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Home-based laboratory experiences during COVID-19 pandemic in undergraduate biochemistry students

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The coronavirus pandemic (COVID-19) pointed out new challenges to teaching in laboratory-based disciplines, such as chemistry, biology, and biochemistry with on-site practical sessions interrupted or suspended during 2020 and 2021. Observation and experimentation are part of education in science-based disciplines and provide necessary skills for professional and academic careers. In an effort to solve this disruption to experimental observations, we designed a set of home-based experiences related to chemistry and biochemistry. These included visual identification of lipids, sugars, proteins, and DNA in biological samples using materials easily found at home, such as alcohol, soap, and oil, among others. Each activity was documented with smartphones and discussed in a final portfolio. Fifty-two students were part of an introductory cell biochemistry course. The home-based laboratories were organized into 2.5-h sessions that included a lab session, a post lab session, and a period for preparing the experiment at home. Thirty-six (17 men and 19 women) students answered a survey designed to assess three major domains: (1) student's demographics and home environment, (2) general perceptions of the laboratory activities, and (3) specific perceptions of each laboratory activity. Sixty two percent of the students thought that these activities helped them to understand how to isolate and identify macromolecules. Eleven percent said these home activities did not contribute to their understanding while 27% stated the activities were not significant for the topic. We conclude that, although the addition of in-house experiments provides a complementary tool for understanding the main concepts in biochemistry along with improving skills in scientific thinking, this should be accompanied by a good feedback mechanism from the instructors. In addition, student to student interaction should be part of the at home activities to increase student motivation. A Flipped laboratory methodology plus tools where metacognition is evaluated, appear to be appropriate to promote the understanding of concepts in the context of the laboratory. And although some aspects of the experimental experience can be substitute with online resources and in home experiences, others can only be achieved by the in-person experience.

KEYWORDS

COVID-19, biochemistry, in-home experiment, active Learning, undergraduate student

Introduction

The COVID-19 pandemic affected all levels of the education system (Nicola et al., 2020). Educational institutions around the world have temporarily closed affecting about 1.7 billion students worldwide (UNESCO, 2020). Many universities also canceled all campus activities to minimize and decrease the transmission of the virus (Mahdy, 2020).

In Chile, all universities closed their classrooms during 2020 and 2021 forcing educators to substitute face-to-face learning environments with online learning approaches for delivery of the curriculum. To continue the education of our students during the pandemic in the institute of chemistry at the Pontificia Universidad Católica de Valparaíso, multiple education solutions were implemented, however, all of them were based on remote online teaching/learning.

Online solutions carry some disadvantages for student learning, including technical problems such as a poor internet connection; failures due to overloaded servers and communication platforms; few opportunities for face-to-face interaction with teachers and peers; and difficulties engaging such as problems with concentration, motivation, and isolation. This led to students who were not actively involved (Pokryszko-Dragan et al., 2021; Khan et al., 2021). On the other hand, online learning also carries positive aspects, including increased convenience with time, more flexibility with study schedule, and during the COVID-19 pandemic, safety by avoiding contacts and potential exposure to infection (Razzak et al., 2022).

The inability to develop experimental work has been a problem for several careers, in particular to the ones related to biology and chemistry. The laboratory environment allows students to gain first-hand experience with course concepts. Further, it provides them with the opportunity to explore methods used by scientists in their discipline. We were concerned about how the shift to remote learning might affect these students, since they miss the physical sensations, such as touching and seeing the actual experiment. In addition, they were not gaining the practical skills from using real equipment and instruments in the laboratory (Mojica and Upmacis, 2021). Studies conducted during the COVID-19 pandemic, have revealed that students believe that the primary role of a teaching laboratory is to provide hands-on experience and that, overall, the online modalities do not compare favorably to the traditional in person laboratory approach (Mojica and Upmacis, 2021). An alternative to on site university experimental activities, has been do it yourself home activities. Many dedicated teachers in the science fields have created home laboratory experiments for use during COVID-19. However, none have used this approach to study macromolecules (Searches of ERIC and Science Citation Index). Here, we describe the experience of the student's performing identification, extraction, and visualization of some common and important biomolecules, such as lipids, proteins, DNA, and sugars in a home-laboratory experience. The students answered a survey designed to assess three major domains: (1) student demographics and home environment; (2) general perceptions of the laboratory activities, and (3) specific perceptions of each laboratory activity.

Materials and methods

Participant recruitment

The participants of this study were first year biochemistry students comprised of 26 women and 26 men; age 18-22 years old. These students had enrolled in the Biochemistry course at the Pontificia Universidad Católica de Valparaíso in March 2021. At the end of the course, they were asked to answer a questionnaire of 33 questions, regarding their perception of the activities performed during the semester. Thirty-six students (69%) answered the questionnaire, (17 men and 19 women). The survey was validated by an expert committee at the Pontificia Universidad Católica de Valparaíso, Chile from the postgraduate program of Didactics in Science.

Laboratory course overview

This study was set within the framework of seven laboratory class experiments conducted over a 16-week period. Laboratory sessions totaled 17.5 h and were taught by the same faculty each time. Four experiences were student lead at-home, while three of them were performed online (sessions about using the microscopy and laboratory tools). For this study, we considered the four at-home sessions that included the visualization of organic molecules according to their chemical characteristics. The laboratory sessions were organized into 2.5-h blocks, which were divided into three parts, a lab session, a post lab session, and a period for preparing the experiment at home. Students were organized in groups of five to discuss practical experiences and collaborate on the laboratory reports. Each student had to complete a portfolio with notes regarding important aspects of the lectures and readings assigned for each session, including observations, methods, discussion, and conclusions

TABLE 1 Portfolio's rubric given to the students.

Item	Grade	Percentage	Total
1. Cover. Title, activity, names, date.		**0.1**	
2. Methods. The students must include step by step detail on making the reagents and conducting the activity.		**0.2**	
3. Observations. Must consider all observations during the experimental activity.		**0.2**	
4. Results. Results allow to understand the experience, by using table, figures, plots. Figure legends must be present for all images.		**0.2**	
5. Discussions. The student must synthetize the results in the context of the theory using bibliographical references. In some cases, the student may explain difficulties that occurred during the experiment		**0.1**	
8. Conclusions. The student may state a hypothesis relating to the activity and combine with previous knowledge to confirm or dispute the hypothesis		**0.1**	
9. Bibliographical references. The student is able to use bibliographical references, citing in the discussion and in APA formatting.		**0.1**	
7 = Contains all aspects in very good shape and clarity	**Total:**		
6–6,9 = Contains all aspects but there are some unclear aspects			
4–5,9 = There are omission and absence of clarity in concepts and requirements			
2–3,9 = lack of basic aspects and concepts			
1 = null			

that were evaluated according to a rubric. Table 1 shows the rubric given to the students. According to the academic grading in Chile, scores range from 1 to 7, where 1.0–1.9 is very deficient; 2.0–2.9 is deficient; 3.0–3.9 is less than sufficient; 4.0–4.9 is sufficient; 5.0–5.9 is good; and 6.0–7.0 is outstanding.

Survey instruments and dissemination

Assessment of students' satisfaction and acceptability of the different online teaching tools was through an in-house constructed survey. The anonymous student survey consisted of 33 questions that evaluated students' attitudes toward the described online instructional methods in the biochemistry course. The student survey was designed to assess three major domains: (1) student's characteristics and home environment conditions; (2) General Perceptions of the laboratory activities, and (3) specific perception of each Laboratory Activity. The survey was constructed with Google Forms and disseminated through a web link sent to the students. By selecting the option "Limit to 1 response," we ensured there were no duplicate submissions. The survey was validated by an expert committee at the Pontificia Universidad Católica de Valparaíso, Chile from the postgraduate program of Didactis in Science. The students were not allowed to edit after submission of the completed form. There were no incentives offered to students for completing the survey (Razzak et al., 2022). Two examples of the survey questions from each domain are shown in Table 2. Learning outcomes of each activity are presented in Table 3.

Results

Student demographics and home environment

Thirty-six (17 men and 19 women, Figure 1A) of 52 students responded to the survey with ages between 18 and 22 year-old (Figure 1B). The percentages described below refer to these 36 students that represent our 100% response. The first questions were designed to evaluate general aspects of the course. In this regard, 62% of the students participated in all activities, while a 37% of the students participate in more than 70% of the activities (Figure 1C). Although 99% of them mentioned that they had access to Internet during the whole course (Figure 1D), the perception of internet speed was asked to the whole group, with 50% reporting connections in the mid-range of speed (Figure 1E). Most of the students (92%) said their home environment had suitable conditions while they were connected to the class (Figure 1F).

General perception of the laboratory activities

The second group of questions was designed to evaluate the general perception of the laboratory activities. Each class session consisted of a prelab study time in which students reviewed material in different formats, such as PDF, word, PPT, and/or videos, before the laboratory session. The laboratory session was divided into three sections. The first section was a synchronous session where the content of the laboratory session was explained.

TABLE 2 Examples of survey questions in each domain.

I) Student'´s characteristics and home environment conditions
1. *Regarding the quality of the internet connection during the course:*
a) Stable
b) Moderately stable
c) Unstable
2. *The conditions or the environment of the place where I performed the experiments was:*
a) Very appropriate
b) appropriate
c) Moderately appropriate
d) less than appropriate
e) Inappropriate
II) General perception of the laboratory activities
1. The instructions in the guide to perform the laboratory activities seemed clear enough to me
a) totally agree
b) Moderately agree
c) Disagree
2. Learning objectives presented in the lab guides were clear to me
a) totally agree
b) Moderately agree
c) Disagree
III) Specific perception of each laboratory activity
1. Indicate the laboratory activity most interesting for you
a) *Lipids*
b) *DNA*
c) *Sugars*
d) *Proteins*
2. Regarding the activities carried out at home:
a) It helped me understand how to isolate and identify macromolecules
b) It did not help me, but it also did not confuse me about my understanding of the topic
c) I was confused about how to isolate and identify macromolecules

The second section was a post class where the contents were reviewed through interactive Quiz. Finally, the third section consisted of the practical activity that students had to perform in their homes. Students were divided into groups of 5. For every lab experiment, students discussed the home experiment on a zoom meeting and delivered a portfolio for evaluation.

Considering the session organization, when students were asked whether instructions to develop the laboratory activities were clear, 62% completely agreed whereas the rest (38%) chose partly agreed. None of the students disagreed (Figure 2A). Students reported that the instructions to develop the portfolio were clear (54%) or fairly clear (46%, Figure 2B). Interestingly, 55% considered the activities to be motivating; whereas 32% said that they were partly motivating and 13% regarded them as not motivating (Figure 2C). When asked about learning outcomes 65% of students stated that outcomes were clearly explained, while 32% said partially clear (Figure 2D). Regarding the relevance of the experience in working at home and making a portfolio we found that 65% of the student stated that it was useful to understand chemical process and organize their observations and discussions (Figure 2E). Finally, to work in a team represented a challenge during pandemic conditions. Only a 58% of the students were able to synchronously work as a team during the experiments at home, while 36% said it was only possible to work together on the portfolio but not on the home laboratory session (Figure 2F).

Specific perception of each laboratory activity

The third group of questions was directed to specifically analyzing each of the home laboratory activities developed: identification and isolation of lipids, sugars, proteins, and DNA. Figures 3–6 show pictures of the experiments submitted by students. Laboratories at home consisted of (a) identification of lipids in whole fat milk, non-fat milk, and butter by adding alcohol and by observing changes in turbidity (Figure 3); (b) identification of non-reducing sugars (starch as a complex carbohydrate), which is colored by iodine (povidone-iodine) when compared to sucrose (Figure 4). (c) casein precipitation (as an example of protein) by lowering the pH of a milk sample using lemon (Figure 5); and (d) DNA isolation from banana by using a high salt solution and adding detergent. The mashed banana was then filtered, and cold alcohol added to visualize precipitated DNA (Figure 6).

When students were asked "how much they learned with the individual activities," 64% of the students said they learned a lot from the experiments related to proteins, followed by lipids (57%), sugars (50%) and DNA (50%), (see Figures 3–6). When students were asked about the difficulty to perform the experiments at home, the DNA experiment was the most difficult to perform (62%), followed by sugars and proteins (58%), and finally Lipids (54%).

After the at home activities, students received feedback. During these feedback sessions given by the teacher and assistants, the students had the opportunity to answer their questions. They received simple explanations about the principles involved in the detection of each biomolecule and their associated methods of extraction and visualization. This was also complemented with slideshows and discussion forums between the teachers and students. In the discussion forums, students were able to leave comments about each experience; some of them are summarized in Table 4.

Finally, a general question about the overall satisfaction was asked. In this regard, 61% of the students said these home activities helped them understand how to isolate and identify macromolecules, 26% considered the "at home lab" not significant for their comprehension and 13% said they were even more confused regarding the isolation methods after participating in these activities (Figure 7A). The students were evaluated with two different instruments: the aspects of the lectures and readings assigned for each session, and a second one for the laboratory

TABLE 3 Activities and learning objectives of each activity.

Activity	General learning outcomes	Specific learning outcomes	Objectives	Theoretical principles	Instructions for the experience at home
Identification of lipids in milk and butter	Know the chemical components that form the different cellular structures Learn about cell structure and biochemical characteristics allowing cell characterization Associates the characteristics of a cellular phenomenon with its biochemical elements	Students who have completed the activity will understand the chemical properties of lipids allowing their identification using organic/non polar reagents	To identify the presence of lipids in a common food	Ethanol is miscible with lipids because of polarity. If we add ethanol to a food sample (liquid or solid), the lipid will spontaneously come out of solution and will form micelles in a solution of ethanol and water.	Put a piece of food of about 5 mm in a glass and add 3 ml of ethanol, shake well with a spoon and after that allow to settle. Perform the same experiment in a glass with 10 drops of water. Try to see a milky-like emulsion which means a positive result meaning that lipid is present. Record all changes.
Identification of non-reducing sugar using povidone-iodine in rice and table sugar		Students who have completed the activity will understand the chemical basis for identification of a non-reducing sugar by using iodide-based compound	To identify the presence of non-reducing sugars in rice and table sugar	The iodine test allows a distinction between table sugar (reducing) and starch (non-reducing), which is made up of molecules of glucose chained together. Long chains found in starch are able to interact with the iodine; by contrast reducing sugars do not interact with iodine.	Put the food sample (rice or table sugar) on a dish and add 5-10 drops of iodine solution onto the food. Record any change in the color of the solution.
Evaluation of the effect of low pH on casein precipitation in the milk		Students who have completed the activity will understand the chemical basis explaining casein precipitation	To perform the isoelectric precipitation of casein present in milk	Since isoelectric point of casein is around 4.6 and milk pH is around 6.0, stable micelles formed by positive and negative charged amino acids giving homogeneity to the milk, however by lowering the pH this equilibrium is disrupted and the protonated phosphate groups causes protein to precipitation	Put 10 to 15 drops of lemon over 1/3 cup of milk in a glass. Wait until you see any change of color and consistency in the milk. Record any change observed.
DNA isolation from banana using salt solution, detergent, and alcohol		Students who have completed the activity will understand the biochemical basis to visualize DNA by performing disruption, extraction and precipitation of DNA from a biological matrix	To perform a DNA extraction from a banana	By mechanical breakdown, tissues can be disrupted. Adding a hypertonic solution (salt plus detergent), breaks down cell membrane. The addition of cold alcohol helps the DNA precipitate which can be visualized as a white structure	Use a small portion of banana. Add a very salty solution. Mix the smashed piece of banana with 3 spoons of table salt and a glass of water. Add detergent and mix with the spoon. To finish, add alcohol (¾ glass), thus obtaining a DNA strand that can be extracted with a toothpick.

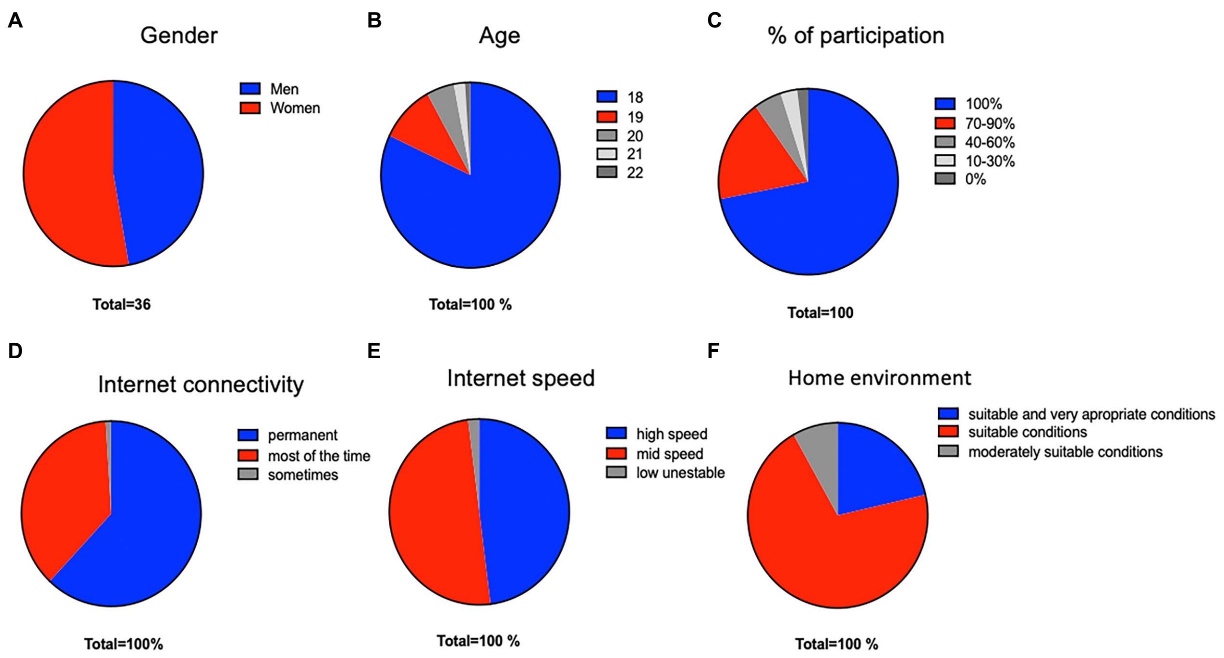

FIGURE 1
Student demographics and home-environment conditions. 17 men and 19 women **(A)** aged 18–22years old **(B)** Student participation in at least 90% of the activities **(C)**. Internet Connectivity **(D)**, speed of connection **(E)**, and suitable home environment **(F)** to perform the activities were evaluated.

activities that included observations, methods, discussion, and conclusions was evaluated according to a rubric given to the students at the beginning of the course.

After the 2022 semester ended, we decided to compare portfolio scores from the 2021 and 2022 classes. The only difference between the courses was the home laboratory experiments versus the on-site laboratory activities. As seen in Figure 7B, final scores for portfolios from 2021 and 2022 courses showed similar grades and no statistical significance were observed. In addition, the analysis of the four activities when compared year to year was not significantly different.

Discussion

In Biochemistry teaching, laboratory practice serves multiple roles in the acquisition of knowledge. It cultivates the students' ability in practical skills, permits the identification of technological innovations and their uses in experimental contexts, and allows development of scientific thinking (Meng et al., 2022).

Due to the COVID-19 pandemic, having traditional laboratories activities within the university was not possible. For this reason, a set of synchronous and asynchronous activities had to be developed. An alternative way to do experiences related to the identification of molecules with biological importance was developed for use in home-based laboratories. This innovation was developed after academic discussions about sustaining student motivation during the pandemic situation. The continuity of education and hopefully discouraging student drop out were concerns. To evaluate the perceptions of the students, we analyzed the results of a survey given to the students regarding their experience in this online and at-home version of the course.

One of our main concerns was whether the students could connect to online classes with their current internet infrastructure. The results of the survey showed that most of our students have a computer or telephone and a suitable environment to connect to classes. In addition, they had access to a good internet connection. These observations contrast with what has been reported for Chile and South America. In Chile, not all students have a laptop, and even more, not all homes have proper internet access that will allow students to engage in online classes. This same problem can be observed in most of the countries in South America and other continents around the world (Cepal, 2017).

The favorable conditions reported by our students, make them more likely to concentrate and learn, maintain motivation, and continue biochemistry major the following year. Recent studies in the medical student population showed that the lack of internet and improper facilitation by the faculty hindered their progress towards achieving a good online medical education (Conway et al., 2021; Dhingra et al., 2021).

These difficulties have created a negative attitude toward online learning in general which has increased the number of students leaving school in the past few years. According to the National Student Clearhouse Report (2021), 74% of first-time freshmen in fall 2019 returned to college for their second year. This means a 2% reduction compared to previous years that can be attributed to the changes in the conditions of education due to pandemic restrictions.

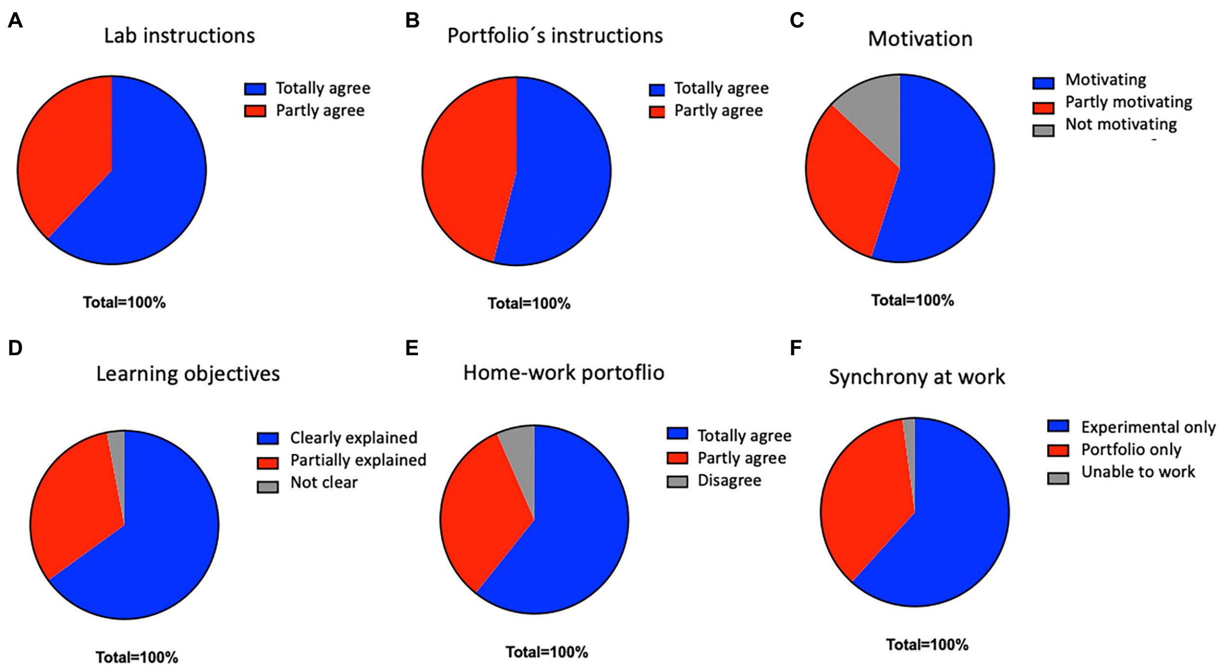

FIGURE 2
General perception of the laboratory activities. Students were asked whether instructions to develop the laboratory activities were clear **(A)** and whether instructions to develop the portfolio were clear **(B)**. Students were also asked whether activities were motivating **(C)** and if the learning objectives were explained **(D)**. In addition, students were asked if the preparation of the portfolio was useful for their learning **(E)** and whether they were able to work in teams during the in-home activities **(F)**.

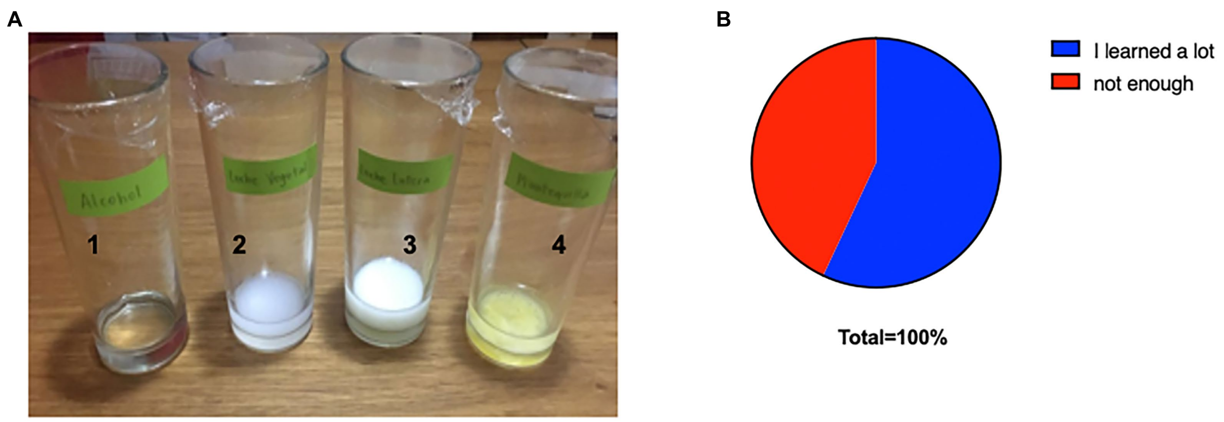

FIGURE 3
Identification of the presence of lipids. **Figure** was extracted from a student portfolio. **(A)** Glasses with Alcohol only (glass #1), non-fat milk (glass #2), whole fat milk (glass #3), and melted butter (glass #4). **(B)** Pie graph showing students' opinions regarding the activity. A 57% of the students said that they learned a lot with the experience while 43% said it was not enough. None of the students considered that the activity was not useful.

Easy experiments at home could compliment online lectures and might be a source of motivation and interaction for students during the pandemic. Many of our students' responses (61%) matched our hypothesis; however, 39% of students were unable to take advantage of this experience favorably. This could be due to a lack of commitment to the activity that might have its roots in the difficulty of interacting with their study group or with the instructors. It has been observed that the interaction of the instructor with the students in meaningful and multiple ways, and the encouragement of student–student interactions helps to

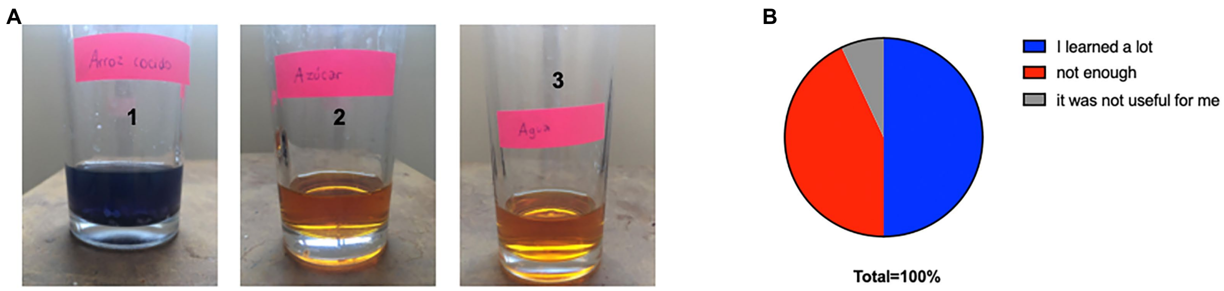

FIGURE 4
Identification of the presence of non-reductor sugar using povidone-iodine. **Figure** was extracted from a student portfolio. **(A)** Glasses with water and rice (glass#1), water and Sugar (glass#2), only water (glass#3). **(B)** Pie graph showing students' opinions regarding the activity. 50% of the students said that they learned a lot from this experience while 43% said it was not enough. A 7% said that the experience was not useful to understand the principles of sugar detection by using iodine.

FIGURE 5
Precipitation of casein from milk in low PH. **(A)** Figure was extracted from students' portfolios and shows example of three experiments. The students used lemon to lower pH in milk. **(B)** Pie graph showing students' opinions regarding the activity. A 64% of the students said that they learned a lot with this experience, while 36% said it was not enough. None of the students considered that the activity was not useful.

improve the commitment of students with the online activities (Dixson, 2010).

Another difficulty in online learning vs. the classroom environment is the absence of immediate feedback to students. Feedback after the documentation of the results (pictures and portfolio) provides an opportunity to correct and redirect any misunderstandings student had, although in online environment, the response by the teacher may not be immediate. This absence of immediacy can discourage the student to pay attention to the feedback given by the teacher which causes it to be inefficient in the learning process of the students (Jensen et al., 2021).

Finally, we explore the possibility that on-line experiences may impact final scores for the biochemistry course. We compared the final grades obtained in cohorts from 2018 and 2019 to the ones obtained in 2021 at the end of the course and found no significant changes in the overall score (grade) when considering all students (data not shown).

Although the results, in terms of grades, did not show significant differences between pre-pandemic and pandemic cohorts, it seemed to us a good metacognition tool to incorporate the development of a portfolio for the students of the 2022 cohort. To evaluate the impact of the activity on the scores related to the portfolios, we compared 2022 (on-site cohort) with the cohort of 2021 (home based laboratories). No statistical differences were observed in the scores for home-based versus on-site laboratories. Both were evaluated according to the same requirements and learning objectives. These results indicate that this at-home intervention is capable of achieving the course learning outcomes. An important aspect of this result may be the motivational encouragement provided by the teaching team during COVID-19. This aspect was not measured in the survey. In addition, it is clear that teachers are critical regardless of available technology.

The home-based activities met several objectives. In the first place, it allowed students to develop skills related to laboratory work such as rigor in the procedure, observation, and obtaining conclusions, among others, in conditions where it was not possible to work in a laboratory. Secondly, it allowed us to bring research closer to the everyday environment by using elements of daily life in experiments. According to our results, this kind of experience had a beneficial result for some of the students but not all of them. In this sense, the home-based experiences could be used as voluntary additional activities. Additionally, the pandemic forced to develop a methodology of classes such as the flipped

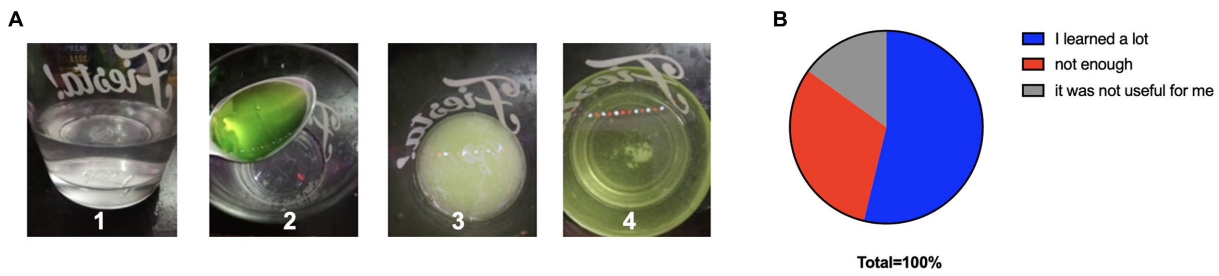

FIGURE 6
DNA isolation from bananas. **Figure** was taken from a student portfolio **(A)**. Glasses with High salt solution (glass#1), hypertonic-soap solution (glass#2), The mashed banana was added to the solution and filtered using gauze (glass#3), visualization of DNA after adding alcohol (glass#4). **(B)** Pie graph showing students' opinions regarding the activity. 50% of the students said that they learned a lot from the DNA extraction and visualization experiment, while 29% said it was not enough. 14% of students declared that it was not useful to understand the basic concept.

classroom. This methodology could be improved and partially applied in future versions of the course. In fact, it has been demonstrated that flipping laboratories can improve students' engagement and learning outcomes (Loveys and Riggs, 2019). Future disruptions of in-person schooling are probable somewhere in the world. Whether caused by another pandemic, war, or inclement weather. These home laboratory activities engage students and help bridge the gap left by online learning.

Main conclusions regarding availability of devices and connectivity coming from student's comments

A national survey of more than 16,000 Chilean homes, performed by the Pontifical University of Chile in 2021 showed that the percentage of students coming from low-income families who could access classes through their own computer was 69.6%. While 77.9% of students from homes with higher income could access classes. Although our data show that availability of technology, internet speed, and connectivity was present in more than 50% of the students' home environment, specific comments regarding the activity and performance of the teaching team demonstrated that technology is a necessary but not sufficient condition for effective remote learning. As mentioned in several opinions in Table 4, the students stated that despite the lockdown situation, the activities were ingenious and even funny in some aspects. Some students "genuinely believe" that given the circumstances, the labs were handled very well online. Importantly, a student states that the activities helped him to understand the concepts, especially because they were performed with homemade materials. At home labs should be considered not only in a lockdown situation, but also as a complementary activity. These observations are also supported by interpreting the data in a wholistic way in Figure 2C in which motivation was evident in more than 50% of the students. Finally, the lessons from the COVID-19 pandemic underscore the need for two-way interaction between students and teachers during remote learning by using all available technology and innovative interventions within the context of the course. An appropriate home environment is essential for learning; Figure 1F showed that more that 70% students had suitable or appropriate conditions.

Main conclusions regarding student's perceptions of learning and evaluations

Almahasees et al. described the students' perceptions of online learning during COVID-19 in closed universities in the Country of Jordan. The study found that it is less effective than face-to-face learning and teaching. Faculty and students indicated that learning challenges lie in adapting to online education, especially for deaf and hard of hearing students. Other concerns were lack of interaction and motivation, technical and Internet issues, data privacy, and security. Even though online learning works as a temporary alternative due to COVID-19, it is not a long-term substitute for face-to-face learning (Almahasees et al., 2021). In a descriptive cross-sectional questionnaire-based study conducted among undergraduate medical students, Saurabh et al., described survey opinions, feedback on utility, feasibility, suitability, and effectiveness of online learning as well as problems faced during e-learning in medical students. The results showed that more than half of their students prefer classroom learning because it facilitates better teacher–student interactions, stimulates understanding, provides a distraction-free environment, and permits an appropriate pace of learning, encouraging interactivity, and independence from technology (Saurabh et al., 2021). Our data showed that more than 60% of the students completely agreed regarding the clarity of lab instructions. Also 65% of students stated that outcomes were

TABLE 4 Student's opinion about the online home-based laboratories.

Taking into account the conditions, it seems to me that the situation was performed in a good way, however the content of the laboratory classes was quite heavy…
Please repeat the labs but face-to-face…
I prefer face-to-face laboratory, since it is easier for me to learn seeing a teacher face-to-face …
I think that the experience was very educational and informative, I learned a lot about the lab and also got an idea of how lab techniques work…
Personally, the work in groups affected me. On the other hand, the issue that we have to go deep in the techniques does not ensure that we are learning the theory of some processes and/or techniques…
Excellent disposition of the assistants…
I consider that they were ingenious activities…
I liked the experiences at home; I think the biggest challenge was putting together the portfolio…
I genuinely believe that given the circumstances, it was resolved very well online. I am very satisfied with the methodology used despite not being the ideal conditions…
I could not find all the materials, I cannot finish with an adequate result, but even so, the activities were funny…
The activities were good; they helped me understand the concepts, especially because they were with homemade materials…
To be online, I still managed well what had to be done experimentally…
In general, the activities were fair and necessary for a better understanding of the subject, but they were not as interesting as they could have been if the presence of the laboratories had been possible…

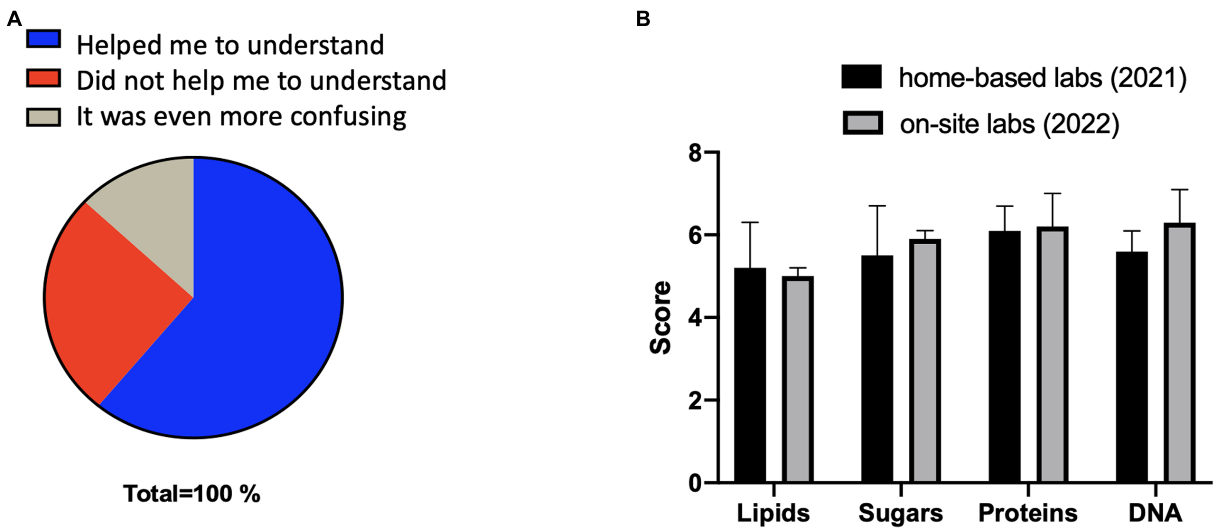

FIGURE 7
(A) Pie graph showing students' opinions regarding the activities. 61 % of the students considered that the activities were enough to understand the chemical basis of identifying biological molecules, while 26% said that the activities were not a significant help to their comprehension and 13% said the home labs did not help. **(B)** After each activity, the student portfolio was evaluated according to the Chilean score that ranges from 1 to 7 and compared to the students' performances in face-to-face lab activities during 2022. No statistical differences were observed in the scores for home-based versus on-site labs. Both were evaluated according to the same requirements and learning objectives.

clearly explained, while 32% said partially clear (Figure 2D). When asked about the portfolio as a useful tool for learning, 65% of the students stated that it was useful for understanding the chemical processes and organize their observations and discussions. As previously mentioned, none of the student comments in Table 4 were negative in terms of the innovation and experience, however some of them pointed out that, although they found this experience innovative, it was not comparable with a real laboratory experience.

Possibilities and limitations of this type of instruction, based on the evidence collected

Important aims for experimental courses are (a) to gain first-hand experience with course concepts, (b) to explore methods used by scientists in their discipline, (c) to use real equipment and instruments in the laboratory, (d) to develop communication and interpersonal skills, and (e) to integrate theory and practice. And although some of these aims were achieved with the modifications implemented in the online courses, some of them were not, as stated by several of the students. Many students prefer face to face experimental activities; they consider that it is easier to learn when they are in the presence of the teacher. In addition, more sophisticated instrumentation for achieving the experimental goals cannot be found at home, and for students that are going to work, as professionals with this sort of equipment, it is important that they acquire experience from the early years of university studies. As mentioned by Gamage et al., laboratories contribute substantially to the social development of scientists and where the exogenous relationships formed with others teach the life skills required in communication and teamwork (Gamage et al., 2020).

As student progress in their discipline, it may not be possible to have home laboratory experiences due to safety and more specialized supplies. Even in a more basic biochemistry class, not every experiment can be replicated at home. However, finding simple and workable solutions provided a teaching component that online lecture alone could not provide.

Conclusion

We conclude that, although the addition of in-house experiments provides a complementary tool for the understanding of main concepts in biochemistry along with improving skills in scientific thinking, this should be accompanied by a good feedback mechanism from the instructors. In addition, student to student interaction should be part of the at home activities to increase student motivation. A Flipped laboratory methodology plus tools where metacognition is evaluated, appear to be appropriate to promote the understanding of concepts in the context of the laboratory. And although some aspects of the experimental experience can be substitute with online resources and in home experiences, some others can only be achieved by the in-person experience.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Comite de bioetica Pontificia Universidad Catolica de Valparaíso. The ethics committee of the Pontificia Universidad Católica de Valparaíso waived the requirement of written informed consent for participation.

Author contributions

AG: conception, design of the work, and analysis and interpretation of data. VV: conception, analysis, and interpretation of data. VR: analysis of the data and critical review of the manuscript. FC-B and MT: acquisition of data. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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