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Dyeing to Degrade: A Bioplastics Experiment for College and High School Classrooms

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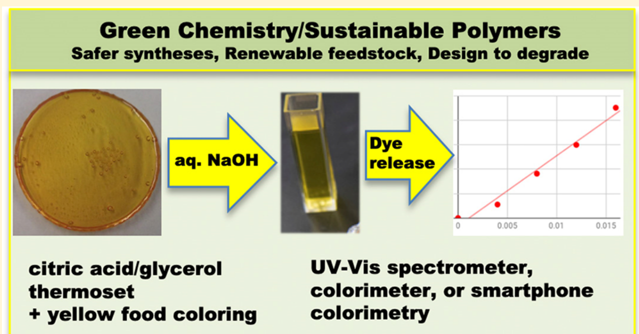
Supporting Information



ABSTRACT: A versatile experiment is described for the high school and college laboratory setting based on the synthesis of biobased polymers prepared from inexpensive, renewable, and nonhazardous chemicals. Combinations of readily available citric acid, glycerol, and tapioca root starch are used to prepare three polymeric materials with different observable physical properties. Simple qualitative comparisons of aqueous degradation rates can be made or a dye can be added for quantitative assessment. Food and Drug Administration (FDA) approved Yellow Dye No. 5 is selected as a dye stable to basic conditions and is added to each sample in the form of commercial food coloring. The dyed polymer samples are observed to degrade in an aqueous sodium hydroxide solution, releasing the dye. Both ultraviolet−visible spectroscopy and smartphone colorimetry are used to follow the increasing dye concentration, which is inversely correlated to polymer degradation. The collected data is suitable for analysis and graphing by students. Potential learning outcomes of the experiment include Le Chatelier's principle, types of intermolecular forces, hydrolysis, absorption spectroscopy, Beer's Law, rate determinations, and graphing. The experiment models green chemistry principles of design for safer chemicals, degradation, and use of renewable feedstocks. Paramount to the educational objectives of the curriculum are the societal connections to plastics that are accumulating in the environment and causing harm, as well as examples of successful advances in commercial bioplastics such as poly(lactide) (PLA).

KEYWORDS: *High School/Introductory Chemistry, First-Year Undergraduate/General, Analytical Chemistry, Hands-On Learning/Manipulatives, Laboratory Instruction, Polymer Chemistry, Green Chemistry, UV−Vis Spectroscopy, Materials Science*

INTRODUCTION

Although precollege students are often familiar with the problem of plastics accumulating in our oceans and on land, their understanding of possible solutions rarely extends beyond recognizing the importance of recycling. Consequently, few students can conceptualize current strategies to address the overall lifecycle and sustainability issues of today's plastics. This includes innovations and research to derive plastics from renewable plant resources rather than depletable fossil fuels and providing an alternative to recycling in the form of biodegradable materials. In addition, both high school and college curricula are typically lacking in instruction on the structure and properties of polymers. In contrast, when prompted with the question, "Where are plastics in your daily life?", students quickly acknowledge the importance of plastics to society and recognize the accumulation in the environment as a problem to be addressed for their generation.

Herein, we describe an experiment that capitalizes on the strong societal connection of plastics to engage students in learning basic polymer chemistry, laboratory skills commonly taught in high school and introductory college chemistry classrooms, and green chemistry principles. Three different biobased polymers are synthesized from combinations of citric acid and glycerol, citric acid and tapioca root starch, and tapioca root starch and glycerol. The Food and Drug Administration (FDA) approved Yellow Dye No. 5 (λ_{max} = 425 nm in water), found in McCormick brand yellow food

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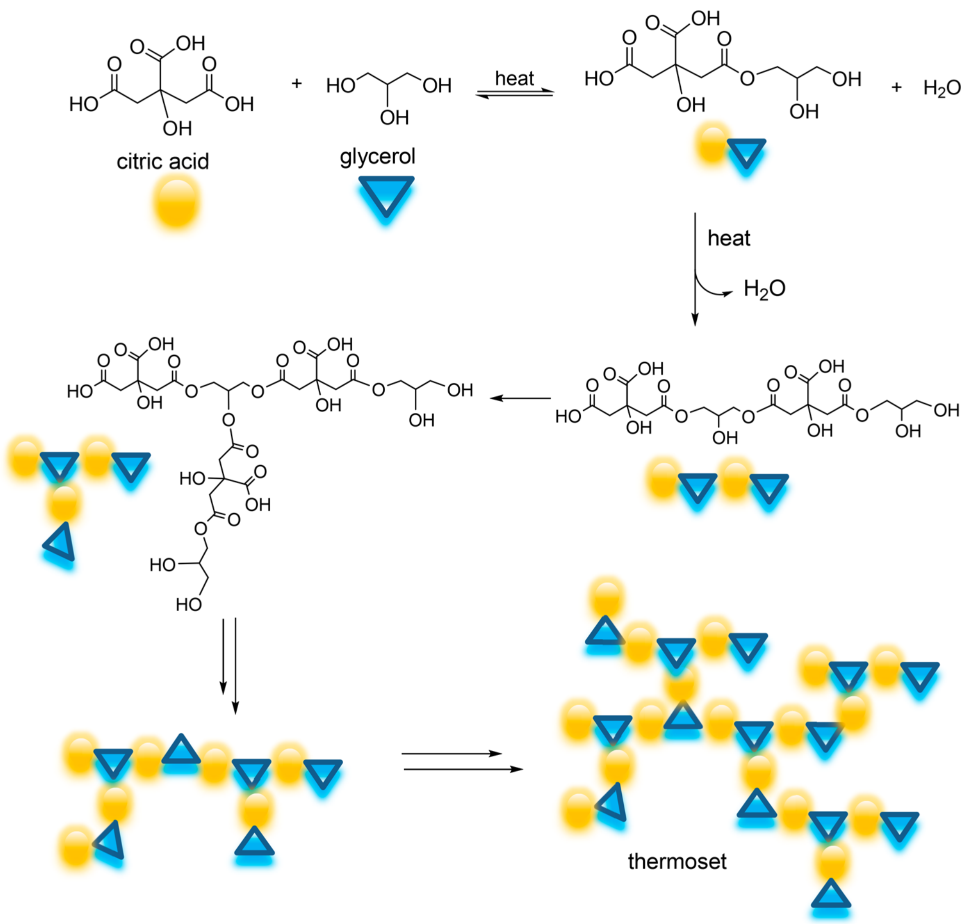
Scheme 1. Polymerization of Citric Acid and Glycerol through Heating and Removal of Water To Form a Cross-Linked Polyester[a]



[a]The yellow balls represent citric acid units, and the triangles represent glycerol units.

coloring, is added to each sample during its preparation. A ~0.1 g sample of each material is then placed in 1.0 M NaOH, and the degradation/disappearance of the sample is followed by release of the dye into the solution. Minimally, students can time how long each sample takes to wholly degrade. Alternatively, ultraviolet−visible (UV−vis) spectroscopy and graphs drawn from the data collected can be used to follow the release of the dye at timed intervals. Various levels of student analysis can be required, from straightforward graphing of the data and calculation of a linear regression line for slope comparisons to instruction on preparing a standard solution curve and concentration determinations. For institutions that do not have access to UV−vis spectrometers, the option of using smartphone colorimetry was proven to be equally as instructive and, in fact, shown to be advantageous in avoiding absorbance problems associated with particulates with the starch samples.

■ BACKGROUND

As a continuation of our efforts to develop green polymer experiments for the high school and college laboratory curricula,[1−3] a collaboration was established with Professor Robert Mathers, who coauthored an article describing the synthesis of a biodegradable thermoset polymer from citric acid and glycerol.[4] In recognizing the nontoxic, economical, simplistic (no solvent or catalyst required), and sustainable attributes of this chemistry, Mathers began exploring the potential of citric acid in his undergraduate classrooms and undergraduate research projects.[5,6] As we collaboratively began to investigate the viability of implementing the use of citric acid and glycerol in our teaching laboratories, beginning at the college level, we saw merit in developing a discovery-based experiment by combining the citric acid chemistry with our work in starch-based samples. We previously developed an experiment titled *Make It and Break It* for the high school curriculum, which explores the differences among corn, potato, and tapioca starch plastic films prepared in water and acid (either vinegar or HCl, depending on the instruction level) and the effects on physical properties and tensile strength from additives such as glycerol, glue, and sugar.[7] There was also precedence for corn starch films cross-linked with citric acid resulting in improved properties over simple corn starch materials.[8] On the basis of this background, we set out to develop an experiment using combinations of citric acid, glycerol, and plant starch for a teaching laboratory experiment.

A primary goal of the new curriculum was to include the degradation of polymers/plastics as a central theme of the learning objectives. This topic aligns with green chemistry principle #10, design for degradation,[9] and connects the discussion of polymers and plastics to societal problems related to current materials persistence in the environment. For college level instruction, the study of polymers themselves and

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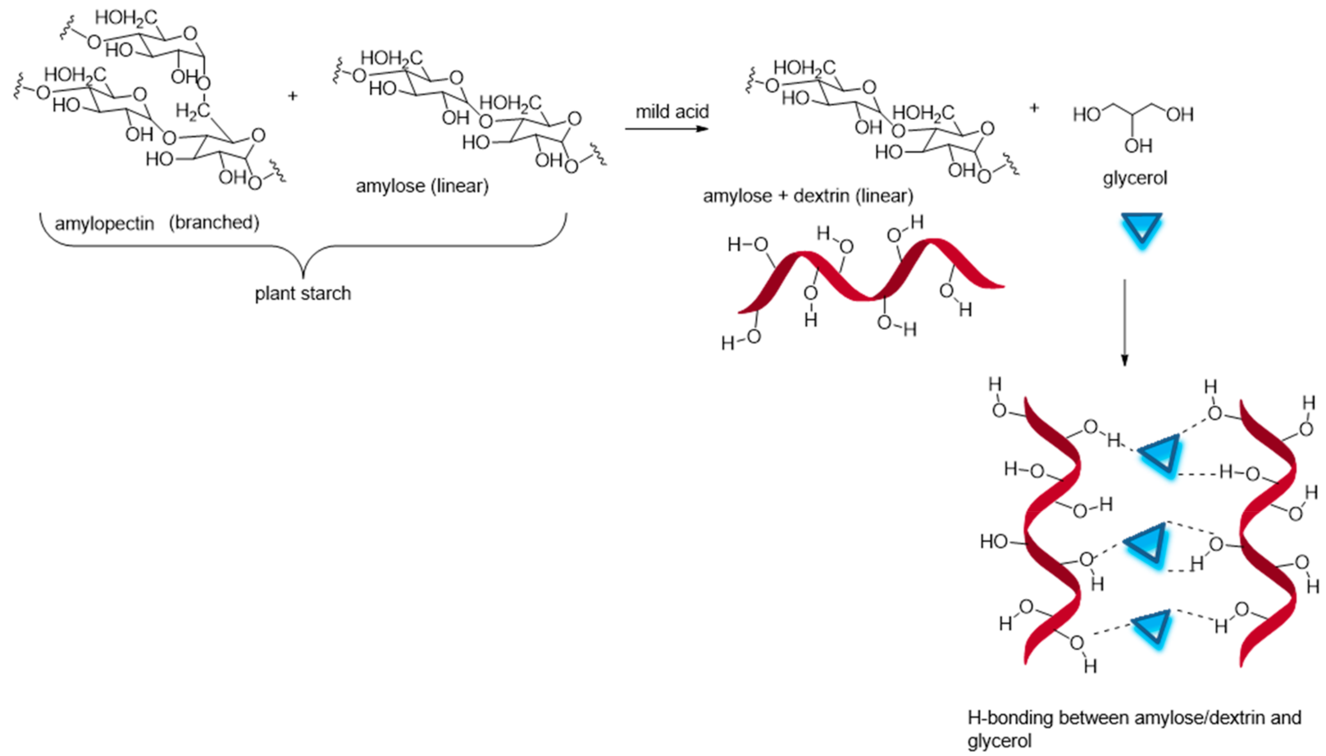
Scheme 2. Generic Structures of Amylose and Amylopectin Found in Plant Starches, Breakdown of Amylopectin to Unbranched Amylose and Dextrin, and Addition of Glycerol as a Plasticizer



understanding the connection between structure and degradation applies to the Committee on Professional Training (CPT) certification criterion of including macromolecular systems in the curriculum.[10] At the high school level, the Next Generation Science Standards include objectives wherein "students should learn about the relationships among science, technology, and society (STS)... with an increasing focus on environmental issues."[11] In addition, the mission of the NSF Center for Sustainable Polymers, which supporting this work, includes educational initiatives that focus on sustainability issues of polymeric materials and strives to inspire a new generation of students with the exciting opportunity for innovation in the field of environmentally friendly polymers.[12,13]

Optimizing Reaction Conditions for Polymer Samples

The published method for polymerization of the citric acid and glycerol to form a cross-linked polyester (Scheme 1) involved mixing freshly ground citric acid powder with glycerol, with or without acidic catalyst, in an aluminum pan and heating in an oven at various times and temperatures to remove the water byproduct.[4] Our initial investigations into adapting this protocol for the classroom setting involved exploring the use of hot plates, commonly found in teaching laboratories, as a mechanism for heating the 1:1 citric acid/glycerol mixture. Space precludes presenting all of the details of this work; however, the conclusions can be summarized as follows: (a) the time required for high conversion to product at the optimal 110 °C temperature setting exceeded that which would comfortably fit into a typical 3 h laboratory period; (b) hot plate models and settings, excluding those with temperature probe control, were highly variable in quality of temperature control, and uneven heating of the aluminum pans was observed; and (c) overheating on hot plates caused discoloration and foaming of the product. Mathers demonstrated microwave heating could be used as an alternative to hot plates by mixing citric acid and glycerol in lightly greased silicon muffin cups and heating for 30−90 s.[14] The resulting thermosets produced from the fast microwave heating were hard foams with air pockets, in contrast to the glassy thin films from slow removal of water.[14] Overall, we found that heating the citric acid/glycerol samples in an oven set at 100 °C for 2−7 days was the most consistent method for synthesizing thin films of the thermoset polymers for the purposes of our experiment.

Plant starches contain a mixture of amylose, a linear polymer chain of α-D-glucose with 1→4-glycosidic bonds, and amylopectin, a branched polymer of α-D-glucose with linear chains of 1→4-glycosidic bonds and α-1→6 branching (Scheme 2). Interestingly, the ratio of linear to branched starches varies, and tapioca has more branched polymer chains than potato or corn.[15] Although many educational experiments focus on potato and corn starch with glycerol,[16−19] experiments with tapioca-based starches are less common. On the basis of our extensive experience with our *Make It and Break It* experiment,[7] which includes tapioca starch, we explored a combination of these three plant starches with citric acid. In contrast to the citric acid/glycerol procedure, the starch reactions, either starch and citric acid or starch and glycerol, require the addition of vinegar to break down the branching in amylopectin, converting it to dextrin (shorter linear chains of D-glucose with 1→4 and 1→6 glycosidic linkages) and amylose. The linear chains facilitate hydrogen-bonding interactions with glycerol, which acts as a plasticizer, increasing flexibility and decreasing brittleness (Scheme 2).

Comparison of the potato starch/citric acid films, corn starch/citric acid films, and tapioca starch/citric acid films led to the conclusion that the tapioca starch/citric acid films consistently resulted in biofilms with the best properties for

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incorporation in the experiment. Most likely, the favorable ratio of linear to branched starches in tapioca starch allowed more homogeneous and flexible films, whereas the biofilms with corn starch tended to be more brittle than those made from either potato or tapioca starch.

Degradation Studies and Dye Selection

With the three different polymeric materials in hand, degradation rates, based on the observed disappearance of each sample, were studied in 1 M HCl, 1 M NaOH, and DI water. In agreement with observations for most alkyl polyesters and glycerol citrate polyesters,[20] the sample degradation rate for the citric acid/glycerol biofilm was fastest in aqueous basic solution and quite slow in both water and aqueous acid. In order to allow completion of degradation studies in a 3 h laboratory period, 1 M NaOH solution was chosen for the final protocol. As illustrated in the Supporting Information, all three samples, determined to have approximately the same density, are observed to completely solubilize in the 1 M NaOH solution, although the starch samples produce small amounts of clear particulate matter that settle between sample readings. In the case of the citric acid/glycerol polymer, the loss of mass over time most likely corresponds to a surface erosion mechanism. Initially, basic hydrolysis of ester bonds forms carboxylic salts and alcohol groups and begins the process of disassembling the thermoset. As hydrolysis continues, water-soluble fragments like sodium citrate and glycerol are released into the aqueous phase. The starch/glycerol and starch/citric acid samples were observed to swell slightly with the diffusion of the aqueous solution into the sample, and continued disruption of the H-bond networks allowed dissolution of the starch and glycerol or citric acid components. It should be noted that although cross-linking has been observed between starch and citric acid, infrared spectra of our starch/citric acid samples (see the Supporting Information) indicate no formation of ester bonds under the relatively mild conditions of preparation.[8]

Degradation was originally followed by loss of sample mass at timed intervals; however, use of a dye and the techniques associated with UV−vis spectroscopy added additional learning outcomes and thus were pursued. Early versions of the experiment allowed students to choose the color of food dye added to their samples, mainly for aesthetic purposes, but the addition of the basic degradation studies revealed the instability of the blue and green food colors, hindering reliable data collection. FD&C Blue No. 1, a triphenylmethane dye, is subject to nucleophilic attack, and it is present in green food dye also. FD&C Yellow Dye No. 5, the azo dye tartrazine, was confirmed to be stable in 1 M NaOH in the UV−vis spectrometer for the 1 h needed for sample degradation, and it gave reliable data using both UV−vis spectrometers and smartphone colorimetry.

UV−Vis Spectroscopy and Smartphone Colorimetry

UV−vis spectrometers are one of the most common instruments found in teaching laboratories and are used for the analysis of colored solutions and the determination of substance concentration through Beer's law. We sought to use this technique to study the comparative rates of degradation of the biobased polymer samples by following the change in color intensity caused by release of the yellow dye from sample degradation. Uniform distribution of dye in the samples was accomplished by thorough mixing of the commercially available yellow food coloring (1 drop) during preparation. The experiment can be performed without generation of a calibration curve if straightforward determination of relative rates is the goal. Our choice was to provide students with the experience of creating a calibration curve. This was successfully accomplished using a drops per milliliter system of dilution using McCormick yellow food coloring, which provided linear plots. In this case, absolute dye concentration was not determined; rather, the relative concentration was calculated from the calibration curve. If a more standard unit of molarity is desired, a protocol is provided in the Supporting Information based on our determination of the McCormick yellow food coloring as 0.1 M in tartrazine. This avoids the unnecessary purchase of the solid chemical tartrazine, which is generally sold in large bottles but is only used in microgram quantities for the experiment.

As an alternative to UV−vis spectrophotometry, recent literature articles have illustrated the application of smartphone camera colorimetry for the determination of analyte concentrations in a wide array of colored solutions, such as sports drinks,[21] crystal violet,[22] gold nanoparticles,[23] and proteins.[24] The use of hand-held cell phone cameras offers an affordable and convenient method for instruction of absorption spectroscopy and Beer's Law at the high school and college levels[25] in classrooms that may not have the funds for UV−vis spectrometers. As further examples, experiments have also been developed for use in analytical, physical, and biochemistry undergraduate teaching laboratories using this modern smart phone technology.[26−29] The use of smartphone colorimetry worked successfully for our experiment as well, with comparable results to those obtained from absorption spectroscopy.

■ EXPERIMENTAL DESIGN

Materials and Instrumentation

Citric acid and glycerol were purchased from Millipore Sigma but are readily available from other suppliers. Tapioca starch, food coloring, canola spray, and white vinegar were purchased from Amazon.com or from a local grocery store. For the food coloring, McCormick brand FD&C Yellow Dye No. 5 was used. It should be noted that McCormick brand yellow food coloring lists Red Dye No. 40 as a component, and an absorbance UV−vis spectrum (see the Supporting Information) confirmed its presence in negligible amounts, and thus it did not interfere with the measurements performed. High school implementation used Vernier Colorimeters, LabQuest Minis, Chromebooks, and the Vernier Graphical Analysis Application. PASCO Spectrometers PS-2600 were used for absorbance measurements with PASCO computer software in the college classroom. Camera FV5-Lite for Androids is an example of a smartphone camera app that can be used because of its ability to (1) automatically acquire images at timed intervals, (2) lock its focus, and (3) lock the white balance.

Part I: Synthesis of Bioplastic Samples

Part I of this experiment introduces students to bioplastics through documentation, a prelab, or both in the context of plastic accumulation in our environment. Additionally, principles of green chemistry are introduced, prompting students to consider how bioplastics could address sustainability goals. In Part I, students synthesize three different bioplastic samples. The first sample is a starch and citric acid polymer prepared by combining tapioca starch, citric acid, deionized water and vinegar in a beaker and mixing well with a

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glass stir rod. The mixture is heated on a hot plate at a low setting for 10−15 min with continued stirring until it thickens. One drop of yellow food coloring is added and distributed evenly throughout the mixture. The mixture is transferred to an aluminum dish and heated on the hot plate for an additional 30−40 min until translucent. The sample is allowed to air-dry for 2−3 days or the week typical between lab periods. The second sample is a starch and glycerol polymer prepared using the same procedure as the starch/citric acid sample. The third sample is a citric acid and glycerol polymer synthesized by thorough mixing of glycerol, citric acid, deionized water, and a drop of yellow food color in a beaker at room temperature. The mixture is transferred to an aluminum dish that has been lightly coated with canola oil. The sample is heated in a 100 °C oven for 2−7 days.

As seen in Figure 1, students have an opportunity to experience different physical properties for each biobased polymer. For example, the starch/citric acid and starch/glycerol samples are opaque and flexible, whereas the citric acid/glycerol sample is clear and hard (similar to a piece of hard candy). Students are provided with the structures of citric acid, glycerol, and the amylose and amylopectin found in starch, with each relevant functional group (carboxylic acids and alcohols) highlighted. As reproduced in Figure 2A, a reaction scheme for the condensation reaction of a generic carboxylic acid and a generic alcohol is given to show the covalent bonds formed, the water byproduct, and equilibrium. A discussion of Le Chatelier's principle is weaved throughout the introduction, and pre- and postdocuments. Students are also provided with an illustration of the hydrogen bonding between glycerol and the amylose of starch (Figure 2B). From this information, students are asked to make predictions about the properties of their samples and their rates of degradation.

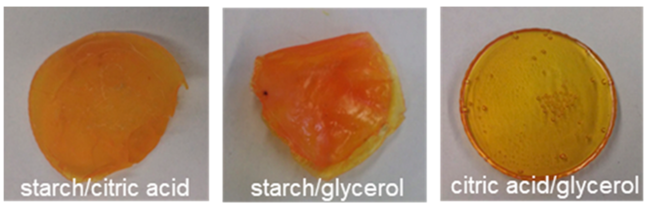

Figure 1. Photos of the three biobased polymers formed, illustrating their different physical characteristics.

Part II: Degradation of Bioplastic Samples

In Part II of this experiment, the degradation of ~0.1 g of each biobased polymer sample is followed via either UV−vis spectrophotometry or smartphone colorimetry. Students also qualitatively follow the degradation of a piece of a poly(lactide) (PLA) or polyethylene terephthalate (PET) that they are asked to identify in a consumer product and bring to class for comparison. A 1.0 M aqueous solution of sodium hydroxide is used for the degradations, and absorbance values are collected every 5 min until no visible sample remains or until 60 min has passed. Most samples degrade in 55 min or less. For UV−vis spectroscopy analysis the instruments are calibrated to 425 nm.

The setup used for the smartphone colorimetry was modeled after that published by Penn and co-workers.[22] A white background, such as that of a blank PowerPoint screen on a computer, is used in a well-lit area with minimal shadows (for a sample setup, see Figure 3). The smartphone is placed in a stable position and focused on the cuvettes, consisting of the five standard solutions and three samples to be studied, in front of the computer screen. The camera is set to autoacquire images at 5 min intervals so that there is minimal disturbance to the system. The collected images can be transferred to a computer for analysis using a color picking extension (e.g., Chrome browser color picking extension) or analyzed directly on the smartphone using a color picking app. The intensity values are recorded for blue (B) in the RGB color model, because blue is the most complementary color to yellow.

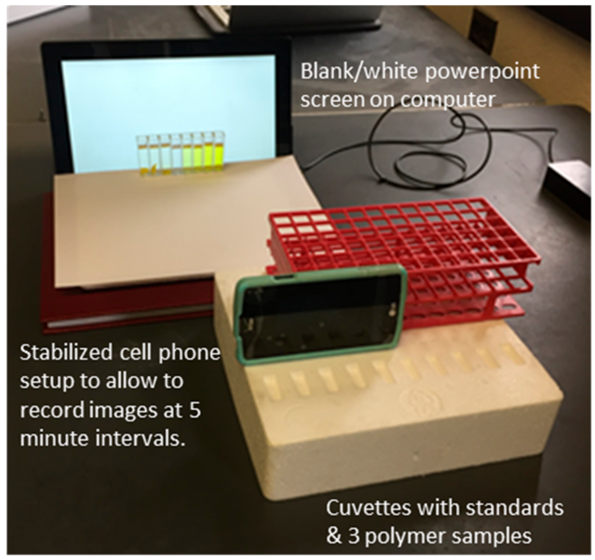

Figure 3. Sample setup for acquisition of images using a smartphone camera.

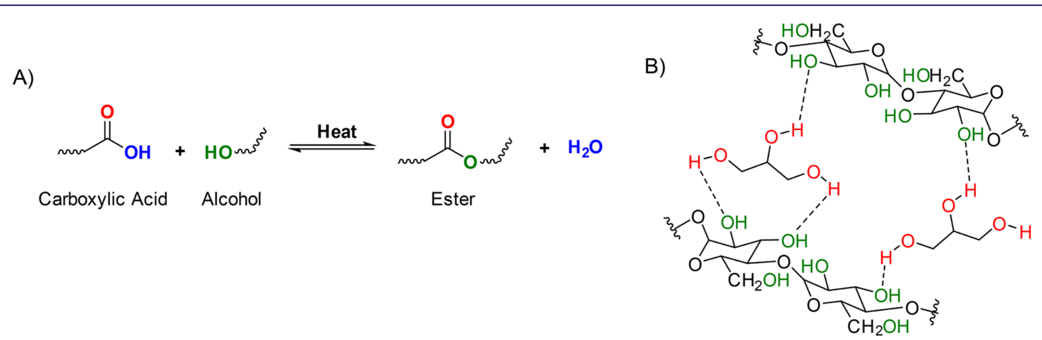

Figure 2. (A) Reaction scheme for the esterification reaction and (B) illustration of hydrogen bonding between the linear polymer chains of amylose and glycerol.

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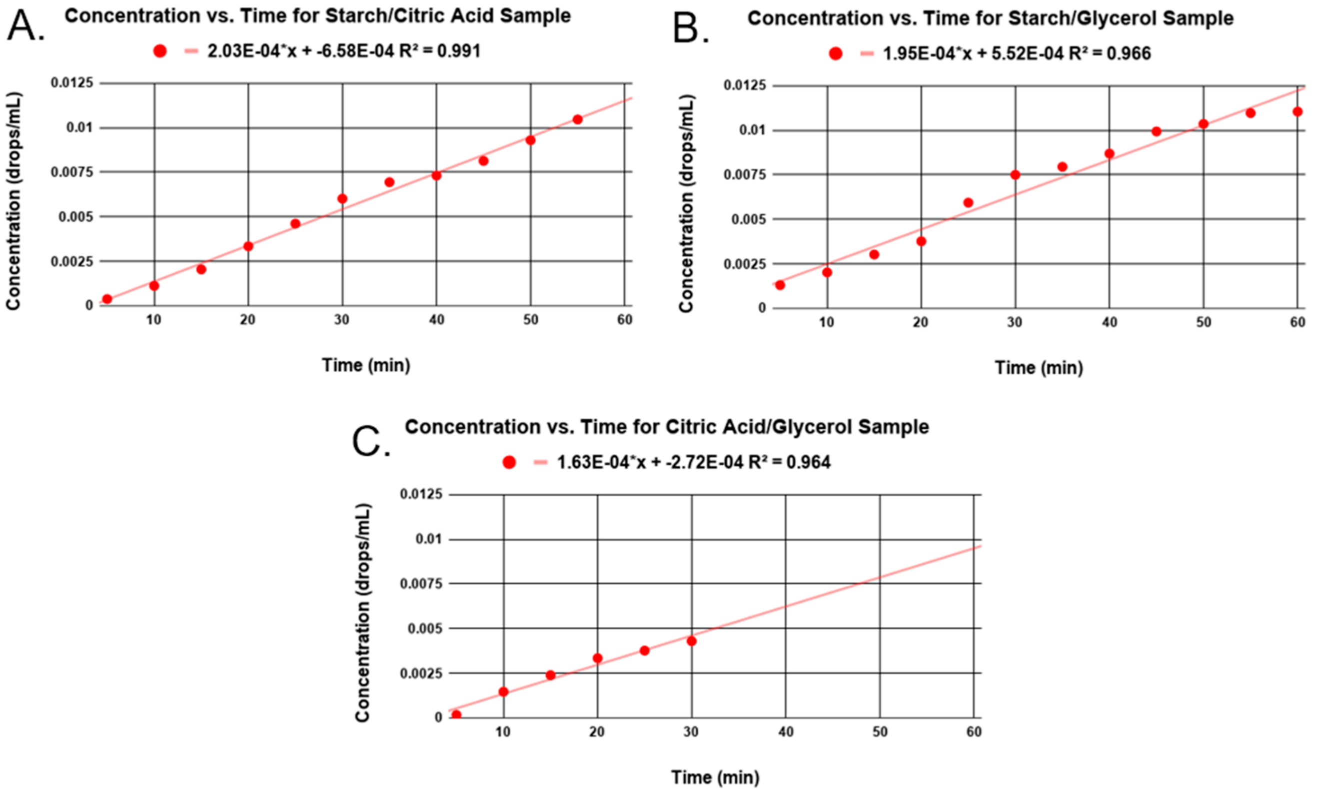

Figure 4. UV−vis spectrometer data: representative plots of concentration (calculated from observed absorbance and standard calibration equations) versus time for (A) starch/citric acid, (B) starch/glycerol, and (C) citric acid/glycerol polymer samples.

As the polymer samples degrade, they release the yellow dye from the added food coloring. See the Supporting Information for photos of all three degradations. The relative concentration of food coloring dye is determined through a Beer's law plot of absorbance versus concentration in drops per milliliter of standard solutions and a calibration plot. By monitoring the increase in concentration of the dye with respect to time, an inverse correlation is made to rates of polymer degradation. Students observe that the polymers containing starch decompose at similar rates, whereas the citric acid/glycerol sample degrades more quickly but at a slower rate and reaches a lower final concentration of dye (Figure 4). We propose that the higher absorbance values for the starch samples are the result of insoluble starch particles. This hypothesis is supported by the fact that the differences in the final concentrations between the starch polymers and citric acid/glycerol polymer are not as great when measured using smartphone colorimetry, which does not involve transmittance of light through a sample.

The observed trends most likely do not match student predictions based on the relative strengths of covalent bonds versus hydrogen bonding. This is an opportunity for students to consider other factors that could influence degradation. For more advanced classes, a prompt to consider a possible reaction of the liberated citric acid with the sodium hydroxide solution (i.e., acid/base chemistry to form a water-soluble salt) may lead students to consider other factors in degradation besides bonding strength, such a solubility or rate of acid/base reactions relative to hydrolysis of esters. For the starch/citric acid polymer, students might have predicted that both covalent bonds and hydrogen bonding are present and therefore conclude that the starch/glycerol sample, having only hydrogen bonds, would degrade the fastest.

■ HAZARDS

Students should wear goggles during the synthesis of the bioplastics samples and should wear gloves when performing the degradation tests. Caution should be used with the hot plate and when handling the hot glassware and aluminum dishes. Tapioca starch is not classified as hazardous. Citric acid, glycerol, and Yellow Dye No. 5 are skin and eye irritants and are hazardous if they have skin contact for prolonged periods. Hands and any exposed skin should be washed thoroughly after handling. Sodium hydroxide is corrosive and a skin and eye irritant. Breathing the fumes should be avoided, and hands and any exposed skin should be washed thoroughly after handling.

■ RESULTS AND DISCUSSION

Classroom Implementation

This experiment was performed in multiple academic settings (see the Conclusion section for a summary); however, the results and discussion presented hereafter will focus on those implementations using the documents provided in the Supporting Information.

Version A was performed in an Advanced Placement (AP) high school chemistry classroom by 17 students. Both UV−vis spectrometer and smartphone colorimetry methods of analysis were employed. Students worked in groups of three or four. Part I, synthesis of bioplastics, was completed in the first day of the experiment during a 50 min class period, and Part II was completed 3 days later to allow time for the samples to

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adequately dry. Data analysis was performed collaboratively using Google docs and sheets.

Version B was performed in a freshman level laboratory course in the University of Minnesota's second semester of "Chemistry for the Life Sciences" sequence during the spring 2018 (N = 249) and 2019 semesters (N= 271). The laboratory course met once a week for 3 h. Students were concurrently enrolled in a lecture course that integrated general chemistry and organic chemistry concepts. Students work in pairs. In the first laboratory session, the three bioplastic samples were prepared, and the UV−vis instrument and software for graphing are introduced through preparation and analysis of the standard solutions so that a calibration curve can be plotted. During the second laboratory period, the dried samples are characterized, and the degradation of each polymer is performed and followed by UV−vis spectroscopy. The data collected was used to plot concentration versus time and compare relative rates based on the slopes of the lines.

Student and Instructor Feedback

Version A student survey feedback demonstrated improved understanding of the definition of a polymer and the goals of green chemistry (Table 1). The survey indicated that four out of five groups obtained linear calibration curves and determined that the citric acid/glycerol sample degraded the fastest, most commonly in 15−20 min. Students reported that both starch polymers required longer than 30 min to degrade, and the order was variable. Stirring between measurements was observed to be very important. Overall, the experiment was positively received by students, and the majority indicated that the "aspects of the experiment" they enjoyed most were synthesizing the polymer samples, learning about green chemistry, and observing polymer degradation. Students appreciated its societal connections as well as the use of everyday household items like starch, food coloring, and vinegar.

Table 1. Pre- and Postsurveys of White Bear Lake High School Students (N = 17)

Question and Correct Answer	Correct in Presurvey (%)	Correct in Postsurvey (%)
Polymers are made of small repeating units called monomers.	71	94
Green Chemistry seeks to design materials from renewable resources that are degradable.	71	100

A summary of student results and feedback from implementation in the Life Sciences Laboratory course (Version B) is represented in Table 2. Overall, the results confirm each aspect of the experiment (synthesis of samples, method used for generating a calibration curve, and analysis of the degradation by UV−vis spectroscopy) was successful. With respect to student plotting of their data, 71% of students reported linear plots with good correlations of data points for at least two of the three samples; 35% reported good correlations on all three plots. As was observed in the high school experiment, the majority (70%) of the students reported that the citric acid/glycerol sample degraded the fastest. Finally, Table 2 illustrates the high enthusiasm for inclusion of the discussion of plastics and their environmental impact as an important topic for the course.

■ CONCLUSION

The versatility of the described experiment was demonstrated by its successful implementation over the last four years in an AP high school classroom, a general chemistry laboratory course, an honors general chemistry laboratory course, an introduction to environmental science course for nonmajors, and a second semester "chemistry for the life sciences" laboratory course. Uniformly, students felt that "the topic of plastics and their environmental impact" was an important subject and suitable for inclusion in their respective curricula. The use of inexpensive, nontoxic, readily available starting materials and the range of learning objectives, from simple observations to comparative rate determinations, allow instructors to tailor the provided student and teacher documentation to their individual classrooms. Unique to this experiment is the synthesis of a thermoset polymer from citric acid and glycerol, which, to our knowledge, has not been incorporated in an educational experiment.

The design characteristics also lend themselves to project-based learning, as students can be tasked with exploring different plant starches or additional additives to the polymer syntheses,[7] reaction conditions such as temperature, or media for degradation. Ultimately, the goal was to provide an engaging experiment that brings awareness to green chemistry strategies for designing more new environmentally friendly plastics, the challenges that lie ahead, and the opportunities that exist for students entering the STEM fields to positively contribute to a sustainable future.

Table 2. Spring 2018 Life Sciences Laboratory Course Student Responses (N = 249)

Statement	Average[a]	Standard Deviation
The synthesis of the starch/citric acid polymer worked as described in the procedure.	4.35	0.75
The synthesis of the starch/glycerol polymer worked as described in the procedure.	4.39	0.71
The synthesis of the citric acid/glycerol worked as described in the procedure.	4.53	0.66
Calibration Curve: The method used for generating the calibration curve by dilution of the standard solution gave a straight trend line with close correlation of each data point.	4.27	0.80
Degradation Measurements: The degradation measurements were reliable and representative of the sample degradation.	3.88	0.89
The use of UV−vis analysis was a good method for observing degradation of the synthesized bioplastics.	4.18	0.70
This experiment increased my knowledge about the PLA compostable consumer products found on campus and in stores.	3.90	1.04
This experiment increased my knowledge about the strategies scientists are taking to design new plastics which are environmentally friendly and sustainable.	4.04	0.90
The topic of plastics and their environmental impact is important and suitable for inclusion in the 1086 curriculum.	4.35	0.69

[a]Based on the Likert Scale: 1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree.

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.9b00461.

Student handout version A, student handout version B, instructor guidelines, and representative data (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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