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Evaluating Peer-Led Team Learning Integrated into Online Instruction in Promoting General Chemistry Student Success

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Jessica D. Young and Scott E. Lewis*

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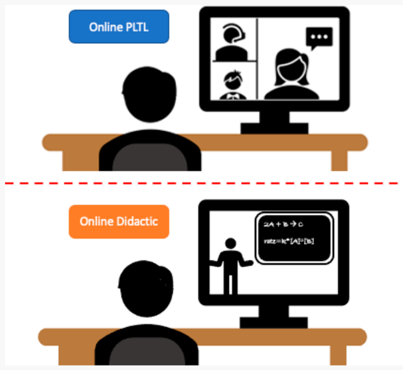
ABSTRACT: This study seeks to examine the effectiveness of peer-led team learning (PLTL) pedagogy when it is implemented in an entirely online environment. Past evaluations of PLTL have demonstrated the effectiveness of this approach when used with in-person teaching, but an online environment is expected to pose unique challenges to students, and therefore, the past work may not generalize to an online environment. The study implemented PLTL within four classes of second-semester general chemistry each offered online. The classes were evaluated in reference to six classes of the same course, also taught exclusively online, that relied primarily on didactic instruction. The evaluation showed the average score for students with online PLTL ranged from 0.15 to 0.20 standard deviations better than students with online didactic across the tests and final exams and that this difference was partially explained by past performance. Further, online PLTL students had a higher likelihood of earning a passing grade in the class which corresponded with a lower proportion of students failing and a lower proportion of students withdrawing from the course. The results indicate that PLTL was an effective instructional technique within an online modality at the research setting.



KEYWORDS: *First-Year Undergraduate/General, Chemical Education Research, Collaborative/Cooperative Learning, Internet/Web-Based Learning, Student-Centered Learning*

FEATURE: Chemical Education Research

A substantial evidence base has been compiled evaluating active learning in postsecondary chemistry education,[1] but nearly all of the literature involves in-person instruction. Left unanswered is whether the efficacy of these techniques would carry through to online instruction. With the pandemic necessitating online instruction at the research setting, an existing reform teaching model, peer-led team learning (PLTL),[2−4] that was already in place at the research setting[5] was adapted to support an online implementation in second-semester General Chemistry. This implementation provides an opportunity to evaluate the efficacy of the teaching model in an online environment relative to online instruction that relied primarily on didactic instruction. This evaluation can inform best practices with online instruction and explore the generalizability of previous evaluations into an online environment.

■ BACKGROUND

PLTL is a pedagogical model originating in use with postsecondary chemistry classes that has since been nationally disseminated and is currently in place at over 100 postsecondary schools. At its essence, PLTL relies on peer leaders, students who have recently, successfully completed a targeted course and return to a later iteration of the course to lead small groups of current students within the course. Peer leaders are trained in cooperative learning pedagogies, and this training can be integrated with reviewing the content of the targeted course to promote pedagogical content knowledge. In PLTL, the small groups of students are instructed to actively engage in problems with the peer leader serving as a resource if the students are stuck, a source of timely feedback on their progress, and to challenge students to explain their problem-solving processes. PLTL is thus uniquely well-suited for bringing active learning into large classes as the number of peer leaders can be recruited to maintain an amenable student-to-peer leader ratio.

The efficacy of PLTL to promote student achievement in postsecondary chemistry classes has been well-addressed in the research literature. Two recent meta-analyses have been

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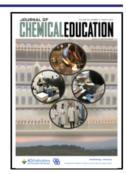

conducted on collectively 18 unique published research articles that examined the impact of PLTL versus a comparison condition on student achievement. The studies found PLTL led to an overall positive impact reporting an average weighted effect size of one-third of a standard deviation[6] or one-half of a standard deviation.[1] Each of these studies examined the impact of PLTL during in-person instruction while research on the efficacy of PLTL in an online environment has been considerably less frequent.[7] The most prominent example of evaluating PLTL in an online environment has been with cyber PLTL in the work of Varma-Nelson and her colleagues. In cyber PLTL, students attend an in-person lecture and attend synchronous, online problem-solving sessions working in small groups and led by a peer leader.[8] An evaluation of cyber PLTL was conducted comparing general chemistry student performance between those attending cyber PLTL and those attending in-person PLTL, where students self-selected into each format. It was found that, between the two formats, students had comparable averages on a standardized final exam, but the in-person PLTL students had higher course grades resulting in a higher passing rate.[8] A follow-on study compared these two formats within an organic chemistry setting and found that students attending in-person PLTL were more likely to enact electron pushing formalism correctly than students attending cyber PLTL.[9] Combined, these studies demonstrate the feasibility for offering an online PLTL experience and highlight some challenges in accomplishing learning objectives with online PLTL compared to in-person PLTL. To date, no literature has evaluated the efficacy of online PLTL relative to online didactic instruction.

There are many challenges particular to online learning,[10] and the extent that PLTL supports student success is unknown when faced with these challenges. Online learning represents a change in course structure that will influence students' experiences with a course. In online learning, there is a reduced social pressure or physical presence of a teacher which reduces the social norm of participating in a class and reduces the formal and informal cues about the timing or relative importance of assignments or exams. Often, students in an online learning environment are tasked with more self-directed learning, where students have more control over sequence, pace, and amount of content, than they would be in-person.[11] The increase in student control can be an advantage as self-directed learning increases autonomy, a universal psychological need, and can lead to higher engagement and academic performance;[12] however, not all students are prepared for the amount of self-directed learning that is required in online learning and may perform poorly.[13]

An increase in self-directed learning with online learning is expected to require an increase in student motivation that is necessary to be successful. Students may need to keep pace with coursework and deadlines more than they would during an in-person course. A study in 2020 by Jeffery and Bauer[14] found that a significant majority of students had negative responses when describing their motivation during emergency remote learning. A decrease in motivation may manifest itself as a decrease in student engagement, defined as the amount of and manner in which one takes part in their own learning, and online learning has also been associated with a decrease in students' engagement.[10,14] Further, in online courses both motivation and engagement have been related to academic success.[15,16]

In addition to motivation and engagement, online learning is expected to influence students' identity formation. Identity is heavily shaped by the individual, the world, and the people with whom one interacts.[17] Often learners feel isolated and disconnected in their online courses due to the lack of a sense of identity and community resulting from a lack of social interactions and structure.[14,18] These feelings of isolation from their peers and teachers hinder the development of a strong sense of identity. However, a strong sense of identity in the classroom plays a critical role in how well students are able to interact socially to cocreate the knowledge base that is necessary to succeed as described in social constructivism.[10] Student identity also plays a role in students' sense of belonging. As one needs to feel they are a valued member of a community in order to fully partake in this knowledge construction, online learning's increased student isolation may not facilitate a strong sense of belonging.[19] Failure to establish a sense of belonging is expected to lead to the aforementioned challenges in motivation and engagement.[10,15]

■ RATIONALE

Online instruction faces unique challenges in students' motivation, engagement, identity, and sense of belonging; thus, it is not clear whether past work evaluating the efficacy of in-person PLTL relative to other modes of instruction would generalize to an online environment. This study seeks to explicitly address this question by comparing online PLTL to online didactic instruction, a comparison that is of direct relevance when an institution is offering online-only instruction. Past work with cyber PLTL provides support for online PLTL to be as effective as in-person PLTL, but it is important to note that cyber PLTL included regular in-person class meetings, and thus, a complete online-only class that used PLTL has yet to be evaluated.

Past work evaluating PLTL has alternated between measuring student retention (e.g., proportion of enrolled students who earn a passing grade) and student achievement (e.g., student performance on an exam).[6] We argue that student retention and student achievement are inextricably tied together. Students who are struggling or experiencing unsatisfactory performance during the semester are more likely to withdraw from a course than students who experience satisfactory performance. This form of selective attrition is important in evaluating pedagogical reforms, as a pedagogy can experience a high withdrawal rate that disproportionately excludes struggling students resulting in an inflated level of academic achievement on later measures of academic achievement.[20] To account for this, it is necessary to measure both student retention and academic achievement in evaluating the impact of a pedagogical reform on student success. Informed by this concern, this study seeks to explore the following research questions:

(1) What is the impact of online PLTL instruction on General Chemistry II (GC2) students' academic achievement relative to online didactic instruction?
(2) What is the impact of online PLTL instruction on GC2 student retention relative to online didactic instruction?

■ METHODS

Research Setting

The study takes place at a large, research-intensive university in the southeastern United States. At this setting, the course GC2 is the second of a two-semester sequence of courses that is required for students majoring in nearly all science fields including chemistry, biology, physics, geology, and environ-

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mental science. The course covers intermolecular forces, properties of solutions, chemical kinetics, chemical equilibrium, weak acids and bases, buffers, thermodynamics with a focus on spontaneity, and electrochemistry. Class sizes ranged from 120 to 271 students per class. There were 10 GC2 classes offered during an academic year, and during this time, all classes were offered exclusively online owing to the COVID-19 pandemic. Of the 10 classes, three were offered during the Fall 2020 semester, and seven were offered during the Spring 2021 semester. In 6 of the 10 online classes, instructors presented content or demonstrated worked solutions either in twice weekly 75 min synchronous meetings with the students (three of the classes) or through posted videos that could be accessed at any time (three of the classes). The synchronous sessions were augmented with opportunities for students to answer questions or occasionally times where students were tasked with working a problem prior to the instructor reviewing a worked solution. The asynchronous classes offered optional, online office hours where students could ask questions. These classes will be referred to as didactic online in this paper owing to their reliance on didactic teaching methods either during the synchronous components of the course or through the posted videos. An analysis comparing the synchronous and asynchronous classes found no consistent differences between the two and is described in the Supporting Information.

The other four online classes had one class meeting per week similar to the above synchronous sessions and reserved the other class meeting to implement a student problem-solving session modeled after peer-led team learning (PLTL). These classes are labeled online PLTL. During this weekly PLTL session, students joined separate online breakout rooms with 10−16 students and one peer leader assigned to each breakout room. The peer leader placed the students in smaller groups of three to four, and the students were given a set of problems to complete during the class session. Prior to the problem-solving session, the peer leader participated in weekly training sessions where the course instructor modeled PLTL for the peer leaders by assigning the peer leaders the same problem set their students would see later in the week and having the peer leaders work in groups on the problem set. One major goal of the training was to emphasize active learning. In line with this goal, peer leader training prioritized (1) serving as a resource when students were stuck on a problem, (2) challenging students to explain their problem-solving process, and (3) avoiding working problems for students or the directly presenting content to students. During the students' problem-solving sessions, the instructor would periodically visit and provide feedback to each peer leader toward reaching these goals. The problem-solving sessions were run in the learning management software Canvas using their Blackboard Collaborate Ultra feature. Students could share video and microphone and communicate in real time or chat via a textbox. Students also had access to a shared virtual whiteboard where they could present their work to the rest of their group in real time. In this way, students enrolled in a large class using online instruction can still participate in active learning and receive personalized timely feedback from both their peers and peer leader.

The classes used common tests that were given at a common time during the semester, and the classes used a common grading scheme. There were three tests and one cumulative final exam given in each semester with each test counting toward 15% of students' grades and the final exam as 25%. In addition, students' grades were determined by a set of online homework assignments that were common across all classes, counting for 10%, and instructors had discretion to set assignments worth 20% of students' grades. Among the online PLTL classes, 5% of this 20% was allotted for regularly attending the online PLTL class meetings, and the remaining 15% were used for online assessments where students had multiple attempts. Among the online didactic classes, all 20% were used for similar online assessments.

Data Collected

The instructors for the set of GC2 classes offered each semester built tests by committee, by splitting up the relevant learning objectives and writing test questions to measure the assigned learning objectives. The question sets were brought together and reviewed and revised by the group of instructors to develop a final version of the test. The test is then given to all the GC2 classes at the same day and time online via the course learning management software. Each semester, the process repeats owing to a concern that the prior semester's exam was no longer secure. Thus, each semester has a different set of tests, but the content coverage for each test is common across semesters. That is, test 1 from Fall 2020 covers the same content and is based on the same learning objectives as test 1 from Spring 2021, although the questions are different. Since the test questions differed from semester to semester, combining test scores from different semesters was problematic as the tests may differ in overall difficulty. To account for possible differences in difficulty, Z-score standardization for each semester's data was performed setting the average score to 0 and the standard deviation to 1. Thus, a Z-score value of 0 indicates that a student's score is identical to the mean score of a test taken by the same cohort as the student, and a Z-score of 0.5 would indicate a student scoring 0.5 standard deviations above the mean score. Z-Scores may be positive or negative, with a positive value indicating that the score is above the mean and a negative score below the mean. After the standardization process, the test scores from the fall and spring semesters were combined. The university's Institutional Review Board reviewed the research protocol and approved this research as a review of educational records.

Analyses Conducted

The evaluation plan is a quasi-experimental design comparing students enrolled in intact classes that used different pedagogies to determine the impact of the pedagogy. One threat to this design is the potential for self-selection bias where students who enroll in courses with one of the pedagogies may have incoming differences from students who enroll in courses with the other pedagogy. These incoming differences may include differences in relevant past achievement or motivation to pursue their studies. While it is not possible to eliminate this threat with the study design, the threat can be mitigated by controlling for a measure of past performance. To do so, students' final exam scores from General Chemistry I (GC1) and final grades from GC1 at the research setting were also collected from the Spring 2020 and Fall 2020 semesters, which directly precede the GC2 semesters being investigated. Instructors in GC1 created common tests in the same fashion as GC2 described above, and thus, the GC1 cumulative final exam scores were Z-score standardized for each semester prior to combining scores across two semesters.

To evaluate the first research question, an independent t-test will be used on each GC2 exam comparing the two pedagogies with differences characterized by effect size. To control for past performance, this analysis will be repeated after a case-matching

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approach where a subset of students from each pedagogy are identified that have identical distributions of GC1 course grades. To evaluate the second research question, student outcomes, such as passing, failing, or withdrawing from the course, will be evaluated using a χ^2 statistic. To control for past performance, a logistic regression will be conducted using the Z-score for the GC1 final exam and pedagogy as predictors and students passing the course as a dichotomous outcome variable.

RESULTS

Research Question 1 (Impact on Academic Achievement)

From the 10 GC2 classes, the total initial enrollment was 2157 students, and of those, 983 students were enrolled in an online PLTL class and 1174 students were enrolled in an online didactic class. To answer the first research question, academic achievement was measured by the set of standardized exam scores. The average Z-scores for students from each pedagogy for each exam are presented in Table 1. The average scores from students with online PLTL were consistently higher than the average scores from students with online didactic. The observed differences had an effect size ranging from 0.15 to 0.20, where an effect size of d = 0.20 is considered small.[21] An independent sample t-test was conducted for each exam, presented in Table 2, and with a Type I error threshold set to 0.05, each observed difference was found to be statistically significant. To put the observed differences into context, with the Fall 2020 data, average scores for online PLTL scores were higher than online didactic from 3.2% to 4.2% for each exam.

Table 1. Exam Averages by Pedagogy

Exam	Online PLTL	Online Didactic
Exam 1 average (std dev, N, percent enrolled)	0.080 (0.987, 819, 83.3%)	−0.073 (1.006, 906, 77.2%)
Exam 2 average (std dev, N, percent enrolled)	0.105 (0.938, 764, 77.7%)	−0.090 (1.042, 890, 75.8%)
Exam 3 average (std dev, N, percent enrolled)	0.097 (0.951, 711, 72.3%)	−0.090 (1.035, 767, 65.3%)
Final exam average (std.dev, N, percent enrolled)	0.079 (0.973, 764, 77.7%)	−0.075 (1.019, 799, 68.1%)

Table 2. Independent Sample t-Test Results

Exam	t-Test (Significance, Cohen's d)
Exam 1	3.19 (0.001, 0.154)
Exam 2	3.99 (<0.001, 0.197)
Exam 3	3.59 (<0.001, 0.187)
Final exam	3.06 (0.002, 0.155)

In reviewing the test score data collected, one area of note was the sizable amount of missing data. At the research setting, students were able to take a makeup exam at a later date, and since the makeup exam was different than the original test and it was taken by considerably fewer students, the decision was made to not include these test scores in the evaluation of the pedagogy. Students who missed the original test and took a makeup may be more likely to struggle or withdraw from a course, representing selective attrition in the data. Therefore, a possible concern in this evaluation was that if one pedagogy had a higher rate of missing data, it could result in higher test scores for the original test. To determine if this was the case, the percentage of enrolled students who took each exam by pedagogy is also reported in Table 1. It was found that online PLTL had a consistently higher proportion of students taking each exam, and therefore, the higher exam scores with online PLTL cannot be attributed to a higher amount of selective attrition.

As the analysis relies on a quasi-experimental design, the analyses were also conducted with a control for students' past performance as measured by GC1 grades. GC1 grades were available for 1316 students, representing 61.0% of the overall sample, with likely reasons for missing a GC1 grade including taking GC1 at another institution, placing out of GC1 based on performance in a high school curriculum, or taking GC1 in an alternative term than when the data was collected. The GC1 grade distribution for the students in online PLTL was compared to the grade distribution of students in online didactic and presented in Figure 1a. In this figure, DFW represents students receiving a grade of C−, D, or F, or withdrawing, which meant they had to take GC1 again before enrolling in GC2. A greater proportion of students with online PLTL earned grades of A+, A−, or B+ grades in GC1 than the proportion of students with online didactic; conversely, a greater proportion of students with online didactic earned grades of B, C + or C than online PLTL. To account for the differences in past student performance in GC1, a case-matching approach was used to create subsets of the online PLTL students and the online didactic students, which have an identical distribution of GC1 grades. Case-matching was done using SPSS version 27 which randomly selects matched pairs from each pedagogy with identical GC1 grades until matches can no longer be made. Owing to missing data that differed for each GC2 exam, the case-matching was conducted separately for each GC2 exam. The distribution of GC1 grades for each pedagogy after case-matching for the first GC2 exam is presented in Figure 1b.

The average Z-scores for each pedagogy on each exam, using the case-matching approach, are presented in Table 3. After the case-matching procedure, the average scores from students with online PLTL remained consistently higher than the average scores from students with online didactic although the differences in scores are smaller than what was observed with the overall sample in Table 1. Independent sample t-tests were conducted, and effect sizes were calculated for the case-matched data. The results are presented in Table 4. The t-tests found statistical significance only on exam 3 and the final exam among the case-match sample. Effect sizes for the case-match sample ranged from 0.04 to 0.14, while the overall sample had effect sizes from 0.15 to 0.20.

From the case-matching approach, it appears that some of the differences observed between pedagogies can be accounted for by students in the online PLTL having performed better in the past as shown in Figure 1a. However, when accounting for past performance by the case-matching approach, students in the online PLTL classes on average overperformed the students with the online didactic classes on the latter two exams offered.

Research Question 2 (Impact on Student Retention)

Turning to the second research question which focuses on student retention, it was noted that a high amount of missing data was found among the test scores. For example, 72.5% of students overall had a final exam score. Missing data could represent students electing to take a makeup exam, or it could represent student attrition in the form of withdrawing from the course or abandoning the course. Abandoning the course would involve no longer taking tests, completing assignments, or attending class and would result in a failing grade. Student attrition is of particular concern in pedagogical evaluation, and

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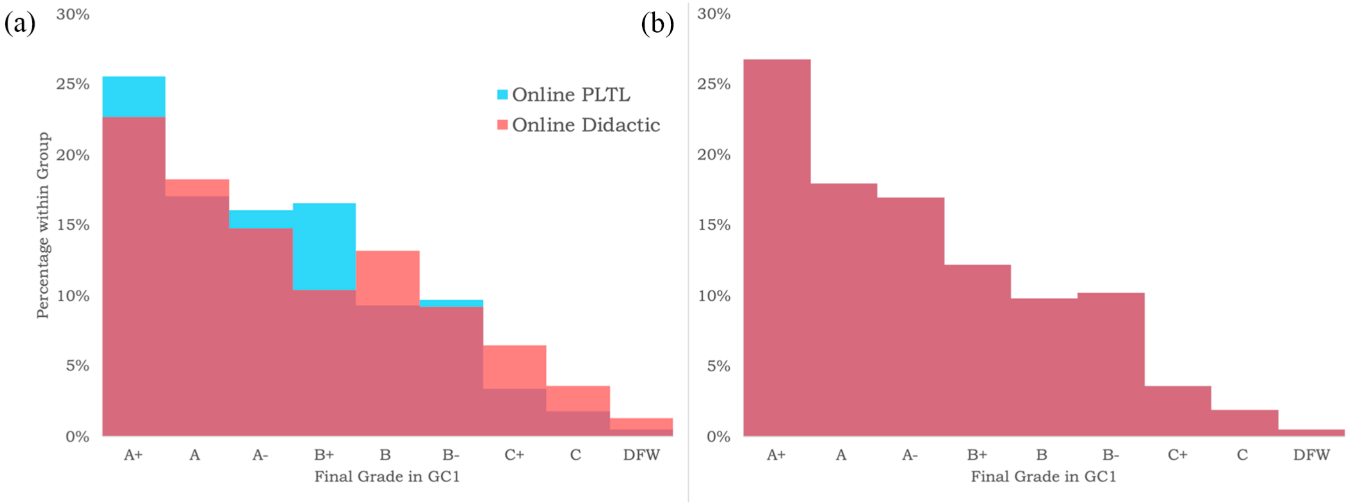

Figure 1. (a) GC1 grade distribution for each pedagogy and (b) GC1 grade distribution after case-matching for those who took GC2 exam 1.

Table 3. Case-Matched Exam Averages by Pedagogy

Exam	Online PLTL	Online Didactic
Exam 1 average (std dev, *N*)	0.140 (0.974, 589)	0.097 (0.939, 589)
Exam 2 average (std dev, *N*)	0.162 (0.939, 560)	0.117 (0.939, 560)
Exam 3 average (std dev, *N*)	0.164 (0.947, 511)	0.031 (0.961, 511)
Final exam average (std dev, *N*)	0.154 (0.981, 544)	0.030 (0.969, 544)

Table 4. Independent Sample *t*-Test of Case-Matched Exam Values

Exam	*t*-Test (Significance, Cohen's *d*)
Exam 1	0.77 (0.221, 0.045)
Exam 2	0.81 (0.209, 0.048)
Exam 3	2.22 (0.013, 0.139)
Final exam	2.10 (0.018, 0.127)

thus, student retention by pedagogy was investigated. Student retention was characterized by whether they completed the course with a passing grade, completed with a failing grade, or withdrew during the semester. A passing grade was operationalized as grades of C or higher which at the setting are the grades needed to satisfy the most common prerequisite requirements. The proportions of students enrolled in each pedagogy receiving a passing grade, receiving a failing grade, or withdrawing during the semester are presented in Table 5.

Table 5. Academic Outcome by Pedagogy

Outcome	Online PLTL	Online Didactic
Percent passing	79.7%	68.3%
Percent failing	12.3%	19.1%
Percent withdrawn	8.0%	12.6%

Students with the online PLTL instruction had a higher pass rate by 11.4% and correspondingly were less likely to fail or withdraw from the class. The relationship between pedagogy and academic outcome was statistically significant ($\chi^2 = 35.253$, $p < 0.001$) with a Cohen's $w = 0.13$, where $w = 0.10$ represents a small effect size.[21]

To determine if the impact of online PLTL on the pass rate was present after controlling for past performance, a logistic regression was run. In the regression, the dichotomous variable of passing was modeled to predict whether students passed GC2 (as defined above) or did not pass (received a failing grade or withdrew). The regression used the final exam *Z*-scores from GC1 and the presence of online PLTL in GC2 as the two predictor variables. The results of the regression are presented in Table 6 and show that the students with online PLTL had a higher pass rate in GC2 after controlling for past performance in GC1.

Table 6. Logistic Regression Predicting GC2 Passing

Variable	Coefficient	Standard Error	Significance
Constant	1.86	0.13	<0.001
Online PLTL in GC2	0.518	0.191	0.007
GC1 final exam *Z*-scores	1.71	0.13	<0.001

To illustrate the impact of online PLTL in the regression equation, the proportion of students modeled to pass the course was plotted based on their GC1 *Z*-score with separate plots for students in online PLTL and online didactic; this plot is shown in Figure 2.

In terms of practical impact, the model shows that students at the average GC1 final exam score (*Z*-score = 0) with online PLTL were expected to have a pass rate 5% higher than online didactic and a difference as much as 13% higher among students whose GC1 final exam scores were 1.2 standard deviations

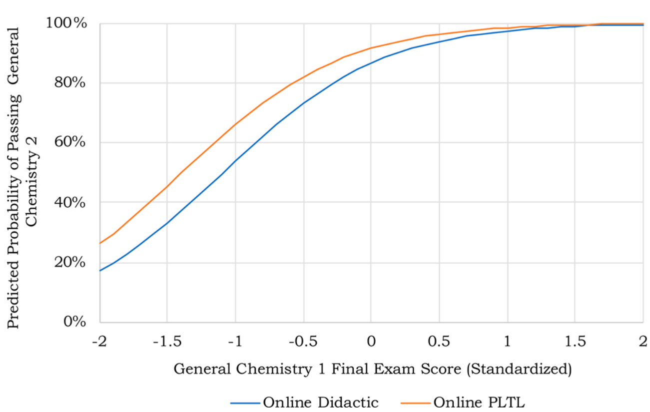

Figure 2. Logistic regression predicting probability of passing GC2 based on GC1 final exam score and online pedagogy.

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below the mean. Among students with GC1 final exam scores greater than 0.5 standard deviations above the mean, a ceiling effect takes over where the pass rates are near 100%, and there was no meaningful difference between the two pedagogies.

■ DISCUSSION

To evaluate the pedagogy, the impacts on students' test scores and student retention need to be considered simultaneously. Both metrics suggest a positive impact of online PLTL compared to online didactic. Students in online PLTL had a higher performance on each test compared to students in online didactic. The higher performance with online PLTL was true even as a greater proportion of students from this pedagogy took each test, and when controlling for past performance, this impact was only partially lessened. In terms of student retention, online PLTL resulted in a higher percent passing than online didactic. The difference in pass rates would mean that if the online didactic had the same pass rate as online PLTL, it would result in 133 more students passing the class out of the 1174 students enrolled. While the effect size observed is small, the practical effect observed should also be considered.

While the online PLTL offered gains in student success compared to online didactic, it is worth characterizing how these observed gains place within the context of the published literature on the impact of PLTL during in-person instruction. This characterization would describe whether the implementation of the PLTL pedagogy was amplified or ameliorated by the incorporation into an online teaching environment. The observed effect sizes of online PLTL on students' test scores ranged from Cohen's d of 0.15 to 0.20. In the aforementioned meta-analyses, this range of observed effect sizes falls at the bottom end of the range of effect sizes observed in the literature.[1,6] In considering the impact on student pass rates, four studies examined the impact of PLTL on students' pass rates. Among those studies, Mitchell and colleagues's study[22] is the most directly comparable to the current study as both examined student performance in GC2. In the study by Mitchell and colleagues, the observed pass rate with PLTL was 72% compared to 60% with teaching as normal. The difference in pass rate of 12% is comparable to the difference of 11.4% observed herein. Other studies also reported differences in pass rates of 11% with implementation in organic chemistry[23] and 12% in general chemistry,[20] while one study reported a gain of 23% in an allied health chemistry course.[24] Two of these studies reporting gains in pass rates also reported medium effect sizes on students' test scores with Cohen's d reported as 0.63[23] and 0.66,[24] substantially more than what was observed herein. In summary, the observed effects of online PLTL in the current study are in line with the range of impacts observed with PLTL in person in the literature, although they may be placed toward the lower end of the range of impacts observed.

With the adoption of online instruction, there was an expected increase in the extent students engage in self-directed learning which required a higher amount of student motivation in order for students to succeed. Further online learning has the potential to encounter challenges including students not forming identities as a chemistry student, students feeling a sense of isolation, or students lacking a sense of belonging. Each of these phenomena represent additional challenges which could hinder student motivation in online learning, precisely when it is needed the most. Online PLTL has the potential to address these challenges by purposefully building in student-to-student conversations into the class time and feedback and interactions in the form of student-to-peer leader conversations. Finding that online PLTL resulted in improved student performance and pass rates relative to online didactic offers support for this possibility, though future work would be needed that seeks to measure one or more of these constructs to determine the direct role online PLTL has on these constructs. In working with the online PLTL pedagogy, it was observed that some students failed to engage with their assigned groups owing to either a lack of motivation to do so or technical difficulties and ranged from students who did not engage throughout the semester to students facing challenges for only one session. Thus, one possible explanation for the lower effect sizes observed is that the pedagogy worked for a portion of the students and failed to reach the remaining students. A prevalent example of technical difficulties that hindered engagement was students not having a microphone that worked. These students frequently relied on the chat feature in the discussion board, but this means of communication was considerably slower and less detailed than audio communication. Some adaptations that were made during the second semester of the study included listing a microphone among the required course materials and developing an introductory video that showed the different features of the online discussion board.

It is also important to recognize the limitations of the work presented. This study represents a quasi-experimental evaluation of a pedagogy, and thus, the observed differences could be attributed to past differences in student motivation or achievement that resulted from students' self-selecting among the GC2 classes. Efforts to mitigate this potential impact include incorporating data across two semesters; in one of these, online PLTL represented a majority of classes offered and the other a minority of the classes offered. In addition, each finding was also tested while controlling for student performance in GC1, a prerequisite course. Still, potential incoming differences among students could be present that are unaccounted for by these efforts. Finding the congruence with the observed literature on in-person PLTL effectiveness is promising, but as this work was conducted at a single institution and online PLTL has not been evaluated in the literature previously, it is unclear to what extent these results would generalize to other institutions. Future work exploring the impact of online PLTL on student achievement would assist in describing the generalizability of these results to other instructional settings. In addition, this work did not explore a theoretical mechanism linking the online PLTL pedagogy with gains in student achievement, and thus, it is not clear which aspect(s) of online PLTL may be essential to promoting student success. Future research in testing such theoretical mechanisms is needed and would inform adaptations of the pedagogy to other institutional settings.

At the current research setting, as the pandemic has continued, GC2 classes have intermittently switched between in-person and online instruction. PLTL in GC2 has been flexible to be used across both formats, with this work setting the groundwork for incorporating the pedagogy into online instruction. The use of PLTL in GC2, either in person or online, is expected to continue in part owing to the results observed herein. Additional gains with the pedagogy are also considered in this decision including the training and experiences gained by the peer leaders and the development of teamwork and communication skills by the students. Future adaptations of online PLTL may incorporate cloud-driven files, such as Google Docs, where student groups can work

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simultaneously on a shared document and an instructor can observe student progress more readily.[25]

IMPLICATIONS FOR EDUCATORS

Educators can improve student outcomes by using active learning in the classroom, even in an online-only environment. Active learning can be incorporated by regularly placing students in small groups and assigning problem sets in line with how the students will be assessed. A key feature of active learning appears to be frequent support in the form of feedback on student progress and serving as a resource when students get stuck. With small classes, an educator can provide sufficient timely support without assistance. With large classes peer leaders can facilitate this support, while the educator would engage in supporting the peer leaders. Support for the peer leaders includes training the peer leaders on active learning techniques and providing timely feedback to the peer leaders on their role in the course.

CONCLUSIONS

Online PLTL was found to be effective in promoting student achievement and retention at the research setting relative to online didactic instruction. This finding serves to expand the research literature evaluating PLTL efficacy into an online modality and suggests that PLTL is a robust approach within both in-person and online instruction. Further, the results serve as an impetus to continue PLTL, either in-person or online, at the research setting. Finally, the results serve as a starting point for expanding the evaluation of evidence-based pedagogical approaches in chemistry education into online instruction.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.1c01118.

Analysis comparing the three pedagogical variants: online PLTL, online synchronous didactic, and online asynchronous didactic (PDF, DOCX)

AUTHOR INFORMATION

Corresponding Author

Scott E. Lewis − *Department of Chemistry, University of South Florida, Tampa, Florida 33620, United States;* orcid.org/0000-0002-6899-9450; Email: slewis@usf.edu

Author

Jessica D. Young − *Department of Chemistry, University of South Florida, Tampa, Florida 33620, United States*

Complete contact information is available at:
https://pubs.acs.org/10.1021/acs.jchemed.1c01118

Notes

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