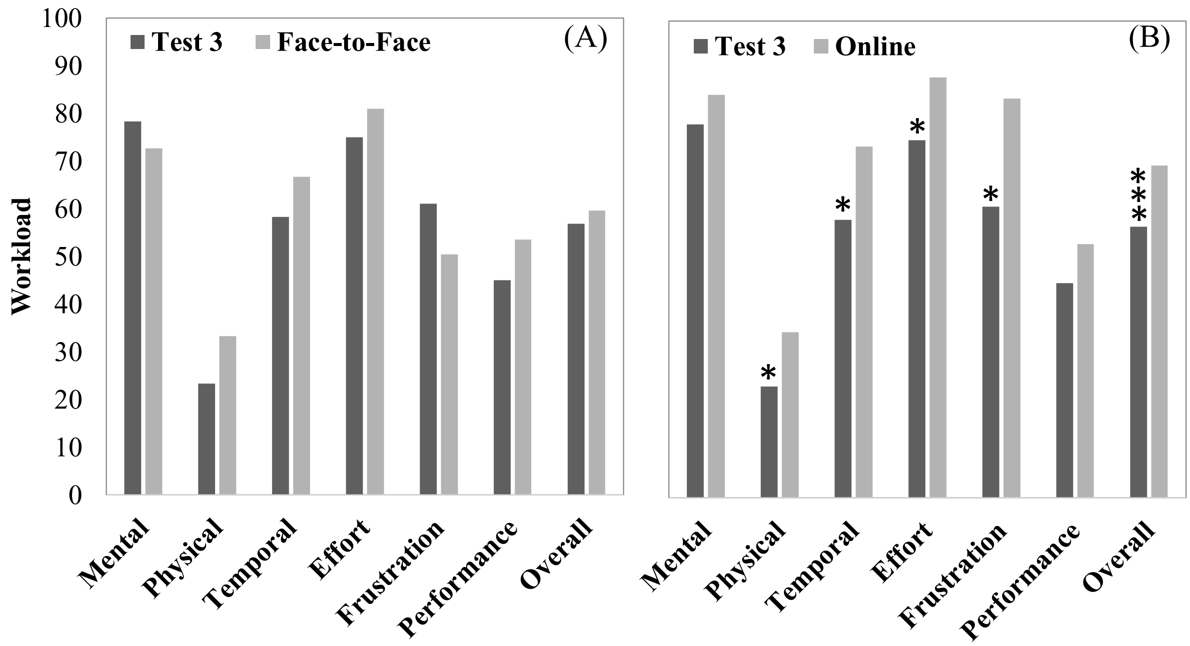

Figure 4. Workload reported using NASA TLX for Test 3 (closed-ended questions and QGIS project), as compared to (A) face-to-face engineering classes ($n = 19$) and (B) online engineering classes ($n = 24$) after COVID-19 disruption (*$p \leq 0.05$, ***$p \leq 0.001$).

Contextualizing Performance on Test 3

First, students performed better on the project-portion of Test 3 (average grade = 89.2 ± 9.1%) than they did on the closed-ended questions (average grade = 75.2 ± 13.1%).

We compared Spring 2020 student performance on the closed-ended portion of Test 3 to previous years to contextualize the impact of continuity of instruction on student performance (Figure 5). Indeed, grades on the closed-ended portion of Test 3 did vary by academic year (2018 – 2020) [$F(2, 126) = 7.99$, $p = 0.001$]. Tukey post hoc analysis showed that the average grade on Test 3 was lower in the 2020 semester (75.2 ± 13.1%), as compared to the 2019 semester (84.4 ± 9.14%) [$p \leq 0.002$].

We also compared student performance on other semester tests and the final exam during Spring 2020 to previous years (Figure 5). Average grades on Tests 1 and 2 in 2020 (before the modality shift) were not statistically different than grades from 2018 and 2019. However, grades on the final exam did vary by academic year (2018 – 2020) [$F(2, 218) = 6.65$, $p = 0.002$]. Tukey post hoc analysis showed that the average grade on the final exam was lower in the 2020 semester (74.6 ± 11.2%), as compared to the 2019 (82.7 ± 10.2%) and 2018 (80.3 ± 10.3%) semesters.

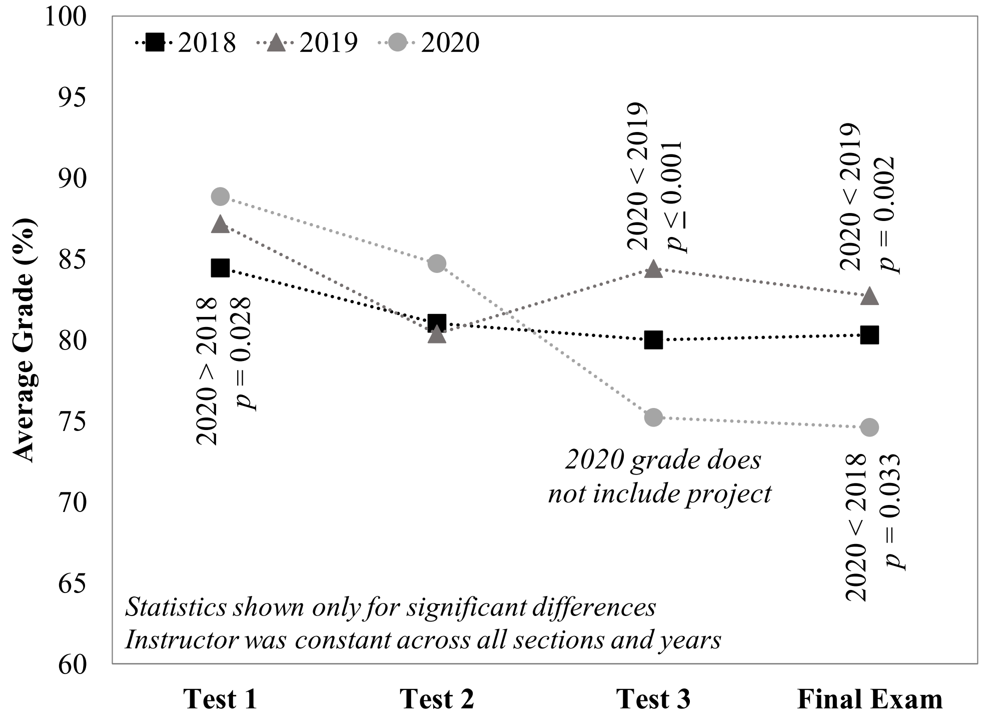

Figure 4. Comparison of closed-ended assessments in the Geomatics courses between 2018 and 2019. For 2020, Tests 1-2 were administered after face-to-face instruction, while Test 3 and the Final Exam were administered after online instruction.

Discussion

How did cognitive load related to the project compare to students' face-to-face and online classes?

Cognitive load, measured as perceived workload, caused by the project was surprisingly manageable, given the mid-semester shifts in modality, pedagogy, and software. Indeed, overall perceived workload – including mental, physical, temporal, effort, frustration, and performance demands – associated with Test 3 were similar to students' face-to-face engineering courses (Figure 4A). In contrast, overall perceived workload – as well as physical, temporal, effort, and frustration demand sources – associated with Test 3 were significantly lower than those for students' emergency online engineering courses (Figure 4B). Mental and performance demands were similar for Test 3 and courses across modalities, suggesting that the project was appropriately rigorous and engaging to facilitate similar learning without exceeding working memory capacity.

How did test/exam performance compare to previous years?

Student performance on closed-ended Test 3 questions was marginal, while performance on the project was exceptional. Indeed, grades on the closed-ended portion of Test 3 administered during continuity of instruction were lower than in previous years (2018, 2019) after face-to-face instruction (Figure 5). Without the QGIS project, students may not have mastered GIS outcomes.

Despite manageable cognitive load and reasonable performance on Test 3, students exhibited lower performance on the online Final Exam compared to previous years (Figure 5). For comparison, the average scores on Tests 1 and 2 in 2020 (before the modality shift) were not different than tests in 2018 and 2019. High workload imposed by students' online classes (Figure 4B) may have limited their final exam preparation. Other factors, including motivation and emotion are also known to influence performance even when load is manageable [6], which may further explain this finding.

Conclusions

We explored the experiences of civil engineering students enrolled in a Geomatics course during the rapid shift to online instruction during the COVID-19 pandemic through the lens of cognitive load theory. Students used the NASA TLX instrument to reflect on the perceived workload (a measure of cognitive load) associated with Test 3, which included closed-ended questions and a self-directed project that required use of open-source QGIS software. Students also used the TLX to reflect on workload associated with their face-to-face and emergency online engineering courses to contextualize the perceived workload associated with Test 3. Student performance on summative assessments were compared between continuity of instruction and previous face-to-face-only course administrations. The following conclusions were made based on the results:

1. Despite the shifts in modality, pedagogy, and software, cognitive load associated with the self-directed project (administered as part of Test 3) was likely manageable, given comparable overall workload and demand sources to face-to-face engineering courses.
2. The project-based pedagogy imparted less overall workload than student's emergency online engineering experience, which was likely lecture-based.
3. The self-directed project was sufficiently rigorous and students were reasonably motivated to succeed, as evidenced by similar mental demand and performance demand, respectively, between Test 3 and both modalities.
4. The self-directed project was essential for promoting student mastery of GIS concepts and skills. Despite similar performance on closed-ended assessments during face-to-face instruction in 2018-2020, performance on closed-ended assessments during the 2020 continuity of instruction was significantly lower than previous in-person years.

The geomatics project, imparting manageable cognitive load and scaffolding GIS mastery, will be implemented in future offerings. No matter the modality, the project (and supporting resources) affords students flexibility to self-direct their learning and manage other commitments. In addition, QGIS provided remote students the opportunity to engage in hands-on experience with mapping, beyond what would have been feasible with passive lectures/demonstrations. QGIS remains an accessible option for remote offerings of surveying-related lecture and laboratory courses.

Acknowledgement

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