Human Salivary α -Amylase and Starch Digestion: A Simple and Inexpensive At-Home Laboratory Experience in Times of the COVID-19 Pandemic

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ABSTRACT: The first case of coronavirus disease 2019 in Colombia was detected on March 6, 2020. Subsequently, schools, colleges, and universities were closed on March 26, which forced a massive migration to virtual education and impacted laboratory-based teaching courses. The teaching of biochemistry requires an experimental component that virtual laboratories cannot emulate. To address this concern, the article describes an at-home biochemistry laboratory experience that explores the hydrolysis of starch by α -amylase as a function of enzyme concentration, reaction time, and pH. The general success of the experience was assessed through the quality of information submitted through laboratory reports and feedback from students. A total of 19 laboratory reports were reviewed, and 50 students were surveyed. The analysis indicated that approximately 90% of students expressed favorable opinions about the experience. They understood the objective of the practice, identified the function of each material, and explained the relationship between the obtained results and concepts of enzyme activity presented in theoretical classes. Finally, the study concluded that the at-home laboratory experience is inexpensive and easy to perform outside the traditional laboratory. Furthermore, it enables a genuine practical experience with observations, data collection, analysis, and discussion of results, which meets the expectations for pharmaceutical chemistry students at the Universidad El Bosque in Bogotá, Colombia.

KEYWORDS: General Public, Upper-Division Undergraduate, Laboratory Instruction, Biochemistry, Distance Learning/Self Instruction, Hands-On Learning/Manipulatives, Enzymes, Carbohydrates

INTRODUCTION

The novel coronavirus outbreak has instigated a state of emergency worldwide. The course of the infection has forced widespread social isolation, which has resulted in the temporary closure of schools and universities in all continents. According to data from the United Nations Educational, Scientific and Cultural Organization, the coronavirus disease 2019 (COVID-19) pandemic has created the largest disruption in educational systems in history, affecting more than a billion learners and impacting approximately 94% of the worldwide population of students and up to 99% of students in low-income and lower-middle-income countries. In Colombia, nearly 12.8 million students at all educational levels have been affected.¹ In response, the educational sector has made efforts to continue learning and teaching processes. A massive migration from conventional face-to-face education to virtual education has been implemented over the previous months. Chemical education has not been exempted from this transition; teachers and students of multiple chemistry courses have also been forced to adapt to the new circumstances. Online courses, live streaming, virtual teaching, and simulated

laboratories have become excellent methods of learning from home.² However, online learning has presented a unique challenge for traditional laboratory-based disciplines. Unfortunately, the teaching–learning modality has lacked a physical environment where students can experiment with materials, reagents, and equipment necessary for learning data acquisition techniques or performing measurements with the accuracy and precision required. In the traditional setting, laboratory training has occurred in a space where students can observe, practice, and experiment with objects, materials, phenomena, and ideas individually and in groups.³ However, under the current circumstances, such activities cannot be performed within a physical space and following the workflow employed

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Scheme 1. Hydrolysis of α -1,4-Glycosidic Linkages in Insoluble Starch^a

^aSource: Own elaboration, except for the image of the crystal structure of human salivary α -amylase, available at the Protein Data Bank. The primary citation is ref 14.

in the traditional laboratory. Thus, traditional laboratories have been moved to virtual environments, which has necessitated modifying the teaching and learning strategies for science courses.⁴ Teachers are aware that experimentation is the essence of science and that virtual laboratories are unable to entirely replace traditional laboratories.⁵ From this perspective, this study found an opportunity for pharmaceutical chemistry students at the Universidad El Bosque to perform laboratory practices through at-home experimentation. The learning objectives were centered on enzyme activity, which is routinely conducted in biochemistry courses.

This study describes the design, implementation, and student perception of the at-home laboratory experience. The catalytic activity of salivary α -amylase was analyzed according to varying enzyme concentrations, reaction times, and pH levels. Before the experiment, the students were provided with a theoretical foundation of enzymes and the structure and function of carbohydrates. A laboratory guide was provided along with descriptions of the objectives and procedure, a template for reporting results, and information that should be reviewed to support the discussion of the results. Additionally, the success of the experience was evaluated using two indicators. The first indicator was the information furnished by the students in the laboratory reports, which indicated the articulation between the theoretical concepts (i.e., starch structure, enzyme activity, and effects of pH and temperature) and the results obtained from the at-home laboratory experience. The second indicator was the students' feedback, which was collected using a survey on their perception of the at-home laboratory experience.

THEORETICAL FOUNDATION

α -Amylase [E.C. 3.2.1.1] is a digestive glycosyl hydrolase enzyme that hydrolyzes the α -glycosidic bond between polysaccharides, disaccharides, or oligosaccharides and non-carbohydrate molecules; consequently, one of the biological functions of α -amylase is the digestion of macromolecules (Scheme 1). α -Amylase is produced from various organisms, such as bacteria, fungi, plants, and animals.^{6–8} In humans, salivary glands (A) and the pancreas (B) produce α -amylase. This secretion is independent, and no correlation exists between "A" and "B". However, salivary and pancreatic α -amylase participate in the digestion of starch present in food.^{9,10} Salivary α -amylase, a calcium-containing metalloenzyme that is present abundantly in saliva, hydrolyzes the

α -1,4 linkages of starch to glucose, maltose, and maltotriose and limit dextrins as the main products (Scheme 1). Trisaccharides and dextrins can be linear, containing only [α -1,4] bonds, or branched, containing both [α -1,4] and [α -1,6] bonds.^{11–13}

Starch is a reserve polysaccharide of many vegetables. It is composed of two glucose oligosaccharides, namely, amylose and amylopectin. Starch can be identified using Lugol's reagent, which forms a blue–black complex¹⁵ whose intensity decreases as a function of α -amylase activity. In other words, the greater the degradation is, the lesser the coloration is.

DESIGNING THE EXPERIMENTS

The essential aspects considered were the development of the experiment at home and understanding of the instructions by students. The other important aspects were as follows:

- Safety in the techniques, materials, and reagents used during the experiment.
- Simplicity of procedures (does not require equipment or reagents that are difficult to access).
- A genuine laboratory guide that is simple but rigorous in terms of procedure and analysis and interesting and motivating for students in terms of the observed phenomena.
- Access to a deep theoretical foundation before the development of the practice.
- The need to develop a practice in which the experimental level, adaptation of content, and students' expectations of a laboratory class are maintained.

To fulfill the stated premises and ensure that the experience provides students with the opportunity to learn at home, the reagents used should be comparable to those used in the laboratory, and the procedure should comply with the prescribed parameters (i.e., concentration, reaction time, and pH) to obtain the best results. Accordingly, saliva was used as a source of α -amylase because of its easy availability, which minimizes the cost and conditions required by enzyme management. Physiological serum solution at 37 °C maintains a more favorable environment for the enzyme.¹⁶ Physiological serum is a solution with 0.9% sodium chloride, commonly known as saline solution. It is used to dilute the enzyme, maintain identical amounts of solutions in different experiments, and preserve maximum enzyme activity in vitro tests.¹⁷ All the experiments were conducted at 37 °C because

this temperature is similar to that of the human body. The students were asked to heat water at 37 °C and use it in a water bath (bain-marie method). The temperature inside the water bath was controlled using a thermometer and by adding hot water when necessary. Commercial flour (cornstarch) was used as the starch source. One of the parameters to be observed during the experiment was the effect of pH on enzyme activity to determine the robustness of the enzyme and if changes in pH could influence the activity. Sodium bicarbonate and lemon were used to simulate an alkaline and an acid medium, respectively. Finally, the critical reagent was povidone–iodine solution (Isodine), which was used as an iodine source (in place of Lugol's solution, a reagent available only in the laboratory) and enabled the observation of the action of salivary α -amylase on starch.

Background

In the traditional setting, students develop their practice in university laboratories through two methodologies. The first is a laboratory guide, which should be in line with the subject discussed in theory. The guide provides the title, objectives, and procedure. Students should be given a background of prior activities using various approaches, such as asking initial questions to enhance their understanding of the experiment, providing a flowchart of the procedure, and disseminating safety data sheets on the reagents used. Commonly, students are provided with certain formats to facilitate the recording of results. Finally, the experiments are performed within the laboratory space, and all questions are answered. The second methodology is dependent on the topics to be explored. Students should be able to suggest a practice procedure, which is framed in several initial objectives. To conclude the experiment, reports that reflect the results obtained with their respective analyses are required (to enable them to present a scientific explanation). Finally, the students provide conclusions. However, because of the obligatory social distancing protocol, the logistics of the traditional process is altered; thus, students are required to perform experimentation at home.

In this study, the laboratory guide was disseminated, and the students reviewed it before the at-home laboratory experience. In the last section of the laboratory guide, six items were investigated by the students; one was the role of the reagents used in the experiment (see [Supporting Information](#)). During the experiment and after obtaining the results, the students were required to submit a report. The at-home laboratory experience was conducted over three sessions: in the first session, all the queries of the students about the procedure and concepts related to the enzyme topic were clarified; in the second session, the practice was performed (asynchronous session); and the last session was dedicated to resolving questions and concerns after the experiment as well as providing corresponding feedback.

HAZARDS

Considering that the proposed at-home laboratory activity has no heating to high temperatures (in this case, temperatures of 37–40 °C were sufficient) or pressure procedures, and it did not involve the use of acids, corrosive materials, hazardous chemicals, or production of vapors or hazardous biological materials, it is considered low risk.¹⁸ Saliva is a body fluid; thus, students should handle their own saliva, discard disposable glasses in contact with saliva, or properly wash the glassware

used in the practice. In addition, as an instruction for the development of the practice, the students were instructed on the importance and obligatory use of safety implements such as gown, gloves, and safety glasses.

ONLINE INTERACTION WITH STUDENTS

Under the new academic normal, in which synchronous meetings with students are conducted remotely and on digital platforms, the clarity of instructions is important. As such, a lesson on enzymes was previously conducted via a synchronous class in Google Meet. Thereafter, the guide was designed and sent to students for reading. The students were required to investigate the role played by each reagent in the enzymatic reaction. Although in this laboratory it is not possible to identify the main starch hydrolysis products in the reaction catalyzed by α -amylase, it was necessary for them to consult the theoretical aspects of this enzyme reaction. At the next synchronized meeting, all concerns regarding the procedure were addressed. However, the teachers disclosed neither the function of each reagent nor the possible results.

The at-home laboratory experience was conducted in groups, in which students could assign team members to conduct the experiment and collect data individually at home. It was recommended that students conduct the experiments at the same time. The teachers suggested scheduling a virtual meeting to share the experiments' results with other team members to promote a better discussion and quality of final report.

To optimize the teachers' working times in this experience, reduce the number of emails from students with similar questions, and obtain the best results in practice, we suggest for future experiences to schedule a synchronous meeting to support the experimental session (second session). When the students conducted the practice at times most convenient for them (asynchronous session), the mistakes and misinterpretations of the results were evident.

In the third session, many doubts emerged when the results of color changes were compared with the parameters studied. Thus, the students were assured that the results may vary as the salivary α -amylase samples were derived from different donors. In addition, several concepts related to enzymes, starch structure, and starch–iodine interaction, as well as the effects of concentration, pH, and temperature on enzyme activity, were discussed.

OUTCOMES OF THE EXPERIMENT

At-home laboratories are known to contribute to the development of students' skills (bibliographic search, data collection, scientific writing, critical thinking, etc.) To achieve this objective, however, a coherent and clear explanation of concepts and procedures to be applied during the experience is necessary.¹⁹

The general objective of the at-home laboratory practice was to enable students to conduct experiments at home, specifically to understand the concepts of enzymes used in the experiment. The student report was the tool for determining the appropriation and understanding of important concepts. The items considered were the general explanation of the experience, correct use of concepts, documentation of the phenomena observed (through a photographic record), description and analysis of results, fulfillment of objectives (what was achieved?), evaluation (is it a good learning

Figure 1. Effect of salivary α -amylase concentration on starch hydrolysis. The intensity of the blue color of the starch–iodine complex decreases with an increase in enzyme concentration. A more intense coloration indicates a higher concentration of starch in the glasses. Lighter colors indicate a lower starch concentration. The enzyme reaction was performed at 37 °C (the bain-marie method). The concentration and time of reaction of the starch were the same for all assays. Physiological serum and cornstarch without enzyme were used as control (glasses 1 and 2). Table 1 provides the assay conditions for the experiment.

activity?), and proposals for improvement. Nineteen reports were appraised to evaluate the understanding of enzymes topic.

The teachers reviewed the reports beginning with the summary and conclusions to infer the students' understanding of the important aspects of the experience. They found that the students described the procedure clearly and explained the effects of the above-mentioned factors (time, concentration, and pH) on enzyme activity. More than 70% of the students were able to describe the most important results (the association between color changes and enzyme activity). The most frequent comment by students in the summary was the difference in work strictness of the traditional laboratory with respect to the at-home laboratory due to reagent purity and measurement instruments employed. This finding is considered beneficial for the students as they realize the advantages and disadvantages of experimentation at home and the traditional laboratory, which demonstrated their critical thinking. Contrary to expectations, the conclusions lacked items on the fulfillment of objectives and ideas for improvement.

The main text in the reports was then analyzed. The study found that all expected results were provided and scientifically explained in depth. The expected items were the explanation of the catalytic activity of enzymes, reactions of starch and behavior of iodine during the hydrolysis process, the role of the reagents, differences between amylose and amylopectin, properties denoting enzyme activity, and explanation of color changes.

Taking a photographic record was an excellent way of determining the development of the procedure. The researchers suggested that students take photos at the end of each assay. The compendium of all photographs demonstrated the influence of concentration, reaction time, and pH on the catalysis of the enzyme. Very interesting results were noted when observing the records. Figure 1 presents an example where an increasing concentration of enzyme evidently increases the amount of starch hydrolysis, resulting in a lighter coloration due to the disappearance of the starch. Increasing the enzyme concentration results in an increased number of active sites that can bind substrate, and the highest hydrolysis rates of cornstarch that are observed in glasses 5 and 6. See also Table 1.

Contrary to the expected outcome, a lower enzyme activity was observed for glass 7, which could be explained by a reduction in the concentration of chlorine (Cl^-) and sodium (Na^+) ions in this glass due to the absence of physiological serum in the reaction (salivary enzymatic extract was used without dilution). A previous study demonstrated an increase in the activity of α -amylase in the presence of these ions

Table 1. Assay Conditions for Evaluating the Effect of α -Amylase Concentrations on Starch Hydrolysis

Reagent Details	Samples						
	1	2	3	4	5	6	7
Cornstarch, mL	0	10	10	10	10	10	10
Physiological serum, mL	20	10	8	6	2	0	0
Enzyme extract (α -amylase; E2), ^a mL	0	0	2	4	8	10	10 ^b
Reaction time, ^c min	20	20	20	20	20	20	20
Iodine solution, drops ^d	3	3	3	3	3	3	3

^aE2 is diluted enzyme (10 mL of salivary enzymatic extract + 10 mL of physiological serum). ^bThis sample (E1) is pure salivary enzyme extract; only E1 was added. ^cDuring the reaction time, the glasses were shaken regularly. ^dIodine solution was added after each reaction time using a glass dropper. After 30 s of agitation, a photograph was taken against a white background.

through electrostatic interactions with the active site.¹⁶ Other studies suggested that a high concentration of enzyme can generate ionic alterations between pairs of enzyme molecules, which results in distortions in the active sites of α -amylase and some sort of enzyme–enzyme inhibition that reduces the ability of the active sites to bind effectively to the starch particles, leading to reduced starch hydrolysis.^{20,21}

Another study parameter was the effect of pH on enzyme activity, the results of which are shown in Figure 2. (See also Table 2). The first and second tests corresponded to the change in colorations of iodine in response to physiological serum and starch compared with the control (starch + serum + enzyme). To determine if there are changes in pH influence enzyme activity, two media were used, namely, lemon (acidic) and sodium bicarbonate (basic), with their respective controls (without enzyme). The result confirmed the occurrence of starch hydrolysis using the acid medium.²² In test 4, the color changed completely without the presence of the enzyme (from black to transparent). In the basic medium, bicarbonate did not affect the properties of starch or inhibit the enzyme activity, which led to complete starch hydrolysis and discoloration of test solution 7. These results indicate that changes pH induced by bicarbonate promoted enzyme activity. The effects on α -amylase activity induced by acid medium could not be observed, due to starch being hydrolyzed in the presence of lemon juice. For this reason, a change in methodology should be considered for future experiments. We suggest incubating the enzyme in acidic and basic media overnight (at a 1:1 volume ratio with enzyme extract) and then observing the effect on starch hydrolysis; a reaction time of 20 min is insufficient to induce changes in enzyme activity. α -

Figure 2. Effect of pH on the catalytic activity of salivary α -amylase and starch hydrolysis. The intensity of the blue color of the starch–iodine complex decreased in acidic and basic media. A more intense coloration indicates a higher concentration of starch in the glasses. Lighter colors indicate a lower starch concentration. Starch hydrolysis was evident in the acidic medium with and without enzyme (glasses 4 and 5). Starch was completely digested in the basic medium (glass 7). The enzymatic reaction was carried out at 37 °C (the bain-marie method). Physiological serum, cornstarch without enzyme, cornstarch + lemon, and cornstarch + sodium bicarbonate were used as controls (glasses 1, 2, 4, and 6, respectively). The starch and enzyme concentrations were the same in the enzymatic reaction. Table 2 describes all the assay conditions in terms of pH.

Table 2. Assay Conditions for Evaluating the Effect of pH on the Catalytic Activity of Salivary α -Amylase and Starch Hydrolysis

Reagent Details	Samples						
	1	2	3	4	5	6	7
Cornstarch, mL	0	10	10	10	10	10	10
Physiological serum, mL	20	10	5	8	3	8	3
Enzyme extract (α -amylase; E2), ^a mL	0	0	5	0	5	0	5
Lemon juice, mL	0	0	0	2	2	0	0
Sodium bicarbonate, mL	0	0	0	0	0	2	2
Reaction time, ^b min	20	20	20	20	20	20	20
Iodine solution, drops ^c	3	3	3	3	3	3	3

^aE2 is diluted enzyme (10 mL of salivary enzymatic extract + 10 mL of physiological serum). ^bDuring the reaction time, the glasses were shaken regularly. ^cIodine solution was added after the reaction times using the glass dropper. After 30 s of agitation, a photograph was taken against a white background.

Amylase is a robust enzyme that retains its structural and functional stability over a wide pH range.²³ A previous study indicated that a pH of 2 (similar to the pH of lemon juice) and a pH of >9 (similar to that of sodium bicarbonate) after 20 h of incubation induced the unfolding of the enzyme with irreversible loss of activity and alterations in its tertiary structure.²³

Figure 3 demonstrates the results according to reaction time and the change in coloration after 1 h of enzyme activity (see also Table 3). The photographic record shows the results at reaction times of 0, 10, 20, 40, and 60 min with the respective Iodine and starch controls (glasses 1 and 2). The discoloration of cornstarch in iodine clearly indicates the progress of hydrolysis over time. As the reaction time increased, the amount of starch hydrolyzed increased, as

indicated by the decrease in color in the starch–iodine complex. The hydrolysis of carbohydrate with the addition of the enzyme was evident at 60 min. The start of each reaction was staggered so that all assays were completed at the same time.

In all the student reports, an understanding of the use of reagents (the reasons why each step of the procedure was performed), influence of each condition on the enzyme, and explanation of the reaction and color changes produced by iodine were evident. The analysis indicated that the students understood the objective of the experiment. Thus, the study infers that the at-home laboratory experience is a successful learning strategy.

By emphasizing the creation of a space for laboratory practice, which is essential for students learning pharmaceutical chemistry, this study proposes that maintaining a focus on a theoretical–practical course is possible. Students can perform an experiment using simpler, inexpensive, and more common materials than those used in the laboratory, which could enhance their skills in terms of procedural monitoring, rigorous data collection, and analysis of results. Achieving such experiences will enable students to acquire a practical approach and learn using an alternative at-home process.

Student's Feedback

Students provided feedback by evaluating the at-home laboratory experience through an online survey with 10 items rated using a Likert-type scale (1 = completely disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = completely agree). The items focused on their perceptions about the clarity and coherence of the laboratory guide and availability of and access to materials required in terms of attributes of or usefulness to the consolidation of theoretical concepts about enzymes. In addition, the study analyzed the students' opinions about the feasibility of conducting the practice in other semesters as well

Figure 3. Effect of the reaction time on α -amylase catalyzed starch hydrolysis. The intensity of the blue color of the starch–iodine complex decreased with the increase in reaction time. A more intense coloration indicates a higher concentration of starch in the glasses. Lighter colors indicate a lower starch concentration. Starch was completely digested after 60 min (glass 8). The enzymatic reaction was carried out at 37 °C (the bain-marie method). The starch and enzyme concentrations were the same for all glasses. Physiological serum and cornstarch without enzyme were used as controls (glasses 1 and 2). Table 3 presents all the assay conditions in terms of reaction time.

Table 3. Assay Conditions for Evaluating the Effect of Reaction Time of α -Amylase and Starch Hydrolysis

Reagent Details	Samples							
	1	2	3	4	5	6	7	8
Cornstarch, mL	0	10	10	10	10	10	10	10
Physiological serum, mL	20	10	8	8	8	8	8	8
Enzyme extract (α -amylase; E2), ^a mL	0	0	2	2	2	2	2	2
Reaction time, ^b min	60	60	0	5	10	20	40	60
Isodine solution, drops ^c	3	3	3	3	3	3	3	3

^aE2 is diluted enzyme (10 mL of salivary enzymatic extract + 10 mL of physiological serum). ^bDuring the reaction time, the glasses were shaken regularly. The temperature was controlled using a thermometer and by adding hot water to the bain-marie when necessary. ^cIsodine solution was added after the specified reaction times using the glass dropper. After 30 s of agitation, a photograph was taken against a white background.

as the design and implementation of the new at-home laboratory experience to support the learning of other biochemistry topics. The survey included one open-ended item to measure the students' perception of the pros and cons of the at-home laboratory experience. The [Supporting Information](#) provides the details of the survey.

Data Collection and Analysis

The survey data were collected via the Google Forms online survey creation and delivery tool. The survey was sent via email to 72 students enrolled in three independent biochemistry courses ($n = 19, 29$, and 24) of pharmaceutical chemistry program at Universidad El Bosque. The data were analyzed for descriptive trends, which indicate the students' perception of the at-home laboratory experience. The responses were tabulated and expressed as percentages, and the mean score per respondent was calculated using the scale values (1–5). The global assessment of all responses was conducted according to three indicators, namely, the relationship between the maximum score assigned to or expected from the survey and the obtained score (eq 1), the frequencies of the responses *agree* and *completely agree*, and the frequencies of the responses *disagree* and *completely disagree*.

$$\text{maximum score expected} = \text{no. items} \times \text{no. students} \\ \times \text{highest possible score}$$

$$\text{where items} = 10, \text{ students} = 50, \text{ highest possible scores} \\ \text{for each item} = 5 \quad (1)$$

Spearman's correlation was used to determine the correlations between the survey items. In addition, a reliability assessment was performed for each survey item by determining Cronbach's α correlation coefficient. The analysis determined the degree to which the survey items were interrelated. The statistical software package SPSS version 23 (IBM SPSS Statistics) was used for analysis.

Findings and Discussion

The survey was sent during the intersemester term to 72 students. The response rate was 69.4% ($n = 50$), and the students were assured that their responses would remain anonymous. Of the 50 students who responded, 90% ($n = 45$) assigned scores of ≥ 3 for all items, whereas only 10% ($n = 5$) assigned scores of < 3 to the majority of items. Given the numeric scale (1–5) used to rate the items, the mean score for each respondent was calculated. The responses were then grouped according to ratings (Figure 4).²⁴ The analysis indicated that 12% ($n = 6$), 40% ($n = 20$), and 38% ($n = 19$) of the students responded with *completely agree*, *agree*, and

Figure 4. Students' perception of the at-home laboratory experience. Each point represents the mean score of the students to the 10 survey items. The students answer the survey using numerical values on Likert-type scales (1 = completely disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = completely agree). The box represents the mean score of all results (3.78). Horizontal lines represent the range of values of the responses.

neutral to the majority of items, with mean scores of 4.88 ± 0.098 , 4.29 ± 0.219 , and 3.47 ± 0.298 , respectively. Five students (10%) assigned scores of < 3 , with a mean score of 1.66 ± 0.615 . The results suggest that a large proportion of the students expressed favorable opinions regarding the experience with only a very low percentage of students disagreeing with the statements of the survey. Table 4 shows the 10 items of the survey and the distribution of the responses or each item.

An overall evaluation of the survey results was conducted by comparing the maximum possible score (2,500 points if, hypothetically, all the responses of all the participants had been *completely agree*) with respect to the sum of the highest scores (*agree* and *strongly agree*), which was 1478 points, which corresponds to 59.01% of the maximum possible score and confirms that a large percentage of students perceived the practice as being simple, being easy to perform at home, having a good design, being capable of reinforcing the enzyme concepts, and being reproducible in other biochemistry classes. The Cronbach's α correlation coefficient displayed a global index of internal consistency of 0.928, which indicates that the survey items were interrelated.

In addition to the Likert-type questions, the following open-ended question was included in the perception study: "Very briefly, please describe the pros and cons of conducting the at-home laboratory experience." The responses to this question revealed that 79.10% of the total opinions ($n = 67$) were favorable. Although not all students answered this question, those who did expressed more than one opinion, which explains the total number of opinions. Some examples of the responses from the students are shown below:

Table 4. Comparison of Students' Perception of the At-Home Laboratory Experience

Item	Student Survey Results by Response Category (Total N = 50)									
	Completely Disagree		Disagree		Neutral		Agree		Completely Agree	
	N	%	N	%	N	%	N	%	N	%
1. The information in the guide was clear and facilitated the understanding of the objectives of the at-home laboratory experience.	2	4.00	4	8.00	10	20.00	21	42.00	13	26.00
2. The equipment, materials, and reagents needed for the experiment were easy to access, and most of them can be found at home.	4	8.00	1	2.00	9	18.00	18	36.00	18	36.00
3. The procedure was sufficiently clear to guide each step in the experiment.	1	2.00	4	8.00	15	30.00	16	32.00	14	28.00
4. The experiments in the guide were well-designed and adequate for the level of training.	4	8.00	2	4.00	6	12.00	17	34.00	21	42.00
5. The concepts taught in the theoretical sessions facilitated the understanding of the phenomena observed during the at-home laboratory experience.	3	6.00	2	4.00	8	16.00	21	42.00	16	32.00
6. The at-home experiment is an excellent pedagogical strategy and complements your academic training.	2	4.00	5	10.00	14	28.00	14	28.00	15	30.00
7. The at-home laboratory experience consolidated the concepts of enzymes taught in the theoretical sessions.	3	6.00	3	6.00	16	32.00	21	42.00	7	14.00
8. The at-home laboratory experience is an activity that promotes discovery and learning.	4	8.00	4	8.00	8	16.00	16	32.00	18	36.00
9. Under the current circumstances, it is recommended to repeat this practice to consolidate the concepts of enzymes.	3	6.00	4	8.00	14	28.00	16	32.00	13	26.00
10. Under the current circumstances, it is recommended to implement novel at-home laboratory experiences.	4	8.00	3	6.00	7	14.00	17	34.00	19	38.00

Figure 5. Pros and cons of the at-home laboratory experience with human salivary α -amylase and starch digestion. The results were grouped according to the most frequent answers in the open-ended item of the survey.

"It is an excellent way to obtain new knowledge and test our capabilities in any situation, such as a pandemic, besides the fact that the guide is quite explicit, and we have the option to investigate separately to strengthen our knowledge. It is a very good strategy."

"It is evident that we need to look for an alternative to be able to carry out the laboratories to strengthen the knowledge, the materials were in accordance with what we had at home. Although it is difficult to carry out these laboratories, it is important that they are implemented more."

"I consider as advantages that the implemented guidelines were clear enough to carry out the development of the practice. However, the implemented materials can complicate the development of the same since in spite of being efficient as kitchen utensils, they do not have the same function that those of a laboratory and it turns out to be complex specifically when measuring properties such as the mass, volume, point of fusion and of boiling."

The most frequent opinion (45%) was related to the consolidation of concepts and self-learning, which confirms that a large proportion of students agreed that the experience reinforced the theoretical concepts taught (starch structure, and starch-iodine interaction, as well as the effects of concentration, pH, and temperature on enzyme activity) in theoretical biochemistry classes. However, some students perceived failure in the consolidation of the concepts about enzymes, which could be associated with differences in the learning methods of each student. The second most frequent statement was related to the clarity of the guide and simplicity of the at-home experiment, which is in agreement with the results of items 1 and 2. Finally, 18% of the students who responded to the open-ended questions expressed that the materials and reagents were easily accessible and inexpensive for the sufficient development of the experience at home. The opposing opinions about the at-home laboratory experience (20.9%) were grouped into three categories. The first is that home experimentation cannot replace face-to-face laboratories

($n = 8$). The second pertains to the students' inconvenience and discomfort during the collection of saliva samples ($n = 3$). The third suggested that conducting the at-home experiment is time-consuming (Figure 5).

On the basis of the opinions, survey results, and evaluation of laboratory reports, the study suggests that the at-home laboratory experience can be improved by conducting the experiment in a synchronous session and following a teacher's instructions. In this manner, students can resolve their concerns in real time, and as required, teachers can emphasize the theoretical concepts. Although collecting the saliva samples caused discontent in some students due to the time required to collect the volume necessary for the experiment and its physical appearance, this variable is difficult to modify. Therefore, a feasible option is acquiring commercially available α -amylase; however, access is limited and costly. Consequently, doing so is not recommended for at-home laboratory experiences. Finally, the study emphasizes that the practice requires the participation of more than one student to collect saliva samples as mentioned in the laboratory guide. Thus, students should change the perception that the practice is time-consuming.

CONCLUSION

The study considers the laboratory experience successful because the majority of students understood the function of salivary α -amylase and starch digestion by conducting a simple, inexpensive experiment with reagents and materials found at home. The at-home laboratory is an affordable and easy way to perform the experiment outside of the traditional laboratory. It promotes a genuine practical experience through observations, data collection, analysis, and discussion of results according to expectations. Importantly, students of pharmaceutical chemistry at Universidad El Bosque in Bogotá, Colombia, agreed that the practice is an easy method to conduct experiments and learn from home.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.1c00046>.

Student survey (PDF, DOCX)

Laboratory guide: Catalytic activity of salivary α -amylase and starch digestion (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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REFERENCES

- (1) UNESCO. COVID-19 educational disruption and response. <https://en.unesco.org/news/covid-19-educational-disruption-and-response> (accessed 2021-09-02).
- (2) Ray, S.; Srivastava, S. Virtualization of science education: a lesson from the COVID-19 pandemic. *Journal of Proteins and Proteomics* **2020**, *11*, 77–80.
- (3) Ka Yuk Chan, C. Laboratory Learning. In *Encyclopedia of the Sciences of Learning*; Seel, N. M., Ed.; Springer US: Boston, MA, 2012; pp 1705–1708.
- (4) Andrews, J. L.; de Los Rios, J. P.; Rayaluru, M.; Lee, S.; Mai, L.; Schusser, A.; Mak, C. H. Experimenting with At-Home General Chemistry Laboratories During the COVID-19 Pandemic. *J. Chem. Educ.* **2020**, *97*, 1887–1894.
- (5) Vasiliadou, R. Virtual laboratories during coronavirus (COVID-19) pandemic. *Biochem. Mol. Biol. Educ.* **2020**, *48*, 482–483.
- (6) Mehta, D.; Satyanarayana, T. Bacterial and Archaeal α -Amylases: Diversity and Amelioration of the Desirable Characteristics for Industrial Applications. *Front. Microbiol.* **2016**, *7*, 7.
- (7) Aquino, A. C. M. M.; Jorge, J. A.; Terenzi, H. F.; Polizeli, M. L. T. M. Studies on a Thermostable α -Amylase from the Thermophilic Fungus *Scytalidium Thermophilum*. *Appl. Microbiol. Biotechnol.* **2003**, *61* (4), 323–328.
- (8) Usha, B.; Krishna, V. G.; Muni, K. D.; Hemalatha, K. P. J. Partial Characterization of α -amylase from germinating little millets (*Panicum Sumatrense*). *J. Phyto.* **2011**, *3* (1), 1–8.
- (9) Granger, D. A.; Kivlighan, K. T.; El-Sheikh, M.; Gordis, E. B.; Stroud, L. R. Salivary alpha-amylase in biobehavioral research: recent developments and applications. *Ann. N. Y. Acad. Sci.* **2007**, *1098*, 122–144.
- (10) Scannapieco, F. A.; Torres, G.; Levine, M. J. Salivary alpha-amylase: role in dental plaque and caries formation. *Crit. Rev. Oral Biol. Med.* **1993**, *4*, 301–307.
- (11) Ramasubbu, N.; Sundar, K.; Ragunath, C.; Rafi, M. M. Structural studies of a Phe256Trp mutant of human salivary α -amylase: implications for the role of a conserved water molecule in enzyme activity. *Arch. Biochem. Biophys.* **2004**, *421*, 115–124.
- (12) Munegumi, T.; Inutsuka, M.; Hayafuji, Y. Investigating the Hydrolysis of Starch Using α -Amylase Contained in Dishwashing Detergent and Human Saliva. *J. Chem. Educ.* **2016**, *93* (8), 1401–1405.

- (13) Pratiwi, M.; Faridah, D. N.; Lioe, H. N. Structural Changes to Starch after Acid Hydrolysis, Debranching, Autoclaving-Cooling Cycles, and Heat Moisture Treatment (HMT): A Review: Structural Changes to Modified Starch. *Starch - Stärke* **2018**, *70* (1–2), 1700028.
- (14) Ramasubbu, N.; Paloth, V.; Luo, Y.; Brayer, G. D.; Levine, M. J. Structure of Human Salivary α -Amylase at 1.6 Å Resolution: Implications for its Role in the Oral Cavity. *Acta Crystallogr., Sect. D: Biol. Crystallogr.* **1996**, *52*, 435–446.
- (15) Goedecke, C. Why Does Iodine Turn Starch Blue? *ChemViews* **2016**, DOI: [10.1002/chemv.201600103](https://doi.org/10.1002/chemv.201600103).
- (16) Skoluda, N.; Dhrami, I.; Nater, U. M. Factors Contributing to Stability and Instability in Alpha-Amylase Activity in Diluted Saliva Samples over Time. *Psychoneuroendocrinology* **2020**, *121*, 104847.
- (17) Rudeekulthamrong, P.; Kaulpiboon, J. Kinetic Inhibition of Human Salivary Alpha-Amylase by a Novel Cellobiose-Containing Tetrasaccharide. *J. Med. Assoc Thai* **2012**, *95* (Suppl 1), S102–108 PMID: 23964451.
- (18) Understanding Risks & Taking Safety Precautions in Science Experiments. 18 February 2015, [Study.Com](https://www.study.com).
- (19) Gao, R.; Lloyd, J.; Kim, Y. A Desirable Combination for Undergraduate Chemistry Laboratories: Face-to-Face Teaching with Computer-Aided, Modifiable Program for Grading and Assessment. *J. Chem. Educ.* **2020**, *97* (9), 3028–3032.
- (20) Özbek, B.; Yüceer, S. α -Amylase Inactivation during Wheat Starch Hydrolysis Process. *Process Biochem.* **2001**, *37* (1), 87–95.
- (21) Apar, D. K.; Özbek, B. α -Amylase Inactivation during Rice Starch Hydrolysis. *Process Biochem.* **2005**, *40* (3–4), 1367–1379.
- (22) Pratiwi, M.; Faridah, D. N.; Lioe, H. N. Structural Changes to Starch after Acid Hydrolysis, Debranching, Autoclaving-Cooling Cycles, and Heat Moisture Treatment (HMT): A Review: Structural Changes to Modified Starch. *Starch - Stärke* **2018**, *70* (1–2), 1700028.
- (23) Singh, K.; Shandilya, M.; Kundu, S.; Kayastha, A. M. Heat, Acid and Chemically Induced Unfolding Pathways, Conformational Stability and Structure-Function Relationship in Wheat α -Amylase. *PLoS One* **2015**, *10* (6), No. e0129203.
- (24) Sullivan, G. M.; Artino, A. R. Analyzing and Interpreting Data from Likert-Type Scales. *Journal of graduate medical education* **2013**, *5*, 541–542.