Hybrid Learning: For Better or Worse? The Effect of Hybrid Learning on Grades and Attitudes of First-year Engineers in Chemistry

Ms. Sydney Anne Morris, Northeastern University

Sydney Morris is a senior at Northeastern University majoring in chemical engineering and minoring in mechanical engineering. She has been involved in the Connections Chemistry Review Program for three years, and is also an active member of the university's chapter of the Society of Women Engineers (SWE). She is currently a co-captain of the ChemE Car team, and is a research assistant in the Complex Electrochemical Systems Laboratory on campus where she works with lithium ion coin cells. She has completed two co-ops, where she has worked on grid-scale energy storage technologies and electrochemically mediated CO_2 capture devices. She is an NSF Graduate Research Fellowship recipient and will begin pursuing a PhD in Materials Science and Engineering at Brown University this Fall.

Ms. Hannah Boyce, Northeastern University

Hannah Boyce is a fourth year undergraduate student pursuing a B.S. in Chemical Engineering at Northeastern University. She has been involved in the Connections Chemistry Review program for a three years, is a peer mentor, President of AIChE and Conference Chair for the 2021 AIChE Northeast Regional Conference. She performs research in drug delivery and extracellular vesicles and is currently at ETH Zurich for coop. Her long term goals are to become a professor in chemical engineering and improve student pedagogy and effective training of tenure track professors in teaching.

Ms. Caroline Ghio, Northeastern University

Caroline Ghio is a senior undergraduate student majoring in Chemical Engineering and minoring in Data Science and Math. She has been a Connections tutor for four years. Ghio conducts independent research studying iron absorption in the gut, serves on the e-boards of the Society of Women Engineers and Tau Beta Pi, and is a Developer and Data Analyst for IDEA, Northeastern University's venture accelerator. Ghio also has completed three co-ops at early stage biopharmaceutical companies. She will be entering a Ph.D. program in Fall of 2021.

Ms. Amanda Dee, Northeastern University

Amanda Dee is a second-year undergraduate student at Northeastern University, majoring in bioengineering and minoring in mathematics and music. This is her first year with the Connections Chemistry Review program. In the past, she has been a first-year tutor for the College of Engineering and is currently a CRLA Level 1 tutor for the Northeastern Peer Tutoring Program. She is also passionate about research and is currently developing tools for engineering and evaluating transgenic root cultures. Outside of academics, she is an avid musician and performs with NUStage, Northeastern's student-run musical theater organization.

Ms. Alexis Pathwick-Paszyc, Northeastern University

Alexis is a third-year undergraduate student majoring in bioengineering at Northeastern University. This is her first year working with the Connections Chemistry Review Program. Additionally, she is working as a COE Undergraduate Program Assistant. She previously worked as a co-op student for the College of Engineering as the COE Undergraduate Upper-class Tutoring Coordinator and Supervisor.

Dr. Paul DiMilla, Northeastern University

During his academic career as a faculty member in engineering and the sciences at Carnegie Mellon University, Olin College, and Northeastern University, Paul A. DiMilla has been the recipient of the first Whitaker Young Investigator Award from the BMES, a Searle Scholar Award, and an Early Career Development Award from the NSF as well as a three-time recipient of the Omega Chi Epsilon Outstanding Faculty Award from the Northeastern Student Affiliate of AIChE and the Dick Sioui Teaching Award from

Northeastern University. He also has led industrial R&D teams at Organogenesis Inc. and Polymerix Corporation developing tissue-engineered medical products and drug- generating biodegradable polymers, respectively, and has co-founded Automated Cell, Inc. In addition to being an inventor on 12 issued US patents, he has published the textbook General Chemistry for Engineers with Cognella Academic Publishing. He currently is an adjunct faculty member focusing on improving content delivery and student engagement in remote learning in Chemical, Biological, and Environmental Engineering at Oregon State University and in Science at Clackamas Community College.

Ms. Rachelle Reisberg, Northeastern University

Rachelle Reisberg is Assistant Dean for Engineering Enrollment and Retention as well as Director of Women in Engineering at Northeastern University. Prior to joining Northeastern University, Rachelle held a wide range of management positions in IBM, Hanover Insurance, and was the President of a high tech start-up company.

Hybrid Learning: For Better or Worse? The Effect of Hybrid Learning on Grades and Attitudes of 1ˢᵗ Year Engineers in Chemistry

Abstract

In this study, we investigated the effects of online supplemental instruction (SI) and hybrid learning on first-year students who were enrolled in a required first-year general chemistry class for engineers at Northeastern University during the Fall 2020 semester. During the COVID-19 pandemic, concerns about spreading contagion compelled many universities to switch to either fully remote or hybrid learning, the latter an instructional method which combines in-person and remote instruction. Studies have reported conflicting outcomes for online and hybrid instruction, with some showing that students taking classes in an online or hybrid environment perform worse than their in-person counterparts [1], and others showing that online or hybrid learning can be more effective than in-person learning [2]. The impact of online and hybrid learning models on academic outcomes and attitudes of first year engineering students, specifically those matriculating during the COVID-19 pandemic, merits further attention and was the motivation for our study.

Approximately two decades ago, the College of Engineering at Northeastern University developed the Connections SI program, which provides first-year engineering students with structured group peer tutoring. In recent years, the Connections team has reported how factors such as student and instructor gender, pre-matriculation credit, and previous experience with SI affected use of SI during the first year and academic outcomes (*e.g.*, GPA) during students' first year through graduation. Specifically, we found that female undergraduates who regularly used SI during enrollment in required first-semester general chemistry had higher rates of retention within engineering and higher first-semester GPAs compared to their male counterparts [3] - [9]. This current study explored how offering SI online during the Fall 2020 semester influenced students' participation in SI and whether previous experiences with online learning affected academic outcomes and behaviors. We also looked at whether there were correlations among hybrid course instruction, use of online SI, and course grades in general chemistry and overall GPAs this past fall. We then compared these outcomes to our previous findings from multiple reports for a recent group of students who had graduated and only had in-person classes and SI [4].

We found that chemistry course grades and course completion rates were higher in Fall 2020 than in Fall 2013, suggesting that online SI and hybrid course instruction did not negatively impact first-semester academic outcomes. However, students in Fall 2020 who attended class in person multiple times weekly, under the University's rotating weekly schedule, had higher GPAs than students who attended class in person only two-to-four times monthly. Participation in SI was impacted by the hybrid format: a lower percentage of students attended SI when it was held remotely in Fall 2020 compared to when SI was held in person in Fall 2013. However, a slightly higher percentage of males used SI during Fall 2020 compared to Fall 2013, while a significantly lower percentage of females used SI during Fall 2020 compared to Fall 2013. Among users of SI, females having significantly higher chemistry course grades and first semester GPAs than males. Based on analysis of surveys offered to enrolled students, we also found that students' attitudes

towards online learning at the end but not the beginning of the semester had a significant correlation with their chemistry course grades and GPAs.

Introduction

Our research team has previously studied the effects of supplemental instruction (SI) on first-year engineering students at Northeastern University and reported how factors such as gender, past SI use, and pre-college academic backgrounds influenced academic success overall and within a required first-year general chemistry course [3] - [9]. For this present study, we investigated the impact of Northeastern University's hybrid learning model, which was adopted in response to the COVID-19 pandemic and combined in-person and online instruction, on academic outcomes and use of SI for first-year engineering students enrolled in this chemistry course in the Fall 2020 semester. We also examined correlations among students' academic success, how students anticipated factors such as sleep issues and mental health would affect their learning, and students' attitudes towards online learning. In addition to the previously identified effects of gender and pre-college credit, a particular interest in this current study was the impact of offering SI remotely during the Fall 2020 semester, as opposed to in-person in the previous years we have reported.

Online learning

Due to the COVID-19 pandemic, many schools and universities have shifted to hybrid or entirely remote learning modalities. Offering engineering classes online is not new, but the size of the populations experiencing this form of higher education has increased greatly during the pandemic. Online learning allows for distanced engineering education, which enables those who are unable to pursue a degree on-site or who do not possess the resources to do so to take courses [8]. In particular, as some universities lack resources to accommodate increasing enrollment in engineering, allowing students to attend courses both in-person and online makes engineering education accessible to more people [9], [10]. Learning from home also allows students to form closer connections between their learning material and their personal lives, while providing more flexibility for students who have family, work, and other personal obligations [11].

Some studies have found that persistence in online learning can be difficult as students may feel more isolated; they may lose confidence or motivation more quickly due to a lack of direct encouragement from peers and instructors [14]. Fischer *et al.* have shown that students with high social presence—or strong engagement with their learning community—have higher academic performance and are more motivated to improve [12]. With in-person learning, there is also more immediate contact with teachers, so help is more readily available compared to online learning [11]. Being in a classroom also provides materials, time, and space dedicated to learning, and it can be difficult to stay motivated without this structure [15]. Aside from easier access to resources, students who moved to online learning during the pandemic have reported feeling less engaged [13]. The drawbacks associated with online learning may result in long-term consequences, including disengagement with studies and negative effects on well-being, attitudes towards academics, and retention [15]. Finally, online learning reduces the number of hands-on experiences for students, which significantly impacts engineering disciplines [13].

Supplemental instruction

One of the long-standing goals of our research has been to examine the effect of SI on student success while also studying how various factors influence SI participation. A central feature of our offerings of SI has been the Connections Program, founded at our institution in 2000 (with support from the National Science Foundation) to increase retention and graduation rates of women enrolled in undergraduate engineering programs. One of the program initiatives has been to provide additional resources for first-year female engineering students in required general chemistry and physics courses. Our past studies have shown that females who used SI had significantly higher grades than females who did not [6]. During the Fall 2020 semester, our offerings of group SI through the Connections Program, as well as one-on-one peer tutoring through the College of Engineering, were both shifted to online formats. We were interested in investigating the impact of this shift on academic outcomes in comparison to in-person SI.

Current literature on the effect of online SI on students is limited. However, Zhan and Mei have reported that online SI may have a comparable, positive effect as in-person SI, with students who participated in online SI having higher grades and lower rates of failure than their non-participating counterparts [14]. Additionally, others have shown there was no significant difference in perceived benefits from online versus traditional in-person SI [15], suggesting that online SI may be a valuable resource for students. A recent study also concluded that utilizing social media platforms, such as Facebook or Twitter, for SI could increase student productivity and be just as, if not more, effective than traditional learning methods [16]. On the other hand, one of these studies also found that there was less live attendance in online SI sessions, and some students expressed negative feelings about attending SI online [14]. Keeping these past experiences with online SI in mind, we explored the effectiveness of our online SI offerings.

Study context

First-year engineering students entering Northeastern University in September 2020 encountered a profound change in instructional strategy compared to previous years in which all classes were offered in-person: during the Fall 2020 semester classes were offered under a hybrid learning model in which a limited number of students could attend each class meeting in-person and the remainder would attend only remotely, based in part on student preferences. This study focused on assessing consequences of this shift in learning model in combination with the change to remote SI on students enrolled in a required general chemistry course. We collected data on grades, SI attendance, and attitudes and behaviors, the latter through surveys administered to enrolled students at the start and end of the semester. Our objectives were to evaluate the impact of remote learning on chemistry course grades, first semester GPA, and participation in SI in the context of self-reported gender, pre-matriculation college credit, prior use of SI, mental health and sleep issues, and attitudes towards online learning.

To place our observations for hybrid learning and online SI in context, we referenced data and compared outcomes from Fall 2020 with data collected from a group of students who enrolled in the same chemistry course in Fall 2013, when both the course and SI were offered in person. We selected the 2013 cohort because we have published multiple papers examining academic outcomes, behaviors, and attitudes for this population, most recently exploring the longitudinal

effects of SI and pre-college credit on their academic progress through graduation. The thorough analysis we previously reported for this cohort made these data attractive as basis for comparing hybrid *vs.* in-person learning in this present study.

Methods

Hybrid instructional model

The model for hybrid instruction adopted by Northeastern University allowed students to select in-person or remote attendance for each class on a weekly basis: some students attended class in person, while remote students attended class live via Zoom. Students indicated their preferences for attending class in person or online on a weekly basis. In combination with classroom capacity limits, an algorithm randomly assigned who could attend in person. Students alternatively could select the option to be fully remote and take all their classes online. Instructors chose whether they taught in-person or remotely. If an instructor was not present in-person, students attending in-person in the classroom watched a video feed of the live lecture on their personal devices. Instructors who chose to teach in-person would teach with cameras in the classroom allowing remote learners to see and hear the presentation, including any content written on whiteboards. Lectures were also recorded for students to watch asynchronously. Institutional data were unavailable for patterns of in-person *vs.* remote attendance.

Supplemental instruction

Two types of student-led SI were offered to students: group tutoring and one-on-one tutoring. Weekly group tutoring sessions for chemistry, organized through the Connections Program, were led by female upper-class engineering students, who sat in on classes. Prior to the pandemic these reviews were offered in-person, with pizza provided to incentivize attendance. Tutors went over review sheets, distributed as hardcopy, and fielded concept questions, and then students were invited to ask homework-related questions. In response to the pandemic procedures for reviews changed: neither tutors nor students were present in-person, review sheets were sent to students in the Zoom chat, and tutors worked through homework questions on whiteboards over video. To ask questions, participants could unmute their microphones or post them in the chat.

Through the College of Engineering (COE) Tutoring Office, students also had the option to receive one-on-one drop-in peer tutoring for most courses taken in the first two years of the engineering curriculum. This office was staffed by undergraduate peer tutors. Prior to the COVID-19 pandemic, peer tutoring was offered in person, which allowed students to "drop-in" during operating hours without an appointment. In Fall 2020 one-on-one tutoring was only offered virtually through Microsoft Teams, although the "drop-in" style was retained. All tutoring information was made available on the COE website, including recordings of Connections group reviews and accompanying review sheets.

Data collection and analysis

Data for student outcomes and attitudes for the Fall 2020 semester was obtained as (1) grade data provided by the Northeastern University Registrar, (2) attendance logs for participation in SI,

and (3) student survey responses. Data for Fall 2013 chemistry course grades and completion rate, pre-matriculation credit, GPA, and SI use were obtained from the chemistry course coordinator and Registrar. Letter grades for the chemistry course were converted to numerically equivalent values that were used for analysis. At the beginning and end of the Fall 2020 semester, the 601 students who were enrolled in the chemistry course were invited to participate in two IRB-approved surveys. Surveys were provided as links posted on instructors' course websites, with extra credit offered to incentivize participation. Only students over the age of 18 had the option of completing the approximately ten-minute surveys, and survey participation was optional. Survey responses, which included self-reported gender, were matched with a student's grades using university-assigned student identification numbers that students self-reported in surveys. To understand the impact of the pandemic on students' preconceptions and expectations, the pre-survey conducted at the start of the semester asked about students' experiences with online learning, expected challenges, and types of SI students expected to use. Post-survey questions posed at the end of the semester asked students to select challenges that impacted their academic performance and experience.

Survey data were analyzed using JMP Pro 14 software to find similarities, differences, and trends and to test hypotheses regarding the impact of the hybrid instructional model on student outcomes during the COVID-19 pandemic. The study population consisted of 131 females (36.4%) and 229 males (63.6%) who responded to both pre- and post-survey and received a final grade for the chemistry course, representing 59.9% of the course enrollment. Two-tailed z- and t-tests were used to determine if means for various subpopulations were statistically significantly higher than another. Z-tests were used for analysis on subpopulations larger than 50, and a t-test was used when subpopulations were less than 50. Calculated p-values were compared to a 0.05 threshold value for statistical significance, indicating a 95% confidence level. One-way analysis of variance (ANOVA) was performed to analyze results when there were more than two subpopulations, and a student's t-test was used to analyze pairwise comparisons of these subpopulations. A Fisher's exact test also was used to compare contingency effects, to discern if different factors had greater effects on subpopulations, and to determine if outcomes for one subpopulation were more likely to occur compared to another subpopulation. Effect sizes between populations were reported using a combination of Cohen's d values and F ratios with p-values for ANOVAs. Results were considered significant if the F ratio was greater than one and the p-value was less than 0.05 [17]. For Cohen's d the following conventions were used: $d<0.4$ was considered a small effect, $0.4<d<0.8$ was considered a medium effect, and $d>0.8$ was a large effect [18]. Odds ratios were also reported when comparing binary outcomes, such as whether students attended SI. Students were identified as having used SI if they attended two or more SI sessions during the semester. This criterion aligns with our previous work [4].

Results and Discussion

Comparison of academic outcomes and SI use under hybrid learning vs. in-person learning

To better understand the implications of the hybrid learning model and remote SI usage during the Fall 2020 semester, we compared academic outcomes and behaviors for first-year engineering students taking general chemistry in Fall 2020 with these outcomes for students taking this class entirely in-person in the Fall 2013 semester. We found that students in the Fall

2020 semester who experienced the hybrid learning model had significantly higher chemistry course grades compared to those students who took the class during the Fall 2013 semester, with an average (±standard deviation) chemistry course grade of 3.47±0.68 and 3.26±0.90, respectively. We also found that the dropout rate for the course (which includes withdrawals, incompletes, and failures) was 1.41 times higher in 2013 compared to 2020. These results indicate that implementation of the hybrid learning model did not have a negative effect on grades or retention rate in this required science course for first-year engineering students. However, differences in pre-matriculation credits between Fall 2013 and Fall 2020 may have been an underlying factor in these observations. Pre-college credits were earned through AP/IB Programs, dual enrollment, or as transfer credits earned from another college before matriculation at Northeastern. The average (± standard deviation) number of college credits students earned prior to matriculating in Fall 2020 was 18.90±14.19, while for Fall 2013 it was 13.55±11.84.

Table 1 presents averages and standard deviations for college credits prior to enrollment, final course grade in chemistry, GPA at the end of the fall semester, and number of times a student used SI, as well as percentages of enrolled students who completed this course and who participated in SI, based on self-reported gender. We found statistical differences between female and male students in Fall 2020 in their course grade ($p=0.01$, Cohen's $d=0.25$) and GPAs ($p=0.01$, Cohen's $d=0.26$). On average, females and males used SI approximately the same number of times during Fall 2020, and the number of times a student used SI during this semester did not have a significant correlation with either their GPA or chemistry course grade (F ratios<1, $p>0.5$). For both genders, however, the number of times students used SI was lower in Fall 2020 under remote SI than it was in Fall 2013 under in-person learning.

Table 1. Comparison of Fall-semester Grades and SI Use for Different Learning Models

	Females		Males	
	Hybrid Learning (2020)	**In-person Learning (2013)**	**Hybrid Learning (2020)**	**In-person Learning (2013)**
Population	131	133	229	352
Pre-matriculation Credits	18.86±14.63	14.35±11.47	18.92±13.96	13.24±11.98
Chemistry Course Grade	3.58±0.55	3.34±0.87	3.41±0.74	3.22±0.90
% Completed Chemistry Course	98.4	97.0	98.2	95.7
First Semester GPA	3.74±0.30	3.53±0.47	3.63±0.44	3.39±0.58
Number of Times Used SI	1.32±2.86	3.13±5.52	1.45±2.86	1.51±3.25
% Used SI	20.61	39.37	25.33	22.36

In addition to overall decreases in SI attendance, the disparity of percent of students using SI between male and female students also decreased with females attending SI less frequently.

There were no significant differences in the number of times SI was attended between genders for Fall 2020, compared to Fall 2013 when females were 2.19-times more likely to use SI compared to males [2]. This outcome could be due to females being more socially oriented and ranking social interaction as more important for learning compared to males [21]. The reduced social interaction provided by remote SI compared to in-person SI may have led females to choose not to attend SI. The same reduced interpersonal aspect to remote SI may have resulted in males having an overall increase in SI attendance for 2020 compared to 2013. It has been shown that males are less likely to ask for help, for fear of appearing weak [22]. It is possible that the online format made it easier for males to feel comfortable seeking help due to its less personal nature, where students can choose to have their cameras off and mute their microphones. These results suggest that different forms of SI might confer preferential benefits for males *vs.* females, and perhaps a hybrid model of SI would result in higher overall attendance, where those students placing a greater value on social interaction would be attracted to in-person SI and those students who are more hesitant to ask for help would be attracted to remote SI.

Table 2 shows there were no notable differences in chemistry course grades in Fall 2020 between females and males who did not use SI ($F=2.43$, $p=0.12$). However, among those students who did not use SI, females had significantly higher GPAs than males ($F=3.55$, $p=0.06$, z test: $p=0.03$). Females who used SI also had higher chemistry course grades than males who used SI ($F=3.88$, $p=0.05$, z-test: $p=0.04$), but there were no significant differences between the GPAs of female and male students who used SI ($F=2.11$, $p=0.15$). For both females and males, chemistry course grades did not differ significantly based on SI use ($F=1.4$, $p=0.24$ and $F=0.18$, $p=0.67$, respectively). Similarly, GPAs did not differ significantly between male and female students ($F=0.04$, $p=0.85$ and $F=0.33$, $p=0.57$, respectively). Overall, SI attendance did not correlate with course grade ($F=0.003$, $p=0.96$) or GPA ($F=0.002$, $p=0.96$). These findings of no correlation between remote SI use and higher GPAs contrast our previous findings for students in Fall 2013: in-person use of SI positively correlated with higher GPAs [4].

Table 2. SI Usage and Grades Under Hybrid Learning in Fall 2020

	Did not use SI			Used SI		
	Overall	**Females**	**Males**	**Overall**	**Females**	**Males**
Population	275	104	171	85	27	58
Chemistry Course Grade	3.47±0.67	3.55±0.59	3.42±0.72	3.47±0.70	3.69±0.36	3.37±0.80
First Semester GPA	3.67±0.39	3.73±0.32	3.64±0.42	3.67±0.42	3.77±0.22	3.62±0.48

Role of pre-college credit

To understand better the effects of pre-matriculation credit on chemistry course grade and GPA in the context of the hybrid learning model, students for the Fall 2020 semester were separated into three sub-populations based on the amount of pre-college credit they had upon entering Northeastern University. This analysis was in accordance with our previous reporting for

students enrolled in general chemistry in the Fall 2013 semester. These subcategories included those students who had zero credits, up to 20 credits, and more than 20 credits. Table 3 compares our findings for Fall 2020 *vs.* Fall 2013. For females entering with zero pre-college credits and up to 20 college credits, Fall 2020 SI attendance decreased by more than 50% of the corresponding Fall 2013 attendance, while SI attendance remained about the same for females who entered with more than 20 college credits. For males entering with no pre-college credit, Fall 2020 SI attendance was nearly 38% higher compared to Fall 2013. For males entering with up to 20 college credits, SI attendance for Fall 2020 and 2013 were similar, while SI attendance for males who entered with more than 20 college credits increased by about 56%. The largest decrease in SI attendance was seen for females who entered with 0-20 credits.

Table 3. Comparison of Chemistry Course Grade, GPA, and SI Usage by Gender Under Hybrid Learning (Fall 2020) and In-Person Learning (Fall 2013, from [4])

	0 Pre-matriculation Credits				Up to 20 Pre-matriculation Credits				Greater than 20 Pre-matriculation Credits			
	Females		Males		Females		Males		Females		Males	
Year	2020	2013	2020	2013	2020	2013	2020	2013	2020	2013	2020	2013
Population size	26	28	32	93	41	85	85	201	64	89	112	195
Population %	19.8%	13.9%	13.9%	19.0%	31.3%	42.1%	37.1%	41.1%	48.9%	44.0%	49.0%	39.9%
Chemistry Course Grade	3.51 ±0.64	2.99 ±1.05	2.82 ±1.07	2.71 ±1.07	3.46 ±0.60	3.31 ±0.91	3.32 ±0.71	3.26 ±0.94	3.68 ±0.46	3.76 ±0.43	3.65 ±0.51	3.59± 0.77
First Semester GPA	3.68 ±0.37	3.41 ±0.52	3.24 ±0.75	3.09 ±0.72	3.65 ±0.36	3.44 ±0.55	3.59 ±0.34	3.40 ±0.52	3.81 ±0.19	3.70 ±0.27	3.78 ±0.28	3.61± 0.38
# of Times Used SI	1.12 ±1.61	5.37 ±8.27	1.47 ±2.90	1.56 ±3.74	0.80 ±1.78	2.83 ±4.57	1.73 ±3.15	1.42 ±2.94	1.73 ±3.67	1.15 ±2.50	1.22 ±2.63	1.16± 4.31
% Used SI	26.9%	55.6%	28.1%	20.5%	14.6%	38.8%	29.4%	24.1%	21.8%	20.5%	21.4%	13.8%

Table 3 shows that, for the overall population, first semester GPA correlated significantly with the number of pre-college credits a student earned before matriculation ($F=37.06$, $p<0.001$). This conclusion was valid for both females ($F=4.67$, $p=0.03$) and males ($F=35.32$, $p<0.0001$), though the effect was much stronger for males. We also found that the number of pre-enrollment credits had a significant correlation with chemistry course grade ($F=28.56$, $p<0.0001$) for the overall population, although this conclusion was only true for males ($F=33.63$, $p<0.0001$) and not for females ($F=1.14$, $p=0.29$). Figure 1 shows linear regressions of this data. Positive slopes in this figure indicated students with greater numbers of pre-college credits tended to have higher chemistry course grades and first semester GPAs.
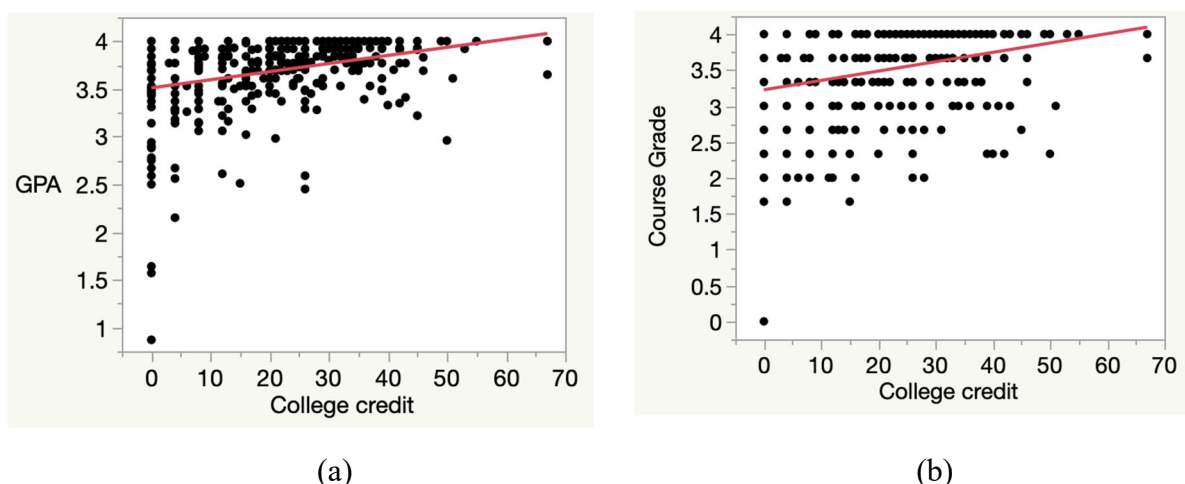
Figure 1. Correlations Between Pre-matriculation College Credits and (a) GPA and (b) Chemistry Course Grade Under Hybrid Learning in Fall 2020

Table 3 shows that many trends we have previously found regarding pre-college credit and GPA for in-person learning remained valid under hybrid learning. However, GPAs were higher for each subcategory for the Fall 2020 semester compared to the Fall 2013 semester, which could be due to the increasing competitiveness of Northeastern University and students entering with an increase in pre-college credits. Further, some course instructors have changed since 2013, which may have resulted in different grading outcomes. It is also possible that given the extenuating circumstances of the pandemic, instructors were more lenient with their grading in Fall 2020 and that there was more prevalent grade inflation. Overall, there was a significant relationship between the subcategories of pre-college credit and GPA ($F=22.52$, $p<0.0001$) as well as chemistry course grades ($F=16.81$, $p<0.0001$).

The most significant relationship for the overall population between pre-college credit and first semester GPA was between students who had more than 20 pre-college credits and their peers who had no pre-college credits, who had significantly lower first semester GPAs (Cohen's $d=0.55$, $p<0.0001$). Students entering with no college credits also had significantly lower first semester GPAs compared to their peers who entered with some (up to 20) college credit (Cohen's $d=0.27$, $p<0.0001$). Further, those students entering with up to 20 college credits had significantly lower first semester GPAs compared to their peers entering with more than 20 credits (Cohen's $d=0.28$, $p<0.0001$). GPAs were not gender dependent for students who had up to 20 credits ($F=0.66$, $p=0.42$) or more than 20 pre-college credits ($F=0.80$, $p=0.37$). However, females entering with no pre-college credits had higher GPAs than males entering with no such credits ($F=7.62$, $p=0.008$).

We found that whether females and males entered with zero, 1-20 college credits, or more than 20 college credits, had a significant impact on their GPA ($F=4.76$, $p=0.01$ and $F=23.89$, $p<0.0001$, respectively). An ordered differences report using t-tests revealed that males' GPAs between each pre-college credit subcategory were significantly different ($p<0.001$), with males who had more than 20 college credits having the highest average GPAs, followed by those with 1-20 credits and then those with zero credits. The only significant differences among pre-college

credit subcategories for females were whether students entered with 1-20 college credits or more than 20 college credits (p=0.004). In this case, those who entered with more than 20 college credits had higher GPAs than those entering with 1-20 credits.

Further, pre-college credit did not significantly affect female course grades (F=2.27, p=0.11), but did impact male course grades (F=19.08, p<0.0001). Again, an ordered differences report using t-tests revealed significant differences between males' course grades in each subcategory (p<0.001). For females, there were only significant differences in course grades between those who entered with 1-20 credits and those who entered with more than 20 credits (p=0.046). Among students entering with zero pre-college credits, females had higher course grades than males (F=8.38, p=0.005). No differences were observed between genders for those entering with 1-20 credits (F=1.29, p=0.26) or those with more than 20 credits (F=0.22, p=0.64).

Previous use of SI and study methods

We also examine whether prior use of SI and other study methods, including attending office hours and studying in groups, in high school correlated with planned SI use for students' first semester in college and subsequent academic outcomes. Our previous research has shown that first semester GPA is predictive of graduation GPA, and therefore understanding the factors that could affect a student's transition to college is important [7]. Table 4 shows usage rates for tutoring, office hours, and study groups in high school, and planned usage rates for these study strategies in college based on pre-surveys administered at the start of the Fall 2020 semester. Table 5 reports actual usage rates for group and one-on-one SI between students who used these approaches in high school or planned to do so at the start of the semester *vs.* their peers who did not use these resources in high school or did not plan to do so during their first semester in college.

Table 4: Percentage of Fall 2020 Students Who Used/Planned to Use Various Study Methods

Gender	% Used in High School				% Planned to Use in College			
	1-on-1 Tutoring	Group Tutoring	Office Hours	Study Group	1-on-1 Tutoring	Group Tutoring	Office Hours	Study Group
Overall	30.6	51.7	58.6	65.5	45.3	74.2	88.1	85.6
Females	35.1	58.8	55	63.8	51.2	82.4	90.1	90.1
Males	27.9	47.6	64.9	69.5	41.9	69.4	86.9	83.0

Table 5: Percentage of Students Who Used SI in Fall 2020 Based on Past and Planned Use

	% Used Group Tutoring in Fall 2020	% Used 1-on-1 Tutoring in Fall 2020
Used Respective SI in High School	20.4	4.5
Did Not Use Respective SI in High School	19.0	7.5
Planned to Use Respective SI in College	20.2	6.7
Did Not Plan to Use Respective SI in College	18.3	6.6

SI usage in high school was not predictive of SI usage during the first semester of college, but was predictive of students plans to use that respective SI. This finding contrasts with our previous finding for in-person learning that students who attended SI in high school attended SI

during their first semester in college at a higher rate than students who did not use SI in high school [9]. This change in SI attendance could be due to the virtual offering of SI as opposed to in-person that was the basis for our previous finding. Students who used one-on-one tutoring in high school were 3.31 times more likely to plan to use it in college; those students who used group tutoring in high school were 6.50 times more likely to plan to do so in college. For office hours, students were 6.69 times more likely, and for group study they were 5.71 times more likely to plan to use the same SI or study habit. Students who used one-on-one tutoring in high school and students who planned to use one-on-one tutoring in college attended SI at a similar rate to their peers who had no SI experience in high school and did not plan to attend one-on-one tutoring, respectively, as shown in Table 5. The same trend was seen for group tutoring, students who used group tutoring in high school and planned to use group tutoring during their first semester actually used group tutoring at a similar rate to those who did not use group tutoring in high school and did not plan to use it during their first semester, respectively, as shown in Table 5. It appears that students entered their first semester in college planning to use their same study methods from high school, but did not necessarily follow through on that plan, as there were similar rates of SI attendance among students who used SI in high school and those who did not use SI in high school.

Overall, females reported using SI in high school more frequently than males, as shown in Table 4. Females were statistically more likely to use certain types of SI in high school, specifically group tutoring (Fisher's exact test, one-sided: $p=0.049$, odds ratio=0.64) and office hours (Fisher's exact test, one-sided: $p=0.04$, odds ratio=0.66). Females also planned to use all forms of SI during their first college semester at a higher rate than males, shown in Table 4. This included group tutoring (Fisher's exact test, one-sided: $p=0.004$, odds ratio=0.48) and study groups (Fisher's exact test, one-sided: $p=0.043$, odds ratio=0.54). Overall, we found that using a study group was the most common among students in high school with 65.8% of students having used this study method. These findings are similar to our past results, where we showed that females used SI in high school and planned to use SI more frequently in college compared to males, specifically for one-on-one tutoring, office hours, and group tutoring [4]. The most popular study method students planned to use in college was professor office hours, with 88.1% of students indicating this plan. Using study groups was the second most common planned use at 85.6%. The SI with the lowest response was one-on-one with 45.3% of student's planning to attend. This shows the importance of establishing good study habits in high school as students will initially plan to follow the same habits when they enter college. Additionally, during hybrid and virtual learning it is more difficult for students to form study groups because they cannot as easily meet and interact with their classmates during class, and this may increase the challenge for students transitioning to college as most of them used study groups in high school.

We found that prior use of any of the inquired SI or study methods (*i.e.* office hours or study group) did not correlate significantly with chemistry course grade or first semester GPA ($F<2.75$, $p>0.10$). There was also no significant difference in chemistry course grade or GPA between students who planned to attend a certain type of SI compared to their peers who did not plan to attend SI.

Impact of in-person class attendance in the hybrid learning model

One unique outcome of the hybrid learning model that we investigated was the effect of the frequency of in-person class attendance, as students were limited by the size of the classroom, number of students who selected an in-person preference for the week, and the algorithm used to select seats for students, as well as their personal preferences. Students were asked in the post-survey at the end of the Fall 2020 semester, "How often did you attend class in person?" and given the response options of: "As much as possible (multiple time per week)," "Frequently (1x week)", "Occasionally (2-3x month)," "Rarely (less than 2x month)," and "Never". There was no statistical correlation among different self-reported attendance patterns and first semester GPA, as shown in Figure 2, nor on chemistry course grades based on ANOVA ($F<1.96$, $p>0.08$). We found that females who reported attending class in person "occasionally" had higher chemistry course grades and first semester GPA than their male counterparts ($F=5.01$, $p=0.03$, $F=3.76$, $p=0.03$, respectively). Students who reported attending class in person as much as possible had higher GPAs compared to students who attended frequently and occasionally (*t* test: $p=0.04$, $p=0.04$). These findings are interesting in light of results from Fall 2013 in which we found overall in-person lecture attendance for general chemistry had a positive effect on the course grades of students ($F=173.16$, $p <0.0001$) [6].
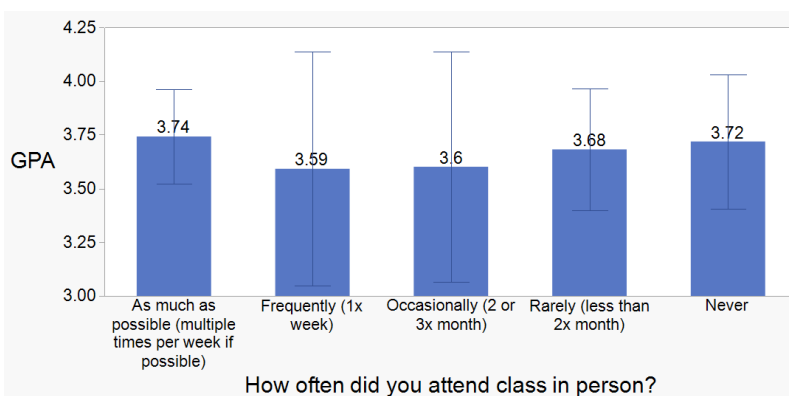

Figure 2. Correlation Between Self-reported In-person Attendance and Mean First Semester GPA Under Hybrid Learning in Fall 2020. Error bars represent one standard deviation.

Impact of sleep issues and mental health

We hypothesized when we began this study that factors such as sleep issues and mental health challenges might result in lower grades under hybrid learning. Students were asked at the end of the Fall 2020 semester in the post-survey to indicate if difficulty focusing, sleep issues, mental health, financial problems, personal or family illness, and/or difficulty managing their time affected their learning during the semester. Whether or not students indicated that difficulty focusing affected their learning correlated with their chemistry course grades and GPAs ($F=4.32$, $p<0.04$ and $F=4.03$, $p<0.045$, respectively), with students indicating difficulty focusing having lower grades and GPAs than their peers who did self-report such difficulty. Further, students' responses concerning mental health in the pre-survey also had a significant effect on GPAs and chemistry grades ($F=5.91$, $p=0.02$ and $F=4.42$, $p=0.04$, respectively), with those concerned about mental health affecting their learning having lower grades and GPAs than their peers. The other

factors had no correlation with lower chemistry grades or 1st-term GPAs ($F<1$, $p>0.05$). 52.5% of respondents reported that sleep issues affected their learning, of which 40.2% were female and 59.8% were male. However overall, sleep issues had no significant effect on GPA ($F=0.03$, $p=0.87$) or course grades ($F=0.06$, $p=0.81$). Further analysis by reported gender showed that sleep issues did not correlate with a significant change in course grade ($F=0.52$, $p=0.47$) or GPA ($F=0.65$, $p=0.42$) for females. For males, sleep issues also had no significant effect ($F=0.11$, $p=0.74$) on course grades and GPA ($F=0.20$, $p=0.66$). Note that we have no data from previous studies regarding the extent to which students who experienced in-person instruction suffered from sleep issues. However, it is known that blue light can cause and exacerbate sleep issues [23]. It is possible that the hybrid model, which increased use of computers and phones to complete coursework, combined with the stress of the pandemic, may have led to worse quality of sleep for students [24].

Further, 55.6% of respondents said mental health affected their learning for the Fall 2020 semester, of which 47% were female and 53% were male. Overall, whether students reported mental health issues affecting their learning did not have a significant impact on course grade ($F=0.24$, $p=0.63$) or GPA ($F=0.13$, $p=0.71$). For both female and male students there were no correlations between self-reported mental health issues and either course grades (females: $F=1.67$, $p=0.20$; males: $F=0.34$, $p=0.56$) or GPA (females: $F=2.40$, $p=0.12$; males: $F=0.24$, $p=0.62$). These results differ from our original hypothesis regarding mental health challenges in light of the pandemic, as we recognize the widespread documentation of these challenges for college students and, more broadly, this age group during the past year. Further examination is warranted to clarify the impact of mental health issues under hybrid learning as it was implemented for this chemistry course and others at our institution.

Feelings towards hybrid learning

We began this study hypothesizing that students who started the semester with negative feelings towards online learning or prior negative experiences with online instruction, would not perform as well during the Fall 2020 semester. Students were asked in the pre-survey "How would you rate your previous experiences with online learning?" and could select either "(1) very dissatisfied", "(2) dissatisfied", "(3) neither dissatisfied or satisfied", "(4) satisfied", or "(5) very satisfied." We found that responses to this question were not predictive of either a student's chemistry course grade or GPA ($F<1.43$, $p>0.21$). Students were also asked in pre- and post-surveys, "How do you feel about online learning?" and could select either "(1) extremely negative", "(2) negative", "(3) neither negative nor positive", "(4) positive", or "(5) extremely positive". For these questions we found that neither chemistry course grade nor first semester GPA (Figure 3) correlated with a student's feelings towards online learning at the start of the semester ($F<0.25$, $p>0.8$). Only four individuals, or 1.1% of the surveyed population, felt extremely positive, 4.2% felt extremely negative, and 52.5% of the population indicated neither positive, nor negative feelings towards online learning. The distribution of feelings about online learning at the start of the semester based on self-reported gender are shown in Figure 4. The only significant finding based on the pre-survey in this figure was that females who felt very positive (4) about online learning had higher GPAs than their male counterparts ($F=4.05$, $p=0.049$, t-test: $p=0.01$).
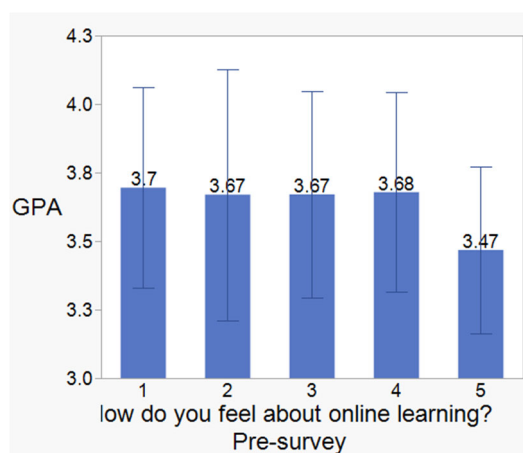
Figure 3. Correlation Between Attitude Towards Online Learning at Start of Semester and First Semester GPA
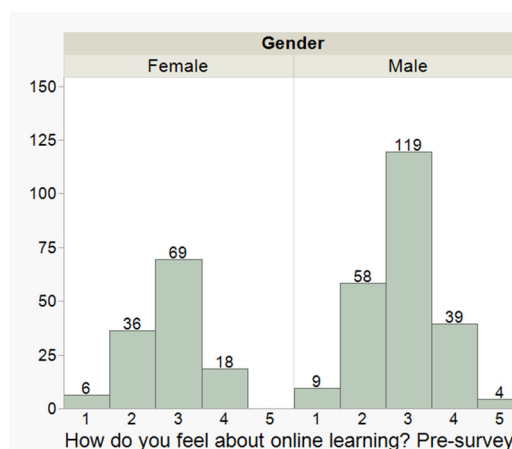

Figure 4. Histograms of Attitude Towards Online Learning at Start of Semester by Gender

In contrast, we found that feelings towards online learning self-reported at the end of the semester did correlate with chemistry course grade and first semester GPA. It is important to note students took the post-survey during the final week of classes before receiving final grades and taking final exams, so final grades would not affect their feelings. ANOVA showed post-survey feelings towards online learning had a significant correlation with chemistry course grades for all students ($F=2.45$, $p=0.046$) and on GPA for females ($F=3.28$, $p=0.01$). We found that females who rated their attitudes towards online learning as either positive or neither negative nor positive had higher GPAs and grades compared to their male counterparts reporting such attitudes ($F>3.4$, $p<0.05$). We also found that females who self-reported a positive experience with online learning during the semester had higher GPAs than females who rated their feelings as either negative or neutral (t test: $p=0.01$, $p=0.002$, respectively).

Comparing pre- and post-survey results, 39.4% ($N=142$) of students did not have a change in attitude, while 27.2% ($N=98$) viewed online learning more negatively at the end of the semester and 33.3% ($N=120$) viewed online learning more favorably. This change in attitude did not correlate significantly with GPA ($F<1.18$, $p>0.35$). Students who felt they had a more positive experience with online learning at the end of the semester performed better, and this evidence suggests that students who were better at transitioning to online learning performed better and therefore had a more positive attitude. Also, post-survey feelings towards online learning had a greater effect on female students given the significant correlation with both chemistry course grades and GPA, whereas for males there was only a significant correlation for chemistry course grade. Interestingly, students who rated their attitude towards online learning as extremely positive ($N=12$) did not exhibit statistically higher academic achievement than any other cohort, and those students who had extremely negative feelings ($N=23$) did not exhibit statistically lower academic achievement. These outcomes indicate that feelings towards online learning were not a primary factor in predicting a student's academic success.

Conclusions

The effects of a hybrid learning model during the COVID-19 pandemic on a group of first-year students enrolled in a general chemistry course for engineers were investigated and compared to the outcomes of students who entered the COE in the Fall of 2013 and attended classes and SI in person. We found that:

- Under in-person learning in Fall 2013, students who attended SI had higher first semester GPAs and chemistry course grades than their peers who did not attend SI. In contrast under hybrid learning in Fall 2020, there were no overall significant differences in first semester GPA and chemistry course grade between those students who used SI and those who did not.
- Male and female students used SI at a similar rate when SI was available remotely in Fall 2020 compared to in-person SI in Fall 2013, when females were more likely to attend. This outcome was a result of decreased use of SI by females for the Fall 2020 semester under hybrid learning. The usage rate for remote SI was less than for in-person SI, and females may be more attracted to attend in-person SI with its more social environment.
- First-semester GPAs and chemistry course grades for hybrid-learning in Fall 2020 were comparable to these metrics for in-person learning in Fall 2013. Course completion rates in chemistry were also higher for Fall 2020 compared to Fall 2013.
- Under hybrid learning in Fall 2020, students who self-reported attending class in-person multiple times weekly had higher first semester GPAs compared to their peers who self-reported attending class only two-to-four times per month,
- Under hybrid learning in Fall 2020, past use of SI was not predictive of either first semester grades nor SI usage during that first semester of college. This finding contrasts with our previous finding for in-person learning that high school SI usage was predictive of SI usage during the first semester of college [9].
- Feelings towards online learning self-reported at the start of the semester did not have a significant correlation with first semester grades. However, these feelings self-reported at the end of the semester directly correlated with first semester grades, with students who ranked their feelings towards online learning as more positive having higher chemistry course grades and for females having higher first semester GPA.

Perhaps our findings of greatest significance are the overall decrease in SI attendance under remote SI, with females' use of SI dropping more than males. This result suggests that, despite the convenience of offering remote SI, in-person SI should continue to be offered when safe to do so. As the world transitions to the post-pandemic environment, it will be important to observe the lingering effects of remote learning, especially on students who started college during the pandemic and had to adapt to online and hybrid learning models.

References

[1] D. Xu and S. S. Jaggars, "Performance gaps between online and face-to-face courses: differences across types of students and academic subject areas," *The Journal of Higher Education*, vol. 85, no. 5, pp. 633-659, 2014.

[2] B. Means, Y. Toyama, R. Murphy, M. Bakia, and K. Jones, *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*. US Department of Education, 2009.

[3] K. B. Coletti, M. Covert, P. A. DiMilla, L. Gianino, and R. Reisberg, "Integrating supplemental instruction into freshman chemistry programs to support women in engineering," in *Proceedings of the American Society of Engineering Education 2012 Annual Conference and Exhibition*, San Antonio, TX, June 10-13, 2012.

[4] K. B. Coletti, M. Covert, P. A. DiMilla, L. Gianino, R. Reisberg, and E. Wisniewski, "Understanding the factors influencing student participation in supplemental instruction in freshman chemistry," in *Proceedings of the American Society of Engineering Education 2013 Annual Conference and Exhibition*, Atlanta, GA, June 23-26, 2013.

[5] K. B. Coletti, E. O. Wisniewski, R. L. Shapiro, P. A. DiMilla, R. Reisberg, and M. Covert, "Correlating freshman engineers' performance in a general chemistry course to their use of supplemental instruction," in *Proceedings of the American Society of Engineering Education 2014 Annual Conference and Exhibition*, Indianapolis, IN, June 15-18, 2014.

[6] E. O. Wisniewski, R. L. Shapiro, E. Kaeli, K. B. Coletti, P. A. DiMilla, and R. Reisberg, "The impact of supplemental instruction on the performance of male and female engineers in a freshman chemistry course," in *Proceedings of the American Society of Engineering Education 2015 Annual Conference and Exhibition*, Seattle, WA, June 14-17, 2015.

[7] B. J. Priem, C. Ghio, H. Boyce, S. A. Morris, E. Kaeli, T. B. Cole, P. A. DiMilla, and R. Reisberg, "A longitudinal study of the effects of pre-college preparation and use of supplemental instruction during the first year on GPA and retention for women in engineering," in *Proceedings of the American Society of Engineering Education 2019 Annual Conference and Exhibition*, Tampa, FL, June 16-19, 2019.

[8] R. L. Shapiro, E. O. Wisniewski, E. Kaeli, T. B. Cole, P. A. DiMilla, and R. Reisberg, "Role of gender and use of supplemental instruction in a required freshman chemistry course by engineering students on their course grades and subsequent academic success," in *Proceedings of the American Society of Engineering Education 2016 Annual Conference and Exhibition*, New Orleans, LA, June 26-29, 2016.

[9] T. B. Cole, E. Kaeli, B. J. Priem, C. Ghio, P. A. DiMilla, and R. Reisberg, "The influence of preconceptions, experience, and gender on use of supplemental instruction and academic success in a freshman chemistry course for engineers," in *Proceedings of the American Society of Engineering Education 2018 Annual Conference and Exhibition*, Salt Lake City, UT, June 24-27, 2018.

[10] J. Bourne, D. Harris, and F. Mayadas, "Online engineering education: learning anywhere, anytime," *Journal for Engineering Education*, vol. 94, no. 1, pp. 131-146, Jan. 2013.

[11] I. Chirikov, T. Semenova, N. Maloshonok, E. Bettinger, and R. F. Kizilcec, "Online education platforms scale college STEM instruction with equivalent learning outcomes at lower cost," *Science Advances*, vol. 6, no. 15, Apr. 2020.

[12] C. Fischer, L. Wu, F. Rodriguez, and G. Washington, "Evaluation of online learning in a first-year engineering design course," in *Proceedings of the American Society of*

Engineering Education 2018 Annual Conference and Exhibition, Salt Lake City, UT, June 24-27, June 2018.

[13] J. Self, *Teaching K-12 Science and Engineering During a Crisis*, Washington DC: The National Academies Press, 2020. [E-book]

[14] Z. Zhan and H. Mei, "Academic self-concept and social presence in face-to-face and online learning: Perceptions and effects on students' learning achievement and satisfaction across environments," *Computer Education*, vol. 69, pp. 131–138, Nov. 2013.

[15] M. Park, J. J. Park, K. Jackson, and G. Vanhoy, "Online Engineering Education Under COVID-19 Pandemic Environment," *International Journal of Multidisciplinary Perspectives in Higher Education*, vol. 5, no. 1, pp. 160-166, Jan. 2021.

[16] S. E. Hizer, P. W. Schultz, and R. Bray, "Supplemental instruction online: as effective as the traditional face-to-face model?," *Journal of Science Education and Technology*, vol. 26, no. 1, pp. 100–115, Feb. 2017.

[17] D. Rennar-Potacco, A. Orellana, P. Chen, and A. Salazar, "Rethinking academic support: improving the academic outcomes of students in high-risk STEM courses with synchronous videoconferencing," *Journal of College Student Retention: Research, Theory & Practice*, vol. 20, no. 4, pp. 455–474, Feb. 2019.

[18] E. Alden, "ConfChem Conference on Select 2016 BCCE presentations: changing roles for changing times—social media and the evolution of the supplemental instructor," *Journal of Chemical Education*, vol. 94, no. 12, pp. 2007–2009, Dec. 2017.

[19] L. S. Kao and C. E. Green, "Analysis of variance: is there a difference in means and what does it mean?," *Journal of Surgical Research*, vol. 144, no. 1, pp. 158–170, Jan. 2008.

[20] D. K. Lee, "Alternatives to p value: confidence interval and effect size," *Korean Journal of Anesthesiology*, vol. 69, no. 6, pp. 555–562, Oct. 2016.

[21] L. Liddon, R. Kingerlee, and J. A. Barry, "Gender differences in preferences for psychological treatment, coping strategies, and triggers to help-seeking," *British Journal of Clinical Psychology*, vol. 57, no. 1, pp. 42–58, July 2017.

[22] J. Jackson, "Gender differences in seeking help," Master's Thesis. Department of Psychology, Eastern Kentucky University, Richmond, KY, 2011.

[23] K. Janků, M. Šmotek, E. Fárková, and J. Kopřivová, "Block the light and sleep well: Evening blue light filtration as a part of cognitive behavioral therapy for insomnia," *Chronobiology International*, vol. 37, no. 2, pp. 248–259, Feb. 2020.

[24] S. Evans, E. Alkan, J. K. Bhangoo, H. Tenenbaum, T. Ng-Knight, "Effects of the COVID-19 lockdown on mental health, wellbeing, sleep, and alcohol use in a UK student sample," *Psychiatry Research*, vol. 298, Art. no. 113819, Apr. 2021.