Outcome-Based Redesign of Physical Chemistry Laboratories During the COVID-19 Pandemic

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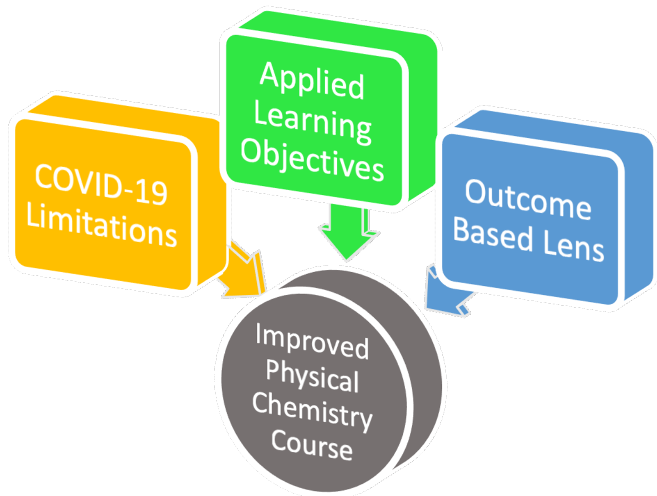
Abstract:
We reported a redesign of a physical chemistry laboratory course (CHEM 166) for our chemistry majors at the University of Vermont carried out during the COVID-19 pandemic. We started to teach this course after a curriculum reform, which split an upper-division undergraduate laboratory course into physical and analytical chemistry laboratories. To address both traditional challenges in course implementation and student engagement as well as additional constraints imposed by the pandemic, an outcome-based approach was applied to better integrate CHEM 166 with the existing physical chemistry curriculum. We developed clear learning objectives for the entire laboratory course, revised each experiment for alignment to those objectives, and provided students with a coherent experience to explore the structure-properties relationships of model molecules. According to direct and indirect assessments, the students taking CHEM 166 in Spring 2021 have achieved the overall learning objectives, indicating a success of the course redesign. While some aspects of the redesign associated with the pandemic (e.g. additional safety measures) may subside, we discuss how other pandemic-related components that were integrated during the redesign will be carried forward based on their apparent positive impacts. In general, this redesign established an integrated structure for students to enhance the physical chemistry learning experience, while also creating new opportunities for practicing advanced skills in scientific communication, problem solving, and critical thinking. This work, as a useful example of outcome-based course design, can be readily adopted by other institutions and for other chemistry laboratory courses.



Keywords: Physical Chemistry, Upper-Division Undergraduate, Laboratory Instruction, Communication / Writing, Problem Solving / Decision Making, Testing / Assessment

Introduction.

Background of CHEM 166 Redesign. The fast development of chemistry and its related areas has required us to update our chemistry curriculum and to provide modern education to students.[1-2] Since 2015, the chemistry department at the University of Vermont (UVM) started to reform its physical chemistry curriculum for undergraduate students of chemistry and biochemistry majors. Main efforts included the shift to physical chemistry lecture courses at the introductory and advanced levels (CHEM 165, Introductory Physical Chemistry and CHEM 260, Advanced Physical Chemistry) with a physical chemistry laboratory course (CHEM 166), in addition to a number of special topic courses like Computational Chemistry,[3] Chemical Thermodynamics, Advanced Quantum Mechanics and Spectroscopy. Originally taught as a component of an upper-division course (CHEM 201 Advanced Chemistry Laboratory) that covered both physical and analytical chemistry laboratories, physical chemistry laboratories are now offered as a course to chemistry BS students in the spring semester of their junior/senior year after the curriculum reform. However, while most students complete both lecture courses (CHEM 165 and 260) before enrolling in CHEM 166, student feedback obtained during the 2018–2020 period indicated the following challenges with the new CHEM 166 implementation: (i) The laboratory course was not yet fully integrated with the lecture components, partially due to different instructors teaching the lecture and laboratory courses during the early stages of implementation. (ii) The eight experiments, ambitiously selected to follow the teaching goals to cover three major areas (thermodynamics, kinetics and quantum chemistry/spectroscopy), were largely independent from each other. Furthermore, the one-semester delay between the lecture and laboratory components of the courses, further increased the challenge for students to foster strong connections between the material taught in the laboratory setting with the content of the lecture courses they had taken previously. Likely, this weakened the learning outcomes for our physical chemistry curriculum. (iii) The course was, with eight laboratories in 14 weeks, advancing with a tightly packed schedule, which made it challenging for students to fully absorb all the material and independently analyze their findings. All these factors resulted in over 70% of the 14 students that had requested one or more deadline extensions for their laboratory reports in 2018. The three laboratories at the end of the semester were extended into the exam week. Overall, these challenges pointed to a need to redesign CHEM 166 at UVM into a more integrated component of the existing physical chemistry curriculum with enhanced learning experiences and outcomes.

On top of the driving forces to redesign CHEM 166, the additional teaching challenges introduced by the COVID-19 pandemic spurred the revaluation of the course. Notably, our course was conducted in the second semester of the academic year after the university had experienced COVID-19 restrictions for ten months. This is in stark contrast to some of the recent literature concerning teaching during the onset of the pandemic which required a rapid transition to entirely remote learning.[4-5] In our case, the course was permitted to be taught in-person with no limit on the class size or in-person component. It is worth highlighting that all the students and instructors who participated in our course had at least six months of previous experience learning in a COVID-19 environment with the virtual resources provided by the university, particularly Microsoft Teams. Guidelines for general university policy as to face coverings, required testing, as well as occupancy limits have been implemented at the university since the beginning of the 2020/2021 academic year. These policies, known collectively as UVM's Academic Laboratories

Guidance to prevent the spread of COVID-19 (hereafter referred to as the Guidance, see Document S1), were directly consulted and implemented in our redesign. In order to facilitate a safe environment within the laboratories, changes to the number of students present in lab at a given time, the formation of groups, and their use of the equipment were all required for the spring 2021 course. In lieu of simply leaving the course structure as is and only modifying the occupancy/group assignment, we chose to seize upon the unique moment brought by the pandemic to improve the laboratory content in a way that harmonized with the Guidance. In total, nine BS chemistry students registered for the course, who were assigned arbitrarily to two groups (Group A with four students, and Group B with five). This assignment was maintained for every laboratory session as required by the Guidance. Further, similar to other chemistry laboratory courses at UVM taught in-person during the spring of 2021, we reduced the number of experiments from eight to four, and had the two groups work on different experiments to minimize the sharing of equipment and further reduce occupancy. However, the reduced number of experiments required us to carefully choose the content and format of the entire course. Therefore, we turned to use the outcome-based design to develop the learning goals and to guide our redesign of experiments and assessments.

Outcome-Based Design. Setting goals and objectives encourages us to stay focused on particular tasks in teaching and learning.[6] As what we teach and what our students actually learn may differ, there is a clear need to identify what successful students are expected to achieve in a curriculum, a course, or even a lesson.[7] Bloom *et al.* has created the taxonomy[8] to qualitatively express different kinds of thinking, expanding upon the previously established[9] six levels of cognitive process (remembering, understanding, applying, analyzing, evaluating, and creating). We followed the revised taxonomy and defined the overall learning objectives — ordered from the basic to higher level of the cognitive process:

i. To deepen students understanding of the concepts and theories covered in the lectures (CHEM165 and CHEM260); connect these concepts and theories with experimental measurements and calculations performed in this course;
ii. To develop advanced laboratory skills in chemistry and the ability to read and interpret modern peer-reviewed chemical literature;
iii. To complete professional lab reports that clearly present the introduction, methods, data, observations, graphs, calculations, conclusions, and references; present chemical data and communicate critical analysis of scientific information through written reports;
iv. To advance skills in critical thinking, problem solving, and creativity in chemical discovery.

In addition, we designed CHEM 166 to build off established engagement of the psychomotor in laboratory technique. By ensuring communication before each lab, students were encouraged to engage in guided response as to the techniques and operations of mechanisms within the laboratory classroom. Expanded within the small group discussions, students also explored the affective domain, both receiving and responding to phenomena in their discussions with each other as well as the teaching assistant (TA). By combining this engagement with constructive alignment[10] in the design of the course, we were able to focus the scope of the students inquiry and thus center them towards their aforementioned goals. Distinct from the modifications due to switch to synchronous[11] or asynchronous[12-13] teaching, we developed these learning objectives regardless of teaching modalities, mainly aiming to select experiments and teaching materials, to better inspire students in learning and thinking, and to assess the impact of our course redesign. With many fast-developing, interdisciplinary fields just like physical chemistry, traditional wet chemistry, or related curricula[7, 14-15] are always updating to adopt new topics and courses. Outcome-based design of CHEM 166 at UVM can serve as a useful example to redesign an existing course, as well as a valuable attempt to inspire future practice to introduce new advances in the study of chemistry curriculum under the outcome-based design.

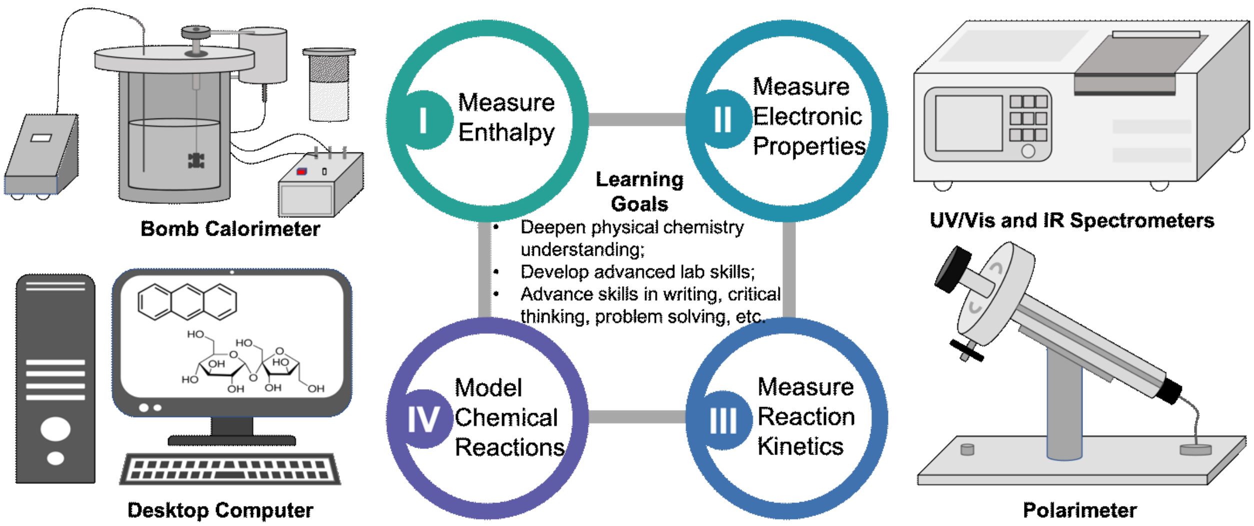


Figure 1. Course structure, learning goals, and major instruments of CHEM 166 at UVM in spring 2021.

The structure imposed by outcome-based design may also have additional benefits for college students learning during the pandemic. This is because anxiety related symptoms may be elevated among college students during a pandemic[16] and one cited reason could be a loss of routine in the students day-to-day activities.[17] Thus, by establishing very clear learning objectives and goals within our revamped curriculum at the very outset of the course, we aspired to help students persevere in a pandemic setting. Indeed, there is enhanced interest to further understand how to aid students mental health during a current pandemic.[18]

Course Design and Implementation.

Experiment design. While textbooks[19-21] provide a comprehensive list of well-tested physical chemistry laboratories, based on outcomes (i) and (ii), which are associated with basic learning in physical chemistry, we adapted four experiments (Table 1). For each experiment, we developed the lab materials and assessments to achieve all four learning outcomes, at both basic and advanced levels of learning. For example, we have compared the concepts of heat and heat capacity under constant pressure (C_p) and constant volume (C_v) in CHEM 165, with a brief introduction of their applications to calorimetry and related experimental setups like the constant-volume bomb calorimeter. For outcome (i) to connect theories and experiments, we chose to use the bomb calorimeter (over several other experiments in thermochemistry like differential scanning calorimetry), as students had previous experience with it from the lecture component. Aiming to establish advanced skills included in outcome (iv), we designed questions in the lab manual to encourage students, e.g., to search literature and databases (like NIST), to apply the understanding of combustion heat to real-life examples (sugar metabolism and explosion). Similarly, we chose quantum calculations at the level of the Hartree-Fock (HF) theory and the Density Functional Theory (DFT), which were covered in CHEM 260. This allowed students in the computational experiment to further understanding the theories and gain molecular modeling skills toward outcomes (i) and (ii). The lab manual included only the basic theory and essential steps of the quantum calculations, so that students were required to think critically when HF and DFT provided different results for the same chemical system, for outcomes (iii) and (iv). Further, we also endeavored to integrate these experiments by studying the same molecules, which allowed students to better understand the structure-property relationships of the focused molecule from different physical models as well as gain insight into the complementary nature of analytical techniques. Two small molecules — anthracene (Lab I and II) and sucrose (Lab I, III, and IV) — were chosen, to respectively represent a typical aromatic molecule and a common biological molecule. We also optimized some procedural preparations and the number of runs for experimental measurements to allow sufficient practice for data collection and consistent analysis for each student. We envisaged the students would be able to expand on their understanding and simultaneously develop new skills, while maintaining consistent reagents for investigation, as an attempt to maximize the learning outcomes.

Table 1. Experiments selected for CHEM 166 in Spring 2021.

Lab	Title	Relevant Phys. Chem. Concepts	Major Chemicals
I	Enthalpy Measurement via Calorimetry	heat, work, state function, internal energy, enthalpy, and heat capacity	anthracene, sucrose
II	Spectroscopy to Probe Molecular Structures and Properties	molecular vibration, electronic transition, energy levels, spectroscopy	anthracene
III	Determination of Reaction Kinetics	reaction rate, rate constant, reaction order	sucrose
IV	Quantum Molecular Modeling	Activation energy, transition state, Hartree-Fock Theory, Density Functional Theory	sucrose models

To achieve the general, advanced learning outcome (iv) , we focused on two aspects in practice: (i) the quantitative predictions of chemical properties provided by physical models and (ii) the natural observable phenomena produced by molecular structure-property relationships. The selected experiments not only allowed students to practice different quantitative physical chemistry approaches, but also inspired them to critically and creatively think about the connections to understand the structure-property relationships in extended contexts even beyond physical chemistry. For example, in Lab I students measured the enthalpy of the combustion reaction of sucrose via calorimetry; the questions in the lab manual as well as the TA in class guide them to discuss the thermodynamics with the reaction occurring in different conditions, such as the calculation of calorie generated by sugar in a can of soda. In Lab IV, students can further their understanding of the internal energy and enthalpy from building the three-dimensional (3D) molecular models in a computer program and are expected to better understand the structure-property relationship of sucrose. Overall, the different levels of learning outcomes are useful to guide our selection and integration of experiments in Chem 166.

Teaching material preparation. Available in Blackboard, our teaching materials were comprised of questions for prelab quizzes, lab manuals, and articles for extra reading. As the major teaching material, our lab manuals of CHEM 166 (provided in SI) shared a basic structure of four core components: Learning Outcomes, Background, Procedure, and Questions for Discussions.
(i) The Learning Outcomes section was provided to students to help them understand the learning goals, which are specialized for each lab from the overall learning outcomes of the course.

(ii) The Background section, typically most of the manual, combined both review from the lecture as well as specific information of the chemical theory being examined. This section was carefully designed to achieve outcomes (i), (ii), and (iii). For example, in Lab I we provided a cartoon illustration of the bomb calorimeter, from our textbook used for CHEM 165 and 260,[22] and some hints for detailed analysis (calibration, graphing).

(iii) The Procedural section of the reports was written with clarity and direction in mind, instead of providing recipe-like procedures. It emphasized important techniques such as standard addition and placing the onus for calculation more on the students, but also prepared students for potential problems. This strategy, combined with small group pre-lab discussion, inspired the teams of students working together and thinking critically about the task in front of them and avoided any simple regurgitation of the manual. These were key to achieve outcome (iv).

(iv) The Questions for Discussions section was designed for each report to connect the experiment with real world chemistry. Comparison of the results with known values, expected chemical trends, and the textbook information allowed the students to advance their experience beyond simple data comparison. These questions were not required to be answered directly in the lab report, but students were encouraged to discussed with the peer/TA/instructor in the online meeting and to incorporate their opinion in their lab report. We implemented this section to further enhance learning outcomes (ii) and (iv).

Course implementation. In spring 2021, we scheduled the four laboratory experiments to complete in 12 weeks (Table 2). All the students finished data collection within the allotted two weeks, and no student missed any of the labs. At the start of each in-person section (Weeks 1-2), students were engaged with a 20-min introduction given by the TA. Due to the nature of the lab schedule (Table 2), each pair of labs was introduced together in Week 1 and a brief refresher upon the cycle switch after three weeks. Specifically, an itemized list of instructions and safety precautions was consistently presented on the whiteboard in addition to the demonstration. Hands-on demonstrations were needed for experimental modules like Lab I and IV, while for others more time was spent connecting the theory required for measurements and calculations.

For the virtual section in Week 3, students joined the breakout rooms that were setup for their groups in Microsoft Teams, while the TA was cycling rooms and questions but also giving the students space to discuss amongst themselves. The discussion propelled by the online meetings also provided an additional opportunity for students to communicate with others during the pandemic. As each lab report was due on the Saturday of Week 3 (submitted to our course management system Blackboard), the virtual meeting provided a convenient and safe means to encourage group and peer help for students to finalize their lab reports. Notably, the implementation of in-person labs and virtual discussion was not merely for pandemic, but more importantly to provide us timely student feedbacks to adjust our teaching practice to best achieve the learning outcomes.

Table 2. Schedule of the CHEM 166 laboratory experiments at UVM in spring 2021.

	Lab	Group A	Group B	Due Date
2/17/21-2/24/21	Experiment 1	Bomb Calorimetry	Spectroscopy	3/6/21
3/10/21-3/17/21	Experiment 2	Spectroscopy	Bomb Calorimetry	3/27/21
3/31/21-4/7/21	Experiment 3	Computation	Polarimetry	4/17/21
4/21/21-4/28/21	Experiment 4	Polarimetry	Computation	5/8/21
	Essay			5/8/21

Assessment design. We have applied four major tools to assess the learning outcomes and the effects of course redesign: (i) pre- and post-course surveys, (ii) four pre-lab quizzes of multiple-choice questions to be completed before each experiment, (iii) four electronic lab reports due one week after the completed lab, and (iv) a 1-page essay to be completed before the semester's end. All of these assignments were facilitated through the Blackboard system with students either submitting their own work or completed pre-designed modules. The pre-lab quizzes and the short essay contributed to 10% respectively to the final grade, while the four lab reports 80%. All these assessments were conducted via Blackboard. For the lab reports, students were provided with a template and a rubric (see Documents S3 and S4), which listed six grading components (i) *Title, Abstract, and Key words*, (ii) *Introduction*, (iii) *Methods*, (iv) *Results and Discussion*, (v) *Conclusions*, and (iv) *References*. These section requirements were selected to advance all four of the learning outcomes, requiring careful review and citation of relevant literature and standards as well as critical thinking and application of theory in the *Results and Discussions.*

As expected in the outcome-based design, students were not only required to display critical thinking, but engage with the learning environment and extrapolate a solid hypothesis to guide their inquiry. Our grading rubric adopted from prior work[15] clearly explained the details of four grading levels: Exemplary (**A**), Proficient (**B**), Basic (**C**), and Unacceptable (**D**) for each of the components. In additional to a grade, students received detailed feedback in Blackboard which summarized the strengths, the weaknesses and potential ways to improve for each report. Reviews of the common issues in lab reports were provided in time as announcement in Blackboard, e.g. regarding the difference between the abstract and the conclusion, suggestions and tools for literature search and reference citation. For the essay, students were asked to choose a compound of interest and discuss the structure-property relationship with data/conclusions from at least two labs. Grading of the essay was mainly on the completion as well as the depth of physical chemistry knowledge reflected. Overall based on the learning outcomes, these assessments were used to evaluate student learning, as well as to provide evidence for us to identify the successful components in our teaching.

Hazards and Safety Precautions.

At all times during the course, students were expected to follow established general chemical safety protocol and minimize the risk of their exposure to any harmful substances. Anthracene is hazardous and may cause skin or eye irritation upon exposure. Hydrochloric acid can cause irreversible eye and skin damage and may be fatal upon ingestion. Acetic acid can also cause irritation and damage to the skin and eyes. Acetone is a volatile solvent which can cause damage upon ingestion or prolonged exposure. Pressurized oxygen gas may explode if heated and should be released with caution. For Lab I, the vessel was charged via regulator under direct supervision of the TA. All students wore safety glasses as well as nitrile gloves for each of the three wet experiments performed. In addition, in accordance with the Guidance, all students wore face masks and stayed a minimum of six feet apart. All reagents and subsequent waste were handled in the hood and appropriately labelled before disposal. The teaching assistant provided important safety review for each of the experiments during the aforementioned short introductions.

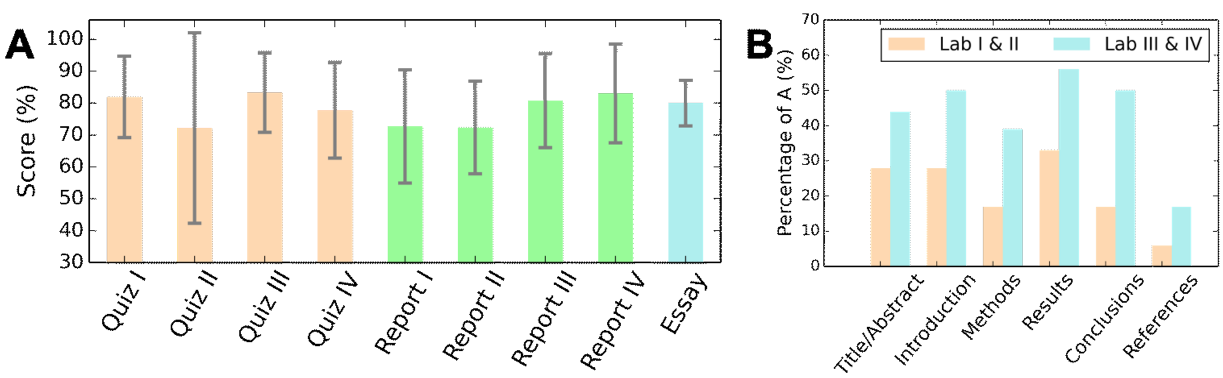


Figure 2. (A) Direct assessments of student learning outcomes in CHEM 166 at UVM in spring 2021, plotted with σ (N = number of students). (B) Comparison of the first two labs and the last two labs in the percentage of students receiving A (including A-, A, and A+) for the grading components.

<u>Assessment of Learning Outcomes.</u>

Direct assessments. We have evaluated the student learning outcomes from direct and indirect assessments. Students performed the experiments in small groups, and they were graded individually per assessment. The student average scores in three direct assessments (pre-lab quizzes, lab reports, and an essay) ranged from 72-83% (Figure 2A), which was improved from the performance of the same group of students in the lecture courses CHEM 167 (73 ± 8%) and CHEM 260 (66 ± 6%). While averages of the reports from Labs III & IV were slightly improved compared with the ones from Labs I & II, our detailed examination indicated enhancement in all six grading components, most significant in the Results and Conclusions. Shown by the percentage of students who received an A on each given section (Figure 2B), there were 23% and 33% improvement in these two components, with nearly twice as many students receiving and A on the Conclusions section of Labs III and IV. The improved performance in data analysis, as well as discussion and conclusion likely indicated a success in outcomes (i) and (iii).

Indirect assessments. A pre-course survey was conducted at the first week of the semester which focused on student expectation of the course and their awareness of the university guidance during the pandemic. In addition, a post-course survey was conducted during the last week of the semester to provide an assessment of the course redesign and students learning outcomes. Based on the pre- and post-course survey the students expectations of course work load, in terms of time, matched their actual experience (Figure S1). While 100% of students supported the idea to have a lab report template with a grading rubric, over 90% found them useful for learning in actual practice (Questions 2 and 3 in the post-course survey), as well as other materials used in CHEM 166. These findings suggest an appropriate workload and effective teaching materials in our course redesign, which facilitated our learning outcome (iii) in particular. This balance of target, perceived, and actual workloads reveal that the structure in the outcome-based design may have provided a reliable routine to the students.

Furthermore, we analyzed the learning outcomes with Questions 4 to 13 (see Document S6 in SI) in the post-course survey (Figure 2). 78% of our students agreed that overall expectations for student learning were clearly defined in CHEM 166 (Question 4). We received the most positive responses (>40% strongly agree and >30% somewhat agree) regarding Question 6 and Questions 10 and 11 showcasing student engagement in conceptual and communal environments. This is consistent with our analysis of the direct assessment, indicating a clear success to achieve the learning outcomes (i) and (iii). Generally positive responses to Questions 5, 8, 12, and 13 also suggest that most students achieved the learning outcome (iv) related to the advanced skills in information processing, problem solving, and critical thinking. We received the least positive responses from Questions 7 and 9, which highlight the weaknesses to practice the advanced lab skills and to interpret professional chemistry literature. Such insufficiency was consistent with the direct assessments, which showed the lowest grading in the lab report components Methods and References (Figure 2B). We believe these few weaknesses may have correlated with difficulties in teaching during the pandemic, namely allowing more students to use the instruments. On the other hand, the additional online discussion times for students could be considered an additional benefit of the course redesign.

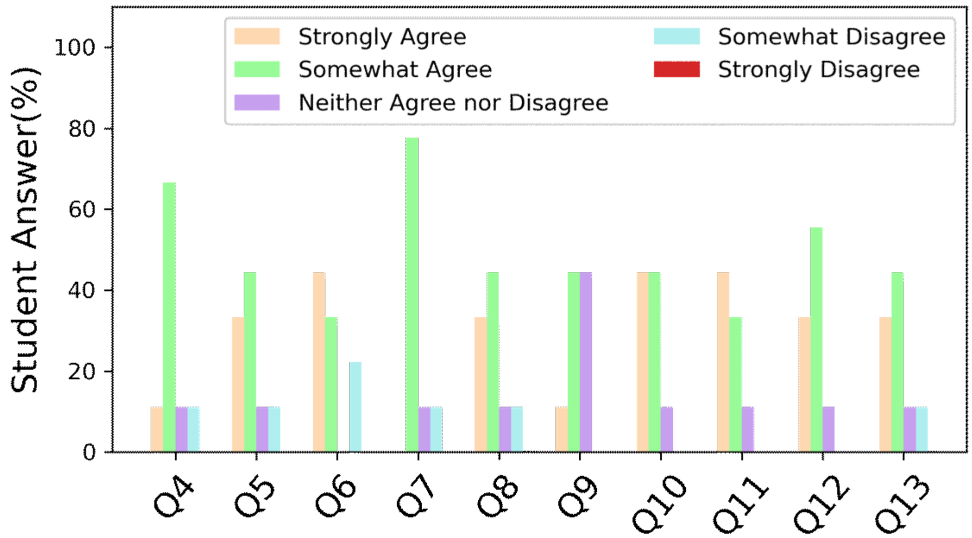


Figure 3. Summary of student post-course survey responses (N=9, 100% survey response rate).

Course evaluation. The chemistry department at UVM conducted the spring 2021 online course-instructor evaluation via the Blackboard survey system. The report with feedback was sent back to the instructor in June 2021. Six out of nine students responded to the online survey, which has a lower survey response rate than our post-course survey in Blackboard. While overall positive feedbacks were received, 67% of the students considered CHEM 166 to be well-organized with clearly defined course requirements. Over 50% of students would recommend it to other students. Some comments from students about what they liked most about the course:

"*Provided clarity in very difficult topics.*"

"*How the labs applied physical chemistry theory and applications to lab settings.*"

These comments also partially reflect the success to achieve our major learning outcomes.

Discussion. Lots of educational efforts and solutions have been reported regarding the disruption of the COVID-19 pandemic to laboratory teaching in spring 2020.[4-5, 11-12, 23] It is generally acknowledged that students learning from virtual laboratory environments miss authentic experience of conducting hand-on experiments and practical skills in instrument operation.[5, 11] While we carefully designed the course and experiments to provide in-person laboratory experience, we found that synchronous virtual meetings and collaborative analysis can be useful in multiple ways. Similar virtual meetings were found helpful in a recent report of teaching Physical Chemistry Laboratory during the pandemic which found having the TA's perform a tutorial style presentation of the course.[4-5] Our assessments of student learning outcomes suggest the effectiveness to combine in-person laboratory and virtual discussion for an advanced chemical laboratory course like Chem 166.

Guided by outcome-based design, our course was taught with an emphasis on data collection and manipulation, with most examinations supplying a theoretical introduction and placing the onus upon the students to connect their data to the calculations. With clear goals for teaching and learning, we were able to circumvent some of the academic integrity challenges faced by other programs[12] in their integration of online course components as most questions were related directly to the students' individual data. As compared to earlier in the pandemic, students were also free of some of the environmental challenges associated with remote learning as related to internet access and time management[23]. Throughout the course, the students who took advantage of the optional virtual meetings did so consistently, with attendance remaining constant throughout the semester. With most students on campus already during the scheduled laboratory time, deadlines as to the virtual assessments were not impugned by poor internet access as has been the case with some virtual programs[24]. The universal access provided by Microsoft Teams also extended benefits to those students who required some additional assistance outside of the pre-scheduled meetings, as they were consistently able to be accommodated by the TA despite the immediacy of their requests. We anticipate these changes, particularly the shift of student assistance to the virtual space, to be carried forth as the pandemic guidelines are relaxed and become established in our post-pandemic pedagogy. We hope to bridge this space with meaningful engagement that can center the students around the experiment at hand and align the goals of their inquiry with those of the course. Moving forward we plan to maintain the assessment design as a guide for assessment outside the laboratory as opposed to shifting assessment on to experiment performance[25], thus centering success on our learning outcomes.

Conclusions.

In conclusion, we have redesigned a physical chemistry laboratory course and assessed its learning outcomes at UVM. Based on different assessment tools, we observed that students taking CHEM 166 in 2021 spring have generally achieved the four learning outcomes, which supports the conclusion of our successful course redesign. In addition, the redesign implemented for this course provided an overall more efficient and concise approach for connecting the observations provided by the experiments and the hypotheses formed by the students. Despite the challenges faced by organizing and teaching this course during the pandemic, the combination of in-person instruction and virtual collaborative analysis afforded the students with a unique opportunity to expand their engagement. While providing helpful to students' unique challenges during the pandemic, there are measurable benefits of our course design — the virtual collaborative discussion sections and the use of more structured and well-designed learning goals and objectives — which we anticipate will persist beyond the pandemic. Overall, this outcome-based redesign established an integrated structure for students to enhance physical chemistry learning experience, while also creating the opportunity for practicing advanced skills in scientific communication, collaboration, problem solving, and critical thinking. This work, as a practical example of outcome-based course design, can be readily adopted by other institutions and for other chemistry lab courses.

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Supporting Information for Publication

The Supporting Information is available on the ACS Publications website at DOI: xxxx/xxxx.

- Document S1. UVM COVID-19 guidance
- Document S2. Course syllabus
- Document S3. Grading rubric
- Document S4. Lab report template
- Document S5-S6. Pre- and post-course surveys
- Document S7-S10. Lab manuals

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