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Piloting Blended Strategies To Resolve Laboratory Capacity Issues in a First-Semester General Chemistry Course

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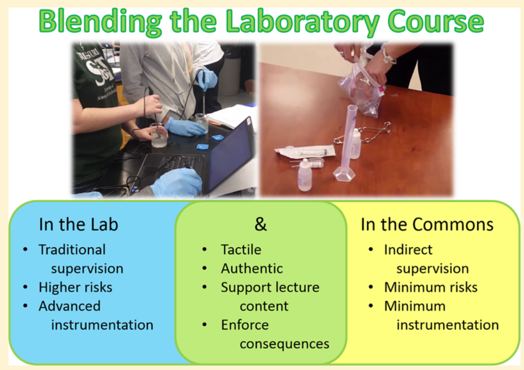
ABSTRACT: Laboratory capacity is an issue that has plagued education for more than a century. New buildings, late night classes, and virtual laboratories have offered transitory relief at great expense. Missouri University of Science and Technology is employing blended strategies to increase capacity and student success. Blended strategies expand learning workspaces so that learners conduct traditional laboratory activities in both traditional and nontraditional laboratory environments. This article focuses on the proof of concept pilot results from blending the first-semester general chemistry laboratory course, which validate the adoption of this strategy for increasing student volume.



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INTRODUCTION

The challenge of inadequate laboratory space is not a new problem. Over the years, institutions have reported and addressed the issue with a multitude of approaches. The Annual Report from Pennsylvania State College shows that the institution was having to move students out of laboratory spaces due to crowding in 1900.[1] Sixteen years later, a separate edition of the same report stated that "in spite of the large addition made to the chemistry laboratory in September 1915, it is already so crowded that satisfactory work is difficult to obtain".[2] Nearly 100 years later, the California State University system is facing the identical challenge of a lack of sufficient space in bottleneck courses.[3]

Such reports and incidents have led the development of policies and best practices. The International Code Council, Building Officials and Code Administrators, National Fire Protection Association (NFPA), and National Science Teachers Association (NSTA) have each published positions with regard to room capacity and student−instructor ratio.[4−7] Keeping these policies and best practices in mind, institutions either construct new facilities or employ imaginative solutions.[8−10] The California State University system invested in virtual courses to double enrollment capacity in 2013.[11] Princeton University completed construction on the new Frick Chemistry Laboratory building in 2010 that will serve several hundred undergraduate students.[12] State Fair Community College in Sedalia, Missouri, has reduced strains on resources by utilizing take-home activities in chemistry laboratory courses with increased content acquisition noted in students enrolled in blended courses.[13−15] Cape Fear Community College in Wilmington, North Carolina, noted higher student test scores for students enrolled in distance chemistry courses compared to conventional students in face-to-face courses.[16]

The American Chemical Society (ACS) has stated that virtual laboratories are an appropriate supplement but not a suitable replacement for physical laboratory experiences.[17] The California State University system agrees and also identified virtual laboratories to be inadequate for science majors.[11] With unlimited funds, time, and space, new facilities are ideal. The majority of institutions, however, are not fortunate enough to be able to build new laboratory spaces every time that they grow past their physical space and time constraints. Each individual situation requires a tailored solution that fits the resources available with the needs of the institution. This paper presents a malleable solution to inadequate laboratory capacity; blended learning opportunities safely allow learners to conduct half of the traditional activities outside of the traditional laboratory setting, which allows for a doubling in capacity without sacrificing established learning goals, which are defined

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as the desired results that establish priorities for instruction and assessment.[18]

TRADITIONAL LABORATORY ACTIVITY CHALLENGE

At Missouri University of Science and Technology (Missouri S&T), the General Chemistry I laboratory course (CHEM 1319) usually taken during the first year has reached the point where expansion is imperative. End-of-term census numbers show that, since the fall of 2010, course capacities have reached an average of 94% capacity (see Table 1) despite measures to increase the absolute number of students served. In the 2012–2013 academic year, Missouri S&T offered 48 more seats by increasing the number of students per section. With this increase, the section size (24 students) approached the maximum student–GTA ratio (25 students) set forth in the ACS guidelines. For fall semester 2014 and fall semester 2015, the campus registrar requested additional sections due to increased enrollment projections. Accordingly, in the 2014–2015 academic year, the course incorporated an additional 96 seats, making the laboratory space occupied 5 days a week in morning, afternoon, and evening sessions, leaving little to no time for experiment preparation and setup.

Table 1. Students Enrolled in CHEM 1319 Based on End-of-Semester Census Data

Academic Year	Enrollment Capacity for CHEM 1319,[a] N	Student Enrollment in CHEM 1319,[a] N	Enrollment Relative to Capacity, %
2010–2011	1008	944	94
2011–2012	1008	953	95
2012–2013	1056	959	91
2013–2014	1056	995	94
2014–2015	1152	1055	92

[a]General Chemistry I laboratory course; corequisite yet independent of Chemistry I lecture course (CHEM 1310).

Even with the added sections and the increased section size, the Chemistry Department was unable to accommodate all students enrolled in the corequisite but independent General Chemistry I lecture course (CHEM 1310). With the current scheduling and space limitations, additional seats are not practical, and the disparity between enrollments in CHEM 1319 and CHEM 1310 has swelled. The lecture- and recitation-based CHEM 1310 has recently undergone a whole-course redesign, which significantly increased the available seats from 1056 in the academic year 2010–2011 to 1479 in the academic year 2013–2014 (see Table 2).[19,20] The lecture course is now a buffet-style blended course that allows students to choose between attending the lecture face-to-face in the classroom or synchronously online from a location of their choice. The recitation portion of the course offers similar options, collaboratively face-to-face or independently online. Because CHEM 1310 and CHEM 1319 are complementary parallel courses, it is highly desirable that both courses serve the same number of students. This is particularly important because all science and engineering majors at Missouri S&T require both courses in their undergraduate degree programs. For example, in the fall of 2013, the number of full-time freshman engineering undergraduates at Missouri S&T was 1386. While CHEM 1310 could accommodate all of the students in the cohort, CHEM 1319 could serve only 76% of the population in that academic year.

Table 2. Students Enrolled in CHEM 1310 Based on End-of-Semester Census Data

Academic Year	Enrollment Capacity in CHEM 1310,[a] N	Students Enrollment in CHEM 1310,[a] N	Enrollment Relative to Capacity, %
2010–2011	1056	1043	99%
2011–2012	1056	1032	98%
2012–2013	1056	1032	98%
2013–2014	1479	1090	74%
2014–2015	1479	1141	77%

[a]General Chemistry I lecture course; corequisite yet independent of Chemistry I laboratory course (CHEM 1319).

TRADITIONAL LABORATORY ACTIVITY SOLUTION

Because additional space and time slots are not available, Missouri S&T decided to seek alternative methods to increase course capacity. An ideal solution should retain an experiential learning format to align with the campus strategic plan, improve learner confidence, and support content acquisition.[21−23] The solution should also circumvent the physical space limitations while allowing the course to continue meeting NSTA and NFPA best practices regarding student-to-teacher ratio and physical space per student.[5,7]

Before exploring potential solutions, the Department recognized specific criteria. Foremost, the experiments conducted need to support the learning objectives identified in the related lecture/recitation course.[24,25] Several of the selected laboratory experiments are only suitable for a traditional laboratory setting because of the instrumentation and chemical hazards associated with the activities. However, some of the activities do not require complex instrumentation, hazardous materials, or even direct supervision while still reinforcing key concepts presented in the lecture. These less hazardous activities naturally lend themselves to a less supervised environment in which students work in a more self-directed and independent manner.

With the above requirements and limitations in mind, a blended laboratory course was designed in which students would conduct half of their activities in the traditional laboratory space (In-the-Lab activities) and the other half in common spaces (In-the-Commons activities). A blended course delivery format allows for a more efficient use of the available space and time slots, effectively doubling the student throughput without sacrificing the traditional laboratory experience. All of the activities involve physical manipulation of reagents and/or equipment to observe the explored chemical phenomena and develop hands-on laboratory skills. Students conduct the more hazardous activities In-the-Lab and experience the less hazardous activities In-the-Commons providing additional opportunities to develop noncognitive skills and self-reliance. The course retains the same number of meeting hours; however, half of the hours occur outside of the traditional laboratory environment.

COURSE ORGANIZATION

Each week, half of the students work in the traditional laboratory space while the other half work in pairs outside of the traditional laboratory space to perform a separate but related activity. The following week, the two groups trade and

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conduct the other activity. This arrangement allows doubling the course capacity without compromising the physical, experiential, and hands-on nature of traditional laboratory activities. Supplies for In-the-Commons activities are packaged in kits that contain all reagents and materials necessary for the activity. For safety and expense concerns, only plastic versions of traditional lab glassware (such as beakers, graduated cylinders, etc.) are provided in the check-out kits, while regular glassware is used for In-the-Lab activities. The kits are checked out at the end of an In-the-Lab activity and returned 2 weeks later at the beginning of the next In-the-Lab activity. To keep track of the kits, an inventory system is employed utilizing a magnetic card swipe, a barcode reader, and a spreadsheet program. To check out a kit, both student lab partners must swipe their student ID cards before a graduate laboratory assistant scans the barcode affixed to the outside of the kit. The acquired information is automatically saved in a specially designed electronic spreadsheet.

Students are required to work with their lab partner for In-the-Lab activities and strongly encouraged to do the same for In-the-Commons activities. Collaboration and consultation between sets of partners is condoned for In-the-Commons activities as the development of interpersonal, collaborative skills is one of most important soft skills fostered with the blended lab model. To ensure completion and participation of In-the-Commons activities and minimize copying work of others, learners were required to include in the images of their electronic homework submissions a unique nametag that was created during the initial laboratory meeting and approved by the instructor (cf. Table 3, first row).

Before choosing appropriate laboratory activities, the Department identified concepts that would best align with the lecture/recitation course CHEM 1310 and then selected activities to direct the learning environment to allow students to rotate between In-the-Lab and In-the-Commons work areas. In essence, pairing activities involving minimal-risk instrumentation with activities of greater-risk instrumentation supported a rotating schedule. Each of the activities chosen for this course is broad enough in scope to address topics covered in 2 weeks of the lecture course. Students who perform the activity in the first week may receive an introductory treatment of the topic in lecture and recitation, while students performing the activity the following week may have already received a more thorough treatment of the topic by that time. Both scenarios complement and support the lecture material: the former in providing scaffolding for the more rigorous and detailed treatment of the material in the lecture course, and the latter in reviewing and concretizing the information.

Activities were selected based upon their inclusion of tactile, authentic, and responsive characteristics. In the experience of the investigators, activities with these qualities were deemed most likely to affect the desired learning outcomes. Tactile activities maximize learner involvement and engage as many of the students' senses as possible through visual color changes, audible fizzing, palpable temperature changes, and noticeable odors. Authentic activities enable learners to feel like real scientists, applying their knowledge to conduct scientific investigations involving real-world problems and techniques. Responsive activities are sensitive to missteps in following written instructions, meaning that a misinterpretation could result in a less successful activity. Such opportunities to fail must allow learners to experience the consequences of their actions while minimizing the possibility of generating a hazardous situation or environment.

Table 3. Schedule, Topic, and Venue Distribution of the Fall 2014 Mini-Pilot Labs

2014 Date Lab Was Offered	Laboratory Topic Investigated by All Students	Laboratory Venue Usage by Student Groups[a] Face-to-Face and Blended
8/25	Nametag/Safety/Glassware Quiz/Glassware Check-in	Lab setting for Face-to-Face and Blended groups
9/1	No lab scheduled: Labor Day	
9/8	Organic Structures	Commons setting for Blended group
9/15	Copper Cycle	Lab setting for Face-to-Face and Blended groups
9/22	Stoichiometry of a Precipitation Reaction	Commons setting for Blended group
9/29	Titration of Hard Water	Lab setting for Face-to-Face and Blended groups
10/6	Boyle's Law	Commons setting for Blended group
10/13	Ionic Precipitation	Lab setting for Face-to-Face and Blended groups
10/20	Spectroscope and the Nature of Light	Commons setting for Blended group
10/27	Flame Lab	Lab setting for Face-to-Face and Blended groups
11/3	Lewis Structure Modeling	Commons setting for Blended group
11/10	Types of Compounds	Lab setting for Face-to-Face and Blended groups
11/17	Chromatography of Food Dyes	Commons setting for Blended group
11/24	No lab scheduled: Thanksgiving Break	
12/1	Titration of Acetic Acid	Commons setting for Blended group
12/8	Silver Bottle Final Lab/Glassware Check-out	Lab setting for Face-to-Face and Blended groups

[a]Face-to-Face group students conducted all of their laboratories in the traditional laboratory space; Blended group students conducted 7 laboratories in the traditional laboratory space and 7 outside of it.

No special prelab videos or extra instructions were provided for the In-the-Commons activities because an intended learning objective is to encourage independent research of topics and techniques.[26] To compensate for the intentional reduction of immediate supervision during the In-the-Commons activities, cyber supervision was provided during the regular laboratory hours via the communication platform Google Hangouts[27] and also asynchronously through the Piazza discussion forum.[28] Piazza proved to be particularly useful for this model, as students' questions are submitted in the format of an Internet forum, where other students can view, discuss, and answer them.

Missouri S&T's administration anticipated that students would often choose to conduct assigned In-the-Commons activities in the common spaces of residential housing facilities; therefore, the project included a review of the residential housing contracts to identify and resolve conflicting policies. Environmental Health and Safety personnel met with project members to verify that all activities conducted In-the-Commons provide a sufficient level of student safety, protection of property, and minimal environmental impact; the parties reached a consensus before the beginning of the course pilot.

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The course redesign has three stages: an initial proof-of-concept pilot launched in the fall of 2014, an expanded logistical pilot in the spring of 2015, and the full implementation for all CHEM 1319 sections in the fall of 2015. The proof-of-concept pilot offered an opportunity to directly compare identical traditional laboratory activities being conducted In-the-Lab and In-the-Commons. Additional information gathered included an evaluation of learner success, suitability of laboratory procedures, and general feedback on the design of the course.

Incubation

State Fair Community College piloted each of the laboratory activities in this project. The small class size and longer meeting times allowed for synchronous communication and instant feedback from students about the activities. These debriefing activities optimized alignment with the CHEM 1310 curriculum and developed outcome measurement tools (rubrics) for the experiments. The debriefing also provided direction to optimize activity instructions and teaching assistant training with an eye to the full transformation in the fall of 2015, which would serve more than 1000 students.

Fall 2014 Pilot

In the fall of 2014, two sections conducted the redesigned activities in two fashions; one section conducted all activities under traditional supervision In-the-Lab while the other section alternated between conducting their activities In-the-Commons and In-the-Lab (see Table 3).

The "blended" section experienced the rotation, and the "face-to-face" section conducted all activities in the traditional laboratory setting. The "pilot" included both the blended section (24 students) and face-to-face section (23 students). The "traditional" sections encompassed the remaining CHEM 1319 sections that were not a part of the pilot (total of 790 students). The blended and face-to-face sections employed the same teaching assistants to reduce variables and bias.

No distinctions between the traditional and pilot sections were made in the course catalogue in order to generate a representative sample of students. When the instructor notified enrolled students about the pilot, students were given the opportunity to switch to a traditional section; however, no student opted to withdraw from the pilot.

The pilot was evaluated using a pre/posttest consisting of 22 multiple choice questions (possible score range is 0−22) designed to probe student misconceptions about chemical phenomena encountered in most general chemistry curricula. All questions were directly related to topics covered in CHEM 1310 (General Chemistry I lecture) and were based on the Chemical Concepts Inventory developed by Doug Mulford for his M.S. Thesis.[29] In addition, the CHEM 1310 performance was used as an independent measure of student success in CHEM 1319 (General Chemistry laboratory), since the primary purpose of the redesigned lab course is to support and complement the lecture course. At Missouri S&T students earn separate grades for CHEM 1310 and CHEM 1319. A comparison of the CHEM 1310 grades and the pre/posttest performance for the traditional and the pilot sections supports that the students in the pilot were not at a disadvantage.

As indicated by Table 4 and Table 5, the pilot students had an average pre/posttest score difference of 0.619, and traditional students had an average pre/posttest score difference of 0.930. Figure 1 shows the distribution of percentage of students who earned the indicated difference between individual pre/posttest scores. The distribution of students is very similar between the two delivery modes, demonstrating that the redesign appears to offer a similar opportunity for student success. While there is some variation in the pre/posttest scores, the changes are not of statistical significance and possibly related to the small number of students in the pilot.

Table 4. Comparison of Pretest and Posttest Scores for Students Experiencing the Pilot Mode of Delivery

	Student Scores[a] by Instrument (N = 47)	
Parameters	Pretest	Posttest
Average	9.864	10.483
Minimum	4	2
Maximum	17	15

[a]The possible range of the scores is 0−22.

Table 5. Comparison of Pretest and Posttest Scores for Students Experiencing the Traditional Mode of Delivery

	Student Scores[a] by Instrument (N = 790)	
Parameters	Pretest	Posttest
Average	10.048	10.978
Minimum	1	2
Maximum	19	19

[a]The possible range of the scores is 0−22.

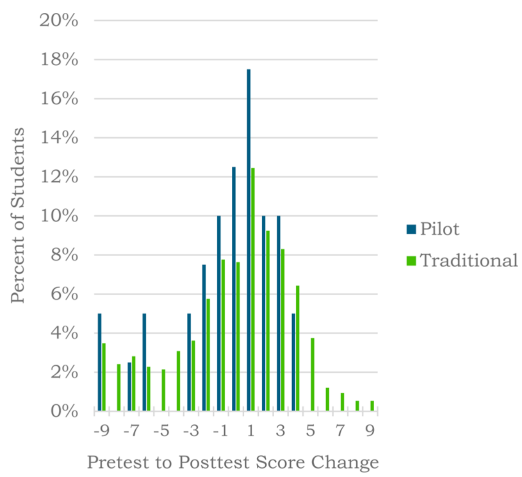

Figure 1. Percent of students with difference between posttest and pretest score.

Figure 2 and Figure 3 show that the grade distributions between the two modes of delivery are also similar. The largest disparity between the traditional and pilot data occurs in the percentage of drops at the end of the course (Figure 3) from 11% of the traditional students compared to only 5% of the pilot students. This variation in percentage of drops could easily be incidental (p value >0.05); on the other hand, it may indicate that the redesign offers a greater opportunity for increased intrinsic motivation to complete the course.

Encouraging information from the mini-pilot came in the form of student feedback. Students offered written and video-recorded feedback about both styles of activities. Learners appreciated

1. the connection between the parallel lecture course content and laboratory activities of the pilot course

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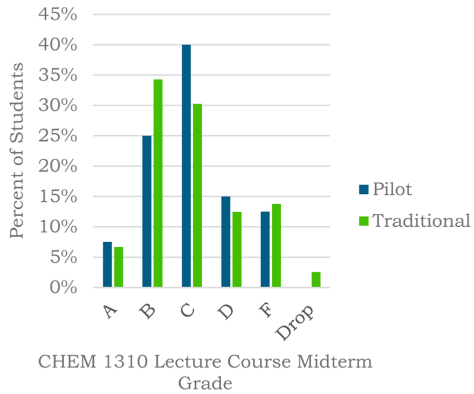

Figure 2. Percent of students with CHEM 1310 midterm grades.

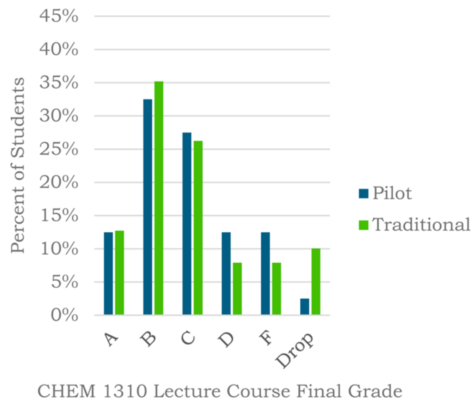

Figure 3. Percent of students with CHEM 1310 final grades.

2. opportunities to collaborate beyond immediate partners in the course.
3. experiencing team-building skills in the course
4. the independent and self-directed nature of In-the-Commons activities.
5. the scheduling flexibility of In-the-Commons activities
6. the reduction of intrusive supervision during In-the-Commons activities
7. the freedom to try different approaches during In-the-Commons activities
8. the authentic environment, which encouraged them to research and explore concepts beyond the graded portion of the course

Some students expressed frustration that the In-the-Commons and In-the-Lab activity instructions were obviously from two distinct sources. The compilation of negligible negative feedback does not indicate that all students were completely satisfied with the course; quite probably, those with negative feedback to offer felt disinclined to participate in the voluntary feedback process.

Additional anecdotal evidence included instructor observations that students in the blended section appeared to be more independent and efficient than those of the face-to-face section. Otherwise, the face-to-face and blended sections did not produce measurable differences in collected data, which seems to support that the blended design offers an appropriate solution to increase capacity. Missouri S&T intends to track grades and success of the pilot students in future courses to see if the participation in the pilot had a measurable impact on their overall success.

CONCLUSION

In the past, a common response to inadequate laboratory teaching space has been to physically expand available space or offer sections at less traditional times. Many institutions lack the funds necessary for either response leading to the examination of alternative solutions.

The anticipated traditional laboratory strategy is becoming difficult to offer at an adequate volume. Blended courses can double physical space capacity while retaining the desirable payoffs of traditional laboratory activities. Furthermore, the data presented supports that blended activities are as effective as traditional offerings with a potential added benefit of improved soft-skill development in participants.

While this article addresses only a blended first-semester general chemistry laboratory course, the concept is applicable to courses of various sizes and disciplines. Hence, blended laboratory activities offer a practical and customizable option for institutions.

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Notes

The authors declare no competing financial interest.

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