Implementing a practical, bachelor’s-level design-based learning course to improve chemistry students’ scientific dissemination skills

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Implementing a Practical, Bachelor’s-Level Design-Based Learning Course To Improve Chemistry Students’ Scientific Dissemination Skills

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Supporting Information

ABSTRACT: This work presents an outline for a full-quartile design-based learning laboratory-based course suitable for final year Bachelor’s students. The course has been run for 5 years in the department of Chemical Engineering and Chemistry. The course attempts to provide a complete laboratory experience for its students, including an authentic research project, experience in writing a research paper with realistic limitations of both space and time, and giving of a presentation appropriate for a scientific conference, finally culminating with a written exam, where the questions are based on the written reports and oral presentations of the other students, making the students also course “teachers”. This article will discuss both the successful aspects of the course and point out the areas that still need improvement and provides enough information as to allow the transfer of the methodology to other educational curricula.

KEYWORDS: Upper-Division Undergraduate, Curriculum, Laboratory Instruction, Collaborative Learning, Hands-On Learning, Problem Solving

Practical laboratory classes for chemistry students are a mainstay in the university curriculum, allowing students to put into practice the raw theory they have acquired in their lecture courses, develop their skills of critical thinking and manual dexterity, as well as pique their scientific curiosity. The ACS recommends that “the certified graduate must have 400 h of laboratory experience beyond the introductory chemistry laboratory” and “research...can account for up to 180 of the required 400 laboratory hours. A student using research to meet the ACS-certification requirements must prepare a well written, comprehensive, and well-documented research report, including safety considerations where appropriate. Thorough and current references to peer reviewed literature play a critical role in establishing the overall scholarship of the report.”

Students who have a more involved experience with the laboratory tend to perceive the laboratory as a more useful part of their chemistry education. There have been many efforts to reinvigorate excitement and a sense of exploration into the undergraduate lab courses, whether focusing on adapting existing reaction pathways, utilizing “research-inspired” projects, or using other techniques, it is generally accepted that improved laboratory experience can enhance student learning. Many traditional lab experiments suffer from overuse (for example, steps and solutions to challenges are too readily available, allowing students to simply download procedures or results from online sources) and/or are structured as “fill in the blank” exercises. Both of these situations tend to encourage passive learning behavior and can even demotivate students. In place of understanding the basis of the chemical problems, chemistry students often resort to memorization of problem-solving methods and become less likely to be able to handle conceptual problems in contrast with algorithmic problems, manifesting itself in the laboratory setting. As a result, many students are disillusioned about the usefulness of university laboratory classes.

At the Eindhoven University of Technology (TU/e) Department of Chemical Engineering and Chemistry, these potential pitfalls were recognized, resulting in the development of the design-based learning (DBL) lab project courses. The DBL courses are used as an opportunity for students to conceive, design, and conduct their own research projects in small groups under the supervision of faculty and Ph.D. candidates. The courses last 8 weeks and consist of 16 contact hours per week. The course is given in the second 8 week session (out of four) in the academic calendar. It runs concurrently to the required Bachelor’s survey course “Energy”, which is a standard lecture course designed to be
at least partly supported by the DBL. Student enrollments were in the range of 46–78 for the first 5 years the course was offered (2014–2018). The vast majority of the students are in their final year of their Chemical Engineering and Chemistry Bachelor’s courses, although each year, there is generally one or two students from other departments (such as Physics or Mechanical Engineering).

The learning objectives of the course as provided to the student in the course guide are:

- to help students to gain insights into the way in which technological knowledge can be used to find practical solutions in developing of new energy systems,
- to enable students to make design decisions based on the performance of material systems using experimental data and theoretical considerations presented in the “Structure-Properties” paradigm, as introduced in the materials science courses,
- to enable students to formulate technological problems and make project planning, and
- to help students to improve presentation techniques and to develop skills of technical writing on a level appropriate for chemical engineers at a university.

The goal for the DBL Energy course is for the students to have a complete research project experience, from planning to execution, to scientific reporting of the results and presentation of the key research in a conference-like setting. As R. L. Dehaan states, “It is generally believed that the more authentic the research experience, such as an apprenticeship guided by a science professional, the more students will learn about scientific inquiry and the more positive will be their feelings toward science.” The DBL course allows the teacher to activate students toward self-learning, reducing the teacher’s role as the student acquires the ability to think and act independently. This authentic experience was accomplished by activating the skills required of advanced academics or for graduates entering an industrial environment:

1) experimental planning and task division,
2) proper, safe lab practice,
3) clear oral presentation of research findings to an unfamiliar audience, and
4) clear written presentation of findings, under both time and space constraints.

**DESIGN-BASED LEARNING (DBL) COURSE DESIGN**

**Project Selection**

The course involved the recruitment of faculty across a variety of background research areas linked to the overall topic “Energy”, with preference given to those who actively participated in the concurrent “Energy” lecture-based course. In the first year (2014), 7 projects were defined, followed by 6 projects in 2015, 9 in 2016, and 10 in both 2017 and 2018, involving 6–8 faculty and 7–14 assistants in total each year, depending on the number of projects. (Some faculty head two projects, and some projects have two or more assistants.) Approximately 2 weeks before the course begins, students receive course details and a one-page description of each project. From this information, students are asked to rank their top three project choices (examples of some of these information sheets are provided in the Supporting Information.) Each student is then assigned a topic with these preferences in mind. In the first 5 years of the DBL, all students have ended up participating in one of their top three selections. Students who did not respond with their preferences were randomly assigned until each group contained approximately the same number of participants, around six to eight.

**Schedule**

Roughly 1 to 2 months before the course begins, a number of volunteer graduate students and/or postdoctoral candidates are recruited as DBL course assistants. They are first introduced to the course by a lecture from the course responsible, outlining the expectations of both the participating students and also the assistants themselves. The learning outcome goals of the course are presented, followed by “tips and tricks” for preparing the projects. A separate 2 hour training session is given to the assistants on a different date by education professionals of the department, focused on providing information and skills for working with Bachelor’s students. In general, the assistants are to monitor day-to-day progress and handle immediate student queries, whereas the faculty is responsible for handling more in-depth questions or discussions.

The course covers a period of 8 weeks: approximately 5 weeks into the course there is a break for the winter holidays, after which there are three consecutive weeks for completion. The students meet three times a week, one full day (four morning and four afternoon hours) and two half days (one morning, one afternoon). Time and space are reserved twice a week for mandatory 60–90 min meetings for the students to gather with their group to plan activities, process data, and analyze results. In most cases, an assistant or faculty member is present during these sessions to monitor quality, answer questions, and offer advice, but the purpose is not to give instruction, as it is the goal of the course to provide the students a real research atmosphere. Given that the projects are exploratory in nature, it is important for students to discuss their research plans not only with the faculty and assistants but also with each other to keep the research coordinated. This time period is also excellent for encouraging the students to collect, plot, and analyze their data from the previous sessions, something that is often not obvious for the students, who often view data collection as the primary goal. The faculty are encouraged to ask questions to probe student knowledge and challenge experimental decisions and their interpretations of data. It is important that the student feels the work to be his or her own responsibility, but the meetings are a good opportunity to subtly nudge the students in the anticipated “correct” direction.

The first day is dedicated to orienting the students on the procedures and expectations of the course and introducing them to their assistants. In general, the rest of the session is dedicated to the individual project leaders presenting a short talk on the background of their project and outlining the goals and expectations as well as providing safety training specific to the materials and methods employed in that laboratory. The students have had previous instruction in safe lab practice and standard protocols and have completed at least one DBL course during the second quartile of their first year, which is focused much less on research than on proper lab practice, but there is generally a refresher safety training specific to each laboratory held on the first day of the course. In week five, the two half days are set aside for midterm presentations, and the last full day of the course is used for final presentations.
The progression of the work and the division of labor is up to the students themselves. The daily assistants and faculty are encouraged to roam the laboratory spaces and take notes as to the participation of the individual students as well as to ask questions to ascertain if the students are well-informed as to the progress of the course and experiments. The lab work, of course, makes up the bulk of the course. From this setup, students experience first-hand a number of important aspects of research, for example, the necessity of good planning (equipment is not always available when you want it), the ability to determine which measurement is appropriate to determine specific features of the material/system under study, and how to communicate their findings among the team. To assist the students in their project planning, in the second week, students are required to produce a document describing their scheduling for the rest of the course, which must be read and approved by the faculty. If the faculty member is not satisfied, then the planning document is returned with commentary, and a revised version is required until the faculty is satisfied that the students have properly considered all of the possible delays and have a realistic view of what might be accomplished.

In this DBL program, faculty and assistants take more of a coaching, rather than a teaching, role. How this role is handled allows for a wide variety of approaches: Some faculty are quite “hands-on”, with daily interaction and guidance, whereas others act more at a distance, allowing students to flounder on occasion. As previously mentioned, the presence of assistants at the group meetings helps train and encourage critical review of progress and decisions of forthcoming work and emphasize that the goal is not simply the accumulation of data. As a coach, it is an ideal time to caution against both optimistic scientific overstatement of results as well as to discuss cases of outright fraud to help students put their own work in proper perspective and encourage critical self-reflection. All of these features are directly relevant to the enhancement of student learning.

Written Reports

Report writing is seen as a standard accompaniment to the practical portion of the laboratory course, and solid writing skills are critical for a successful career in science and engineering. Despite this, it is common that the standard lab report is often a long, rambling diatribe including every item of data taken during the entire program written with the specific mentor in mind. Previously, DBL reports were not restricted in length and were often dull to read and not accessible to the other students and so met a very limited audience.

In the redesigned DBL Energy course, the students are provided with a template from a prominent chemistry journal to use as their model for their reports (currently that of the Journal of the American Chemical Society). Students are strictly limited to a maximum eight pages (including references). The final paper is delivered by a strict deadline and immediately uploaded to a common site to allow access by all students in the class. The papers are evaluated by a number of different faculty and assistants in the course, not all being familiar with the topics being described. Thus the students must consider a broader readership, and placing their work in a context with an adequate introduction is very important. As a consequence, each group had to find, read, and cite references in their reports to provide their readers a better understanding of the research context. It was found that the reports became clearer in the Energy DBL compared with other DBL courses, perhaps because students began the process of writing earlier than students from previous DBL courses, realizing that the report needed several iterations before it was finally uploaded for everyone to see. In addition, the limited space impressed upon the authors the importance of brevity and the exactness of expression, both valuable lessons as the students move toward their professional careers.

Presentations

One challenge we found in other DBL courses was maintaining participation and interest during presentation sessions. Whereas attendance at the presentations was required by all students, in actual practice, the only attendees actually listening to the presentation were students directly involved in the research and their advisors/mentors: the rest of the class had no incentive besides personal interest to give any attention. As a consequence, the question and answer period was effectively useless, as there were few or no questions, and little learning came about as a result.

Clear, well-structured, lucid oral presentations are paramount to a scientist. To better support this skill, the new course students deliver both a midterm and a final presentation, allowing the widest number of students the opportunity to present original research work before an audience of faculty and peers with various chemistry backgrounds. The midterm presentation (12 min, with 3 min for questions and answers) is designed to introduce the topic of the research, with more emphasis on the background and experimental setup, as most of the students are still in the process of generating data at this point of the course, and the final presentation (15 min with 5 min for questions) covers the entire project.

Active audience participation in the presentation sessions has increased markedly: the students attending the presentations are now much more critical and ask detailed and well-considered questions because they are, in essence, preparing for their final written examination, as is described in the following section. Thus the student presenters are now cast in the role of experts and teachers, and the faculty members’ role at the final presentations is primarily to ensure quality control of the answers.

Final Written Exam

This is an unusual feature of the course (for a Dutch University); a sit-down written examination about the research projects is based on the written and oral presentations of the student groups. Previous studies have recommended the use of quizzes, exams, or oral exams as a method to assess the mastery of material presented in lectures and associated laboratory work. The DBL exam is designed to question the students on the contents of all of the research projects that took place during the course. The study material provided for exam preparation includes the written reports and information from the oral presentations of their fellow students. The students were allowed to bring in unmarked PDF files of the reports and one A4 page of hand-written (only!) notes as study aids. As a consequence of including a final exam, it was generally felt by the faculty evaluating the course that, from their experience, the quality of both the final report and the presentations has dramatically improved compared with DBL courses they had previously taught. This was seen in the greater care taken in preparing and expressing the introductory material and explaining the methods and purposes of experiments because the authors had a vested interest knowing they would be
indirectly evaluated by their peers, who needed to understand the presented material to successfully pass the written exam with a good score.

## RESULTS

### Written Report and Presentations

The reports were assessed by the individual faculty and/or lab assistants of the course based on the university’s 1–10 point scale, with a 5.5 required to pass the competency. The evaluators were all experienced at writing scientific papers. Each paper was judged by three separate faculty members, and an average of the scores was assigned as the final report mark: the results are presented in Table S1 of the Supporting Information. The papers were judged on the quality and accessibility of the introduction, the clarity of the figures, the logic of the discussion, and the use of appropriate references to support the work.

The presentations were judged on both presentation style and on scientific content but an with emphasis on the latter for purposes of the group score. All faculty and assistants were invited to listen to the presentations and asked to send a list of scores for the structure and content of the presentations. Separate communications experts judged the quality of the presentation style. Each talk was thus evaluated by 3 to 10 persons, depending on the year and the session. The averaged marks for all talks and reports, which constituted the group mark and accounted for 30% of the final mark, are given in Table S1.

### Final Written Exam

The individual exam questions were written by the responsible faculty. The questions were required to relate to the material presented within the oral presentations and student reports or material they would reasonably be expected to know from their standard classes. Thus writing of the questions had to be delayed until the full content of the reports and presentations were known. In our case, given the close time proximity of the submission of the final paper and the written exam, faculty had just a few days to write the exam. This left a period of only about a single day to review the entire exam to try and balance the difficulty and the lengths of the questions asked by the different project leaders. Because of the large number of projects (7–10), it was felt that the students could not reasonably be expected to read and effectively assimilate all of the information in the short time period, so the students were requested to respond to only a limited number of projects of their choosing. This was based on time restrictions but also allowed students to focus their study on a more discrete set of papers and to mitigate the possibility that some student presentations/papers would be of lesser clarity/completeness, so these might easily be skipped in taking the final exam. A sample exam from one of the course iterations is included in the Supporting Information. The average scores for the exam, which account for 20% of the final mark, are found in Table S2. In general, the results of the exam are consistent across the years and across the various formats.

For the 2018–2019 school year the format of the final exam was changed somewhat. The projects were divided into two sets, each with five of the projects. Students were told they could select one of the two sets of five projects to prepare for the final exam. They would then receive questions based on those five projects and were marked on the best four of them, with the goal of the exam to take 75 min in total to complete.

The test was taken directly online in a monitored environment, with 3–5 multiple choice and 2–3 short open-ended questions requiring a written response for each topic.

### Personal Evaluation and Peer Review

Each faculty and laboratory assistant evaluated each of their students for their lab practice and general performance as a contributing team member, taking into account their participation in meetings, handling of data, and the like. A rubric was provided to assist this evaluation for the past 3 years to normalize the ratings. (The 2016–2018 versions are available in the S1.) The results of the faculty/assistant student evaluations, accounting for 30% of the final mark, are found in Table S3.

As part of their career development at the TU/e, students are given training in peer review. In this training, they learn how to evaluate one another and practice both giving and receiving feedback. This training involves attending a session during their Bachelor’s year led by one of the education experts of the university and instructs students on strategies for both giving feedback to others as well as receiving and processing feedback in a constructive manner as well as how to handle potential conflicts in a group dynamic. This training is refreshed during the DBL Energy course with a 1 h long session at the beginning of the course, with the educator taking an active role in the midterm peer review and a more observatory role during the final peer review at the end of the course. In summary, the students learn how to give and receive criticism in a constructive manner.

For the Energy DBL, the students were required to evaluate one another on their participation level, the quality of work delivered, their communication, their honoring of agreements, their ability to communicate in a focused and structured manner, and their teamwork with a numerical mark, to be sent to the course responsible as one list of values as decided on by the students: this mark was to comprise 20% of the final grade. Individual work in a project team can be stimulated by peer-to-peer feedback. While the students took the work seriously, some controls were put in place to discourage the practice of giving all top marks to unfairly raise the final grade. To allow for this, the following formula was employed

\[
P_{\text{final}} = R \pm \sqrt{\left|P_{\text{md}} - P_{\text{av}}\right|^2 \over P_{\text{av}}}\tag{1}
\]

In this equation, the students would thus have a base group mark received from faculty/assistant evaluations of the written report and oral presentation scores (R). The individual peer-review marks (P_{md}) were assessed by considering the variation of the average peer-review score (P_{av}): those scoring higher among their peers would gain a few tenths higher of a group mark, whereas those below average would lose fractions in a similar way. In this manner, students were free to assign marks in any way they saw fit and were not restricted in how they evaluated one another but at the same time were not able to unjustly skew the results in comparison with the other groups.

The results of the raw student evaluations and the final scores, P_{final} accounted for 20% of the final mark.

### Indirect Assessments

Students are routinely asked for written feedback for each of their courses each year. Response rates are generally low, however, making evaluation sometimes difficult. A selection of the responses for the period 2014–2018 are given in Table 1.
Table 1. Comparison of Course Evaluation Response Scores

<table>
<thead>
<tr>
<th>Statements for Response</th>
<th>Evaluation Scores by Year&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a scale of 1 to 10, how would you rate this course/project (with 10 being “excellent”)?</td>
<td>7.8</td>
</tr>
<tr>
<td>The educational setup (e.g., structure, content, teaching/learning methods, level, and coherence) worked well and was suitable for this course.</td>
<td>3.8</td>
</tr>
<tr>
<td>The course was well organized (e.g., availability of lecturers/faculty, availability of information, scheduling and planning)</td>
<td>3.3</td>
</tr>
<tr>
<td>The assessment of this course was appropriate (e.g., methods used, relevance and clarity of the questions/assignments)</td>
<td>3.3</td>
</tr>
<tr>
<td>The number of credits I applied to complete this course corresponds to the number of credits (140 h). 'Rated from 1 = &quot;much less effort&quot; to 5 = &quot;much more effort&quot;'</td>
<td>3.4</td>
</tr>
<tr>
<td>Did you obtain, from the former courses or study, sufficient knowledge to be able to follow this course?</td>
<td>4.1</td>
</tr>
<tr>
<td>What is your opinion about the level of difficulty of the final exam? 'Rated from 1 = &quot;too easy&quot; to 5 = &quot;too difficult&quot;'</td>
<td>3.7</td>
</tr>
<tr>
<td>The final exam was sufficiently representative of the lectured subject</td>
<td>2.7</td>
</tr>
<tr>
<td>I enjoyed the course</td>
<td>4.4</td>
</tr>
<tr>
<td>I am satisfied with the knowledge I’ve gained in this course</td>
<td>3.9</td>
</tr>
<tr>
<td>I felt I was able to do original research during this DBL</td>
<td>3.9</td>
</tr>
<tr>
<td>You received enough support from the lab assistants</td>
<td>4.4</td>
</tr>
<tr>
<td>You received enough support from the faculty member</td>
<td>4.3</td>
</tr>
<tr>
<td>I was satisfied to be assigned 5 papers and answer 4 questions on the final exam instead of reading 10 papers and answering 8 questions</td>
<td>4.3</td>
</tr>
<tr>
<td>Do you feel the research was challenging enough?</td>
<td>3.7</td>
</tr>
</tbody>
</table>

```
"Unless otherwise stated, the scores were based on a scale of 1−5, with 1 = "strongly disagree" and 5 = "strongly agree". bThe 2014 course had 49 participants and a response rate of 18.4%; in 2015 this was 49 (32.7%); in 2016, 62 (25.8%); in 2017, 79 (31.6%); and in 2018, 73 (41.1%), respectively. "This question was not included on the response form.
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Some interesting individual comments from the most recent iterations of the course (2017–2018) offering additional insight into the course from the student’s perspective are included in the Supporting Information.

**DISCUSSION**

**The Projects Themselves**

One of the possible pitfalls of this course is the potential for project failure (as it is for real research). Because the goal is original work, not every project will meet with a successful outcome, which can be used as a good learning experience. However, this can cause challenges to the faculty in several ways. First, it can be demotivating for the students who feel they have somehow “failed” in their work. Second, writing a report and presenting results for a generally unsuccessful series of experiments is often difficult. It is very important for the experienced scientist to make his or her students aware of the expectations of the course. Obtaining a good mark for the course should not hinge upon the accumulation of positive experimental results but more on the successful carrying out of appropriate experiments and the correct interpretation and explanation of the results.

At this time, there are a wide range of lab experiences. Some projects are overly crowded for the amount of work to be done, and others are very ambitious and probably beyond the reach of the students’ capabilities. Some are more simulation-centered, and some are strictly experimental. Some employ very “hands-on” assistants, and some are very “hands-off.” It is difficult to ensure enough projects each year that are significantly different from the previous year’s projects to keep the student group sizes to eight or fewer. Four to six projects would be ideal, but resources and time do not allow us to increase the number of projects at this time. Some complaints from students were that there was sometimes not sufficient work to do for all eight students. Some of these disadvantages are mitigated by the allowance of students to choose their topics, so there is a degree of “word-of-mouth” as well as a familiarity with the responsible persons through viewing the faculty in the classroom or having listened to presentations, so the students are not joining projects completely uninformed.

**Laboratory Report**

To this point, a rubric has not yet been created for the evaluation of the written reports. This leaves one concerned about the continuity of marking over time and between groups. However, all evaluators have professional experience and have been verbally instructed to realize that the students are at the Bachelor’s level and to take this into consideration. In our case, the students are writing in English, which is not their native language, so concessions have been requested for this. Each paper is read by a minimum of three different evaluators, and, as seen in Table S1, the results of the marking to date have been remarkably consistent. Nevertheless, in consultation with our in-house education professionals, a rubric is being developed with experts in the field of writing within our university to see if a more standardized evaluation is possible for the next course iteration.

Additionally, in 2019–2020 a new peer-review plan will be implemented where students will be required to provide written feedback on (primarily) the introduction of another group’s paper approximately 2 weeks before the final version is due, and the writers of the reviewed paper will be expected to indicate an understanding of the commentary and demonstrate some level of adaptation of the text to accommodate the review. This procedure will, hopefully, generate two positive outcomes. First, students will need to start writing their paper earlier than usual, which is always valuable, and this will
improve the readability of the introduction for the other students.

Final Examination

It was determined there was not sufficient time between the availability of the written reports and the taking of the final examination (due to university scheduling policies, there was exactly 1 week between the events). It was too much to expect the students to read 80 pages of reports over the span of a week in which they also were preparing for other courses, and, in many cases, the students attempted to read the papers during the examination period, which meant that 85% of the students were still present at the end of the 3 h period, having found it difficult to complete seven questions in this time frame.

Remaining the greatest challenge is the format of the final examination, which still does not work completely as anticipated, although the latest online iteration is closer than previous years to the best solution because it is faster for the students to take and quicker to be marked. One potential alternative solution is an oral exam, allowing the faculty to directly assess the student’s involvement and knowledge. The main challenge is the sheer number of students involved: as we have surpassed 80, individual examinations become practically impossible. Perhaps group exams with four to five students could be feasible, but they would still be very taxing for the examiner, and it would certainly be difficult to recruit willing volunteers to assist in the evaluation. This aspect of the course is being carefully considered.

Additional Thoughts

The results of the student projects in the DBL course may find their way into the scientific literature. For example, in my personal case, the students produced valuable supplemental data for one of my research projects. This potential to contribute to the research world has several benefits: it can be very motivating for the students, it can improve the quality of the work being done by the participating Bachelor’s student as they realize that the collection of data could be useful outside world, and it may help the Ph.D. students collect additional data for their theses, especially data that would often be tedious to collect but is still seen as quite exciting for the Bachelor’s student. The quality of the data, of course, should be carefully controlled by the students and faculty before use, but the potential is good to convert the student work into usable results if the research question is well-defined for the students and they are trained in the importance of careful measurement and recording of details.

CONCLUSIONS

While not yet perfect, this DBL course has breathed new life into a somewhat strained practical chemistry course in our university. The quality of both student reports and presentations has dramatically improved, exposing students to the necessity of reporting within a limited number of pages and orally presenting an extended project in a restricted time period. The students had the opportunity to teach their fellow students an aspect of chemistry they were likely not previously exposed to and thus obtained valuable experience for their future careers. The students are able to have their first real taste of research during their Bachelor’s coursework, an invaluable experience as they look to obtain internships and enter a Master’s program.

Finally, the author wishes to emphasize the impact and advantages of including a written exam in this laboratory-based course. With one activity, the overall educational value of the course increased significantly, impacting the quality of both written and oral reporting, enlivening question sessions, and broadening the horizons of the students as well as preparing them for actual situations faced by scientists, whether attending scientific conferences or the industrial boardroom. The perfect format of this examination is still being sought, but its impact on improving the written reports and the presentation sessions in this DBL course cannot be denied.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.9b00166.

Tables analyzing course outcomes, sample project descriptions, assessment rubric and peer review, sample written exam, and selected student commentary on the course (PDF, DOCX)

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Notes

The author declares no competing financial interest.

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