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General Chemistry Education in a Pandemic

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Draft

ABSTRACT

With the start of the COVID-19 pandemic and the decision to close post-secondary schools to in-person teaching, an opportunity was presented to examine the challenges, benefits, and ability to pivot to an online teaching environment. Given the tight deadline to present Chemistry 121 (General Chemistry and Laboratory I) for the first time as an online course, during the Summer 2020 semester at Simon Fraser University, a team-based approach to develop and run the course was used. The approaches adopted and new course components utilized are analyzed from the students' perspective to gauge their efficiency. The insight gained from converting this large enrollment course will be offered.

KEYWORDS

Audience: First-Year Undergraduates/General

Domain: Curriculum

Pedagogy: Inquiry-Based/Discovery Learning

Topics: Computer-Based Learning, Multimedia-Based Learning

GRAPHICAL ABSTRACT

Draft

INTRODUCTION

Every educator has experienced the anxieties of teaching from the middle of night panics that the final exam will be too easy, to worries about how the lectures will go, apprehension about what to do if a student gets ill during class or simply wondering “why don’t they laugh at my lecture jokes?”, but no one could have envisioned the turmoil the education system would undergo in the wake of the COVID-19 pandemic. In March 2020, most if not all instructors in post-secondary schools in Canada received a similar notice from their institute administration: “All in class education is cancelled. Instruction will shift online.” With only a few weeks left in the semester, instructors were able to scramble to complete the term. However, it became clear that the summer semester was going to be entirely online. Finishing a few weeks online is different than running a whole semester online, especially for instructors who have never taught in such a manner and students who are unaccustomed to learning remotely. Instructors were required to teach a course that was not designed for the online curriculum, determine effective online teaching strategies, and learn new technology in only a few short weeks. This was the situation we found ourselves in April 2020 as we started planning the online version of our Chemistry 121 (Chem 121) course: General Chemistry and Laboratory I. We needed to determine effective methods to teach both the lecture and laboratory components online.

Although the condensed timeline to develop and implement our course changes prevented a thorough analysis of the literature, the benefits, and challenges of online education versus the in-person experience has been the subject of numerous publications.¹⁻⁶ The published material ranges from the conversion of a course to an online format, such as the work described here, to online activities that can be used to complement an in-person course. These efforts also introduce online material for general chemistry courses. Activities includes the use of online homework systems or approaches,⁷⁻⁹ online simulations,¹⁰ online poster presentations,¹¹ and

the use of instructional videos.^{12,13} Videos have been used to present the lectures, experimental details and procedures, specific concepts as well as safety information. With the start of the COVID-19 pandemic, and the conversion of most university programs to an online format, a renewed effort to the development of online teaching strategies commenced including efforts in the online delivery of the chemistry material. Recent development from this time has been presented, such as the special edition of *Journal of Chemical Education*, which was dedicated to online teaching in the field of chemistry.¹⁴

Herein, we presented our approach to converting a traditional in-person first year chemistry lecture/laboratory course to an online model, as well as the study on its effect on student learning. We were able to examine which approaches were preferred by the students, and whether the shift to the online delivery of the content had a detrimental effect on their performance in the course.

CHEMISTRY 121

Standard method of Instruction

Our Chem 121 course, which has a full lecture and laboratory component, normally runs at two campuses (Burnaby and Surrey). At the larger Burnaby campus, in the fall and spring semesters, due to the larger enrollment, the course runs with two instructors. One instructor is responsible for the lecture and the other the laboratory sections. In the summer with an average enrollment 175 students, one instructor is responsible for both components of the course. At our smaller Surrey campus, with an average summer enrollment of 75 students and over double the amount in the fall semester, one instructor runs both aspects of the course. The two offerings of the course are run in a similar manner. The lectures consist of 3 x 50 minute in-person lectures and 1 x 50 minute in-person tutorial per week. Students are asked to complete 7-8 online problem sets via LON-CAPA^{15,16} and write one midterm and one final exam (both in-person). In the laboratory, students complete 6 x 4-hour experiments and 1 x 2-hour experiment. Each experiment is accompanied with an online LON-CAPA prelab

assignment (the exception being the 1 x 2-hour experiment) and a report sheet to be completed during the laboratory period. Our semesters run with 13 weeks of instructions followed by a 2-week final exam period. A laboratory manual is provided to the students along with extra support through the course textbook: Chemical Principles by Zumdahl & Decoste.¹⁷ The grading rubric for the course is typically 10% LON-CAPA Problem Sets, 20% Laboratory, 25% Midterm Exam, and 45% Final Exam. The 20% laboratory component is often comprised of 10% Laboratory LON-CAPA Problem Sets, 20% Quizzes and 70% Report Sheets.

The instructors are also aided by the course Teaching Assistants (TAs). The lecture TAs run the tutorials, which are weekly review sessions conducted in small groups (< 30 students) and provide extra assistance through their office hours. The laboratory TAs aid the students during the laboratory period, and their office hours. These TAs are also involved in the grading of the report sheets and laboratory quizzes.

Online method of Instruction

In response to the move to online instruction, the two offerings of the course were combined into one online section, with all instructors tasked to work together to develop the online course. Dr. Goyan (RLG) focused on adapting the lecture to the online platform, while Dr. Canal (JPC) and Dr. Mund (GM) devised the online laboratory portion of the course. All three instructors contributed to the exams and the administrative duties associated with the course.

Based on Dr. Goyan's previous experience with running a semi-flipped classroom,¹⁸⁻²² she implemented many new approaches in presenting the lecture materials. Due to the online restrictions, a synchronous 50-minute lecture was presented using a ZOOM webinar, three times a week, with recording made available post lecture. The dedicated questions and answers time at the end of each lecture allowed for student-instructor interactions. The lectures shifted from a traditional delivery of the lecture notes to a focus on problem solving. The textbook was changed to Interactive General Chemistry²³ due to its interactive learning tools. The problem set was expanded from the standard LON-CAPA based assignments to include daily assignments generated by the Sapling Learning Online Homework system.²⁴ This added a mix

of low and high stakes assignments, which helped the students identify weaknesses in their understanding.

The students first participated in an online and optional Learning Curve Assignment, which directed students to extra resources when answering questions incorrectly. The lecture material covered each week was reinforced through a graded homework. Students could repeat the questions though a 5% penalty was applied to each incorrect attempt. Final mastery of the week's material was assessed using the online Concept Mastery Quiz. These components made use of the questions provided to the instructors by the Sapling Learning system. More complex problems, which often integrated topics from previous weeks of the course, were presented to the students using the standard LON-CAPA assignments. Unlike traditional in-person semesters, the lecture tutorials were based on interactive figures from the textbook and were graded.

The in-person midterm and final exams were replaced with exams developed and completed online using LON-CAPA. Prior to the transfers to the online format, instructors of Chem 121 used the LON-CAPA program to establish a repository of midterm and final exam questions. As LON-CAPA allows for variables in the question, such as using a different starting mass or changing the compound to analyze, LON-CAPA was previously used to generate 4-6 different versions of the written exam.¹⁵ These exams consisted mainly of multiple-choice questions (computer graded) and 2-3 long answer calculations (hand graded). With the switch to online exams, the decision was made not to use too many of the questions from the repository. New multiple-choice questions were created in LON-CAPA, and other questions crafted through modifications made to the LON-CAPA assignment questions. These were all computer graded questions. The style and type of the new multiple-choice questions were consistent with the previously used questions as they were shown to be effective. To help address the issue of student integrity with online exams, we used questions based on their homework assignments, as the method to answer these questions should have been known to all students. Also, with the ability to vary features of the questions using LON-CAPA, all students had a different exam. Using the same format of the LON-CAPA assignments for the exams, allowed the students to

get comfortable with the technology and address any technical issues before the exam day (see the Supplementary Material for an in-depth analysis of all the course lecture components, including examples of the exam questions).

The laboratory component was run with a mix of new and established resources. During the even numbered weeks of the semester the students were asked to approach the experiments in the same manner as in previous semesters. Students reviewed an experiment in the laboratory manual and completed a modified version of the existing online LON-CAPA pre-lab assignments. These assignments tended to focus on the calculations related to the experiment and were based on sample data. In lieu of the traditional report sheet based on a completed in-person experiment, students were asked to answer concept-based problems, getting them to investigate why certain steps in the experiment would have been performed. In the odd numbered weeks, the students completed an online virtual experiment related to the pre-lab assignment and experiment they reviewed the previous week. We made use of the Connect for LearnSmart Labs – Chemistry system by McGraw-Hill Connect.²⁵ The LearnSmart Labs consisted of a virtual hands-on laboratory experience and related laboratory assignments.

Both components of the course were supported by TAs. The lecture TAs ran an online tutorial session (< 30 students) via ZOOM, where they helped students work through an additional and optional problem set, as well as answer questions related to the course material. These TAs also aided with the online exam by hosting ZOOM sessions where students could get immediate feedback on questions about the exam. The laboratory TAs through their office hours, provided the first avenue for students to ask questions about the laboratory material, as well as grading the Canvas Laboratory Reports.

To reflect the course changes, the grading rubric was altered from the typical values to: 5% LON-CAPA Problem Sets, 10% Online Assignments (Sapling Learning Online Homework), 10% End of Chapter Quizzes (Concept Mastery Quiz), 10% Tutorials (Graded Assignments), 15% Midterm Exam, 20% Laboratory, and 30% Final Exam. The 20% laboratory component comprised of 20% Laboratory LON-CAPA Problem Sets, 30% Canvas Report Sheets and 50% McGraw-Hill virtual experiments.

TEACHING ONLINE STRATEGY

Once the panic and anxiety of converting an in-person lecture/laboratory chemistry course into an online course had passed, we commenced with the implementation of the changes. The task was made easier by combining the two campus course offerings into one section. This allowed for three instructors to combine their efforts into developing the course. To make the transition successful, collaboration was imperative allowing us to play off each other's strengths and knowing when to ask for help. RLG, with her experience running a semi-flipped classroom and having taught a chemistry distance education course, was an obvious choice to run the lecture component. The task of devising the online laboratory component was split between GM and JPC. GM, with his years of experience teaching this course, populated the course website, developed the concept-based laboratory reports, and directed the teaching assistant in their tasks. JPC, who is the Chair of the Department's Teaching Technology Committee, which is tasked with supporting the computer-based programs employed in the department, focused his efforts in coordinating the programs used by the students, including LON-CAPA, Turnitin,²⁶ and Connect for LearnSmart Labs – Chemistry.

The course design decisions were made based on our experience and expertise, as well as through a collaborative sharing of ideas among our chemistry colleagues at other post-secondary institutions. At the start of the pandemic one of our authors, JPC, created an online ZOOM based forum where Canadian based instructors shared resources and approaches on how to transition to an online environment. This group now consists of 40 members from 20 post-secondary institutions.²⁷ Although mainly centered in British Columbia, members from Alberta, Ontario, the Yukon, and Newfoundland and Labrador contribute to this group. At the height of the urgency to transfer to online teaching, this group met monthly on ZOOM to discuss their approaches to online teaching, ask for suggestions, and to learn about new ideas. In addition, member's individual online resources were collected into a large online database created by JPC that is available to all. In the Metro Vancouver and neighboring areas alone, this database was provided to over 300 science teachers. It was through this group we received

feedback on our plans for this course and learned about programs such as the Connect for LearnSmart Labs – Chemistry system. We were also able to discuss ideas with international colleagues through an established Facebook Group, Strategies for Teaching Chemistry Online.²⁸ It is through sharing of methods that we were able to refine some of our ideas and were made aware of new resources.

The strategy of our online lecture format was guided by three principles, namely, to provide an interactive/personal education, to support the students in their new experience with eLearning systems²⁹ and provide a level of instruction comparable to the in-person course. To help achieve an interactive/personal experience, ZOOM webinars were used as they provided students with regular live lectures and tutorials that focused on problem solving. These were structured to provide time for group exercises and at the end of each lecture/tutorial for individual questions and answers. The individual attention extended to students also occurred in the instructors' office hours. Student access to the instructor/TAs was done to help provide meaningful interactions with students. This approach was furthered by the adoption of a textbook designed for the online teaching experience.

As eLearning is a new approach to most of our students, we used a 4-part assignment strategy to help students stay focused and on schedule in the course. This provided students with a structured workload and course expectations. The initial reaction by the students was mixed; many complained about the workload and the set schedule. It was only after the first midterm that the advantages of the format became apparent, and acceptance of the format increased.³⁰

In our laboratory section, a three-part assessment (LON-CAPA assignments, Canvas Lab Reports, and the LearnSmart Labs) was chosen to:

- Provide a similar experience as students would have obtained in the in-person laboratory. The LON-CAPA pre-lab assignments were continued and were used to ensure that students understood the general calculations associated with the experiments.

- Initiate the experimental thought process by the development of the concept-based Canvas Lab Reports. This allowed the students to think about the experimental steps, why certain things are done in a particular experiment and potential sources of error in an experiment.
- Provide students with a visual representation of the laboratory experiments. The virtual experiments were chosen as they provided (to some degree) a visualization of the typical glassware used, and the experimental procedures conducted in an undergraduate experiment.

One of the challenges of introducing technology into the classroom is the requirement for the students to learn how to use the programs in conjunction with the course material. To aid in the process we allowed the students time and resources to gain familiarity. For the lecture component, students were encouraged to attempt the optional practice questions provided by Sapling Learning Online Homework. As the LON-CAPA program has a long history within our department, we provided students with a previously used and effective set of instructions. Given the extensive practice with LON-CAPA through the assignments, LON-CAPA was the ideal choice for the exam format. In the laboratory components, the students were told that the first virtual experiment was not for marks, rather for them to learn how to use the Connect for LearnSmart Labs – Chemistry program.

EFFECTIVENESS OF THE APPROACH

To garner the effectiveness of our approach to teaching first-year chemistry online, we evaluated both the students' academic results and the results of a student survey.

Research Questions

The goal of this research was to evaluate how students responded to a sudden transition to online education, due to the pandemic. The ultimate intent is to improve student learning of general chemistry topics. Through the project, we wished to answer two questions:

- How would the students' academic performance in a general chemistry course be affected by the transition to an online format?

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- Which aspects of the online format were deemed more favorable by the students?

Framework and Methods

To discern the students' academic performance in the course, we undertook a comparison study of student results from the new online format with the results from five previous in-person summer semesters. To allow for a meaningful comparison, only aspects of the course that were consistent were analyzed such as the LON-CAPA based lecture assignments and pre-lab assignments. The average results from each component was used in the comparison.

The student feedback on different aspects of the course was garnered through an online student survey. This voluntary and anonymous survey was conducted at the end of the course and was advertised to all students via the class email list.

This study was conducted in accordance with the policies of SFU's Office of Research Ethics, with ethics exemption granted and no restrictions placed on dissemination of the work.

Limitations

This study presents some limitation, in part because it analyzed data from several semesters. The students' academic performance in a course is affected by numerous factors, such as the instructor of the course, and the other students enrolled. To help minimize the variables, we only examined components of the course that varied little, as well as limit the study to the summer semester offering of the course as the make-up of the student body in the summer tends to be different than in the fall or spring offerings. In the summer we often have a greater portion of students re-taking the course. The limitation to only the summer semester is an attempt to provide a more equal comparison.

The limitation of this study also extended to the results of the student survey, as they represent the view of the respondents. As each student was given equal opportunity to complete the survey it is assumed that the results are representative of the student body. The data taken from these surveys can provide broader conclusions as opposed to a focus on the specific values.

Lecture/Laboratory Comparison

To provide a meaningful evaluation of the student results, we compared several components from the online course to the student results obtained in Chem 121 during the past 5 summer semesters (2015—2019). As shown in Table 1, the comparison of the lecture material was limited to three assessments, with two components used in the laboratory section assessment. These were chosen as they were the most consistent between the two course structures and can provide the best comparisons. The results of the previous offerings of the course can provide a baseline to provide a level of context to the results from our new online approach to the course.

In the lecture portion of this review, we compared both the midterm and final exam grades, as the exams were similar in style and length to the exams used in the in-person course. The LON-CAPA assignments also did not change much between the online and in-person offerings of the course. For the laboratory section, we used the laboratory specific LON-CAPA assignments and the total grade from the laboratory portion of the course.

A comparison of the student results from the 2015-2019 summer offerings of Chem 121 with the results from the 2020 semesters (see Table 1) indicates that the transfer of the course from in-person to online-only (with the related changes), did not adversely affect the student grades. In the lecture section of the course, the average results from the LON-CAPA assignments were 78.5% which was in the historical range and close to the historical average of 80.4%. A similar result was observed with the midterm exam. The average midterm grade (65.3%) was only 1.2% outside the historical range and only 1.4% above the historical average of 63.9%. The final exam average of 62.1% was within the historical range and 2.3% above the historical average of 59.8%.

The results from the laboratory section illustrated the student's understanding of the experiments was like the in-person experience, as tested by their LON-CAPA assignments. The average value of 87.7% was within the historical range and 3.6% below the historical average of 91.3%. Although a comparison of the overall laboratory grade presents many variables that

effect the results, the student value of 84.3% is only 2.5% outside the historical range and 6.1% above the historical average. Part of this difference may be explained by the introduction of the virtual experiments. On average, students obtained a grade of 90.0% on the virtual experiments, which is much higher than for the in-person experiment suggesting that the students did not find the online virtual experiments as challenging as the in-person experiments. This is not unexpected as the in-person experiments generally consisted of an intense 3-hour experiment followed by a 1-hour laboratory report write up, while students were given 24 hours to complete the 1-3 hour long online (virtual lab) assignment. Students were also given the ability to re-start the online (virtual lab) assignment. The extra time for the virtual experiments allowed us to address any technical difficulties that arose as well as for students in different time-zones.

The average overall final grade of 74.9% was 9.4% above the historical average of 65.5%, but only 3.1% outside of the historical range. This higher result was due to the higher laboratory mark as well as the additional online assignments that were added to the course. However, if we use the weighting scheme associated with the elements available in a traditional in-person class, a student average grade of 69.1% is obtained, which is within the historical class average.

The analysis of the grades obtained in the COVID-19 affected semester versus the average marks of the past four offerings of Chem 121, show that our changes did not have a detrimental effect on student learning. This suggests that our first-year students are adaptable and able to learn in different teaching environments. For a well-designed online course or a traditional in-person lecture environment, the mode of instruction does not seem as important as the effort that is put in by the students and instructor(s).³¹

Student Survey

To garner more information about the course we asked students to complete a voluntary and anonymous survey. Of the 290-students enrolled in the course, 60 students provided feedback for this study, which represents a 20.6% response rate. This survey was conducted in

the last week of the semester, the busiest time for the students, which at least partially explains the low participation rate. A cross-institutional analysis by Nulty found that participation rates on online feedback surveys tend to be low,^{32,33} hence a participation rate of 20.6% is not out of the ordinary. The results of this study must be considered within this limitation. Our study contained several survey questions that dealt with the logistics of attending an online course, with other questions asking about specific aspects of the course.

Our analysis found that 98.3% of the respondents had easily accessible internet, with 70.0% suggesting that high-speed internet was needed for this course. We also found that 51.7% of our students always or almost always attended lecture, with 40.0% only attending sometimes. The preferred lecturing format (asynchronous versus synchronous) was examined, and we found an almost equal preference. Of the respondents, 30.0% preferred the synchronous lectures, 25.0% preferring the asynchronous approach with 45.0% expressing an equal affinity for both methods. An advantage of providing both the synchronous and asynchronous options, is it allows students the ability to attend “live” when they wanted an a more interactive experience (i.e., being able to participate in the question-and-answer session), but it also allows them to view the lecture on their own time when that was preferable to them. Given that options were still available for students to interact directly with the instructor or TAs (i.e., tutorials or office hours), missing the live lecture was not as detrimental as for the in-person experience, as some instructors, including the authors of this manuscript, do not record their in-person lectures. The results of our approach saw a decrease in the numbers of students attending the synchronous lecture, as the semester proceeded. This was expected given that many students feel stressed and overworked at the end of the semester and chose to view the lectures on their own time.³⁴ The decrease in the attendance to the synchronous lecture did not greatly affect attendance to the tutorials nor the completion rate of the assignments. For the LON-CAPA (lecture) assignments, there was a 5-10% decrease in the number of students who completed the final two assignments versus those that completed the first five assignments. This was consistent with the previous offerings of the course.

The move to the online format limited our textbook options to an e-textbook. The preference of the e-books over the hard copy textbook was examined. Again, we found an almost even split. Of the respondents, 41.7% preferred the e-book with 40.0% preferring the hard-copy text. The remaining 18.3% of the students did not have a preference either way.

To learn about the student's opinion of the course components and their overall learning experience, we conducted a survey using a five-point Likert-type scale from "Very Poor" to "Excellent". The Likert-type rating mean for each statement is shown in Table 2.

The results of the student analysis on the different components of the course were not surprising. As shown in Table 2, most students rated the components as fair to good. The lowest values were for the LON-CAPA assignments (laboratory and lecture) but this was expected as the LON-CAPA assignments can be challenging and can require a significant amount of time to complete. This is contrasted to the Sampling Assignments, which had straightforward but interactive questions. It is not surprising that it received the highest rating from the students.

In Table 2, the overall effectiveness of the online construct of this course was examined by asking the students to rate the overall quality of their learning experience. On the five-point Likert-type scale, the students gave this course a rating of 3.55. This question was also included in the course evaluations completed in the previous offering of this course, thus providing a baseline value to compare with. We were only able to access the results from our previous, large enrollment, summer semester offerings of the course. The average rating given by the students in the summer 2016 and 2019 semesters, was also 3.55.

The addition of the virtual laboratory experiments and new online laboratory reports was one of the largest changes to this laboratory section of this course and warranted further investigation on its use. This was conducted using another five-point Likert-type scale from "Strongly Disagree" to "Strongly Agree" and the results shown in Table 3.

The results of the student's opinion to the virtual laboratory experiments and Canvas Lab Reports provided us with an idea of their effectiveness. It is interesting that the students were fairly "neutral" in their opinion of both the virtual laboratory being engaging and the Canvas

Lab Reports enhancing their laboratory skill knowledge. This result was expected as it is difficult to replace an in-person, hands-on experience with a virtual facsimile. It is also a difficult comparison for freshman students to make considering the lack of laboratory experience of these students.

Instructor's Experience

Although the experience of developing a new online version of an existing course had its challenges, overall, it was a positive experience (for both students and instructors). Given the short timeline to develop the course, there was stress associated with having to make quick decisions and develop course content. Decisions were required on which course components were to be kept, discarded, or changed. In doing so, we became more focused on what it was the course was trying to achieve.

The adoption of the online format increased the technical problems encountered by students. Although the programs we used worked as intended for most, there were a few students that encountered issues, which were easily corrected.

We developed a strategy to handle the electronic based messages from students. This was to prevent instructors from getting inundated with emails, but also to provide clear communication paths for the students. All lecture-based communication was through one instructor with another instructor responsible for all the laboratory messages. Within the lecture or laboratory components, the TAs were also given specific tasks related to student communication. With this approach the students knew who to email and when (e.g., fixed office hours). In addition to emails, all course information was posted using Canvas,³⁵ which is the course management system used at SFU (a separate page was developed for the lecture and laboratory, which further reduced any student confusion). Within Canvas, students could communicate with TAs and instructors and feedback could be provided in a timely and efficient way.

As the slow transition back to in-person education occurs, there are several lessons that we have learned from this experience that could be applied to future teaching. This includes but not limited to:

- **Homework:** We made the decision to increase the homework load in the online version of this course to provide extra support for the students, such as the optional Learning Curve Assignment. It was noticed that students who did well on the midterm exam also completed the Learning Curve Assignments suggesting that students benefit from the extra support.
- **Online Technology:** The sharing of information via online platforms was successful, including the information related to their laboratory experience. With limited in-person experiments now occurring, other laboratory courses have adopted all or selected components of the online system.
- **New Ideas:** The success of the rapid adaptation to the online course has provided a greater willingness to try new ideas and approaches in our future teachings.
- **Online Course:** In the past, a student who did not pass the lecture portion of the course, was required to retake it. With the success of the online lecture, it has been discussed whether to instead allow the student to take the online lecture as a remedial course to fulfill the “lecture” requirement. The plans we developed could also be used to establish a permanently offered online version of the course along with the traditional in-person course.
- **Online Laboratory Assignments:** In the laboratory portion of Chem 121, our students traditionally conducted an in-person experiment every other week. We have discussed introducing online assignments during the weeks the students are not in the laboratory, to reinforce the topics presented in the experiments.
- **Online Exam:** With evidence suggesting that our online exam was as effective as the in-person exam, it has been suggested that these online exams could be used by students requiring a make-up exam or be used to allow an exam to run that otherwise would have to be cancelled due to unforeseen circumstances, such as a snow day.

CONCLUSION

The analysis of the student results from the COVID-19 modified version of Chem 121, showed that the changes introduced did not alter the average student outcome (in terms of the average grades obtained) and the student's evaluation of their learning experience. The online survey illustrated that the students did not have a strong opinion (either positive or negative) on the changes we introduced. The exercise allowed us to study how students would respond to a dramatic change to a course. When presented with course changes that are well thought out, done with the student's benefit in mind, and where students are kept informed with the new aspects of the course, the results of our study indicate that on average, students are resilient and will respond positively. The authors do realize that this was not the case for every student, with some experiencing greater anxiety and required extra support during this pandemic.

Given these results and the time constraint in developing the online version of the course, we feel that we achieved the main goal in this course transition. We wanted students to have a positive educational experience and learn the material at the same level as they would in the in-person version of the course. We whole-heartedly agree that nothing can replace in-person learning but considering the extraordinary circumstances we found ourselves in at that moment, we could not have asked for a better result.

SUPPLEMENTARY MATERIAL

Supplementary material for this article are available on the journal website

(www.nrcresearchpress.com/loi/cjc)

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TABLES

Table 1. Comparison of student results

Lecture:	2020 Percentage (number of students)^a	2015-2019 Percentage (number of students)^a	2015-2019 Percentage Range
LON-CAPA Assignments	78.5 (273)	80.4 (1074)	78.2 - 85.7
Midterm	65.8 (289)	63.9 (1296)	59.9 - 64.1
Final Exam	62.1 (276)	59.8 (1062)	58.1 - 67.2
Laboratory:			
LON-CAPA Assignments	87.7 (219)	91.3 (878)	89.4 - 93.7
Overall Laboratory Grade	84.3 (224)	78.2 (945)	77.1 - 81.8
Course Grade^b	74.9 (285) ^c	65.6 (1081)	63.3 - 71.7
	69.1 (285) ^d		

^a The lower student number in the lab vs. lecture is due to the students who are only enrolled in the lecture portion of this course. The difference in the student total between the midterm and final exams is due to attrition. The lower number of students completing the LON-CAPA assignments versus the exams is also due to attrition and students who chose not to complete the assignments.

^b The "Course Grade" includes the both the lecture/lab and lecture only students

^c The 2020 grade breakdown: 5% LON-CAPA (Lecture), 15% Midterm, 20% Laboratory, 30% Homework, 30% Final Exam.

^d The 2020 grades based on the 2105-2019 grade breakdown: 10% LON-CAPA (Lecture), 20% Laboratory, 30% Midterm, 40% Final Exam.

Table 2. Student opinions the course components

Please rate the following lecture/laboratory components in terms of effectiveness as a teaching tool/resource	Mean Score^a
Lecture	(N=60)^b
LON-CAPA	3.0
Tutorials	3.8
Lecture	3.9
Homework and concept mastery quiz	4.2
Learning Curve Assignment	3.5
Laboratory	(N = 51)^c
LON-CAPA	3.3
Canvas Lab Reports	3.4
McGraw-Hill Connect Virtual Labs	3.4
Overall, the quality of my learning experience in this course was:	(N= 60)
Lecture and laboratory	3.6

^a Likert-type rating as follows: very poor = 1; poor = 2; fair = 3; good = 4; excellent = 5.

^b N = number of student responses.

^c The lower N values for the laboratory section is due to some students who are only enrolled in the lecture portion of this course.

Table 3. Virtual Experiment Analysis

How strongly do you agree/disagree with the following statements?	Mean Scores^a (N = 48)
The McGraw-Hill Connect Virtual labs were engaging	3.6
My understanding of why certain things are done in a laboratory session were likely enhanced by the online Canvas lab reports	3.0

^a Likert-type rating as follows: strongly disagree = 1; disagree = 2; neutral = 3; agree = 4; strongly agree = 5.

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