Chemical Catalysis: Making Sustainable Chemistry Possible

Lesson Plan - Overview

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Summary:

This inquiry based chemistry activity uses three catalyzed reactions to teach students about catalysis pathways and their importance in sustainable chemistry. Students will integrate evidence from the reactions to deduce that catalysts **facilitate** chemical reactions, **participate** chemically, and **regenerate** so that they are not consumed. Students will engage in the scientific practice of **constructing explanations** and will **identify** important aspects of catalyzed reactions, **assimilate** observations and knowledge, and **infer** missing steps in explanations. Results are integrated first colloquially and constructively via a jigsaw session and are then formalized via a presentation.

Context of Teaching Experience

Teaching team members:

Chris Bernt (Design team leader)
Robert Lewis (Logistics lead)
Max Fisch (Documentation lead)
Megan Chewy (Co-Logistics lead).

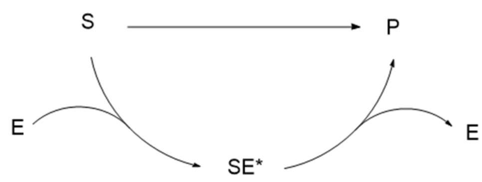
Teaching venue:

School for Scientific Thought (SST) program at UCSB. Dates include: 9/27, 10/4, 10/11, 10/18, 10/25. Students are from local high schools, mostly sophomores and juniors. Science background will likely vary.

Most activities will be done at UCSB in labs PSBN 2664 and 2666. Some activities will take place outside.

Goals of Activity

Content learning outcome: Students will explain a chemical phenomenon using the concept of a catalyst and a diagram of a reaction network. The network diagram will include: Substrates, reactants and catalyst; the catalyst **participating** in the reaction while being **regenerated**; and proper **relationships** between the components.



Science practice learning outcome:

Students will work on the core practice of **constructing explanations**. For this activity students will explain the catalyzed reaction using experimental evidence gained through student investigations. The students will **identify** significant data, **assimilate** accumulated knowledge and infer aspects of the **chemical** observed phenomena.

<u>Essential Components of Inquiry Activity</u>

Starter(s):

Starters will be brief demonstrations that introduce a catalyzed reaction to the students. By demonstrating interesting phenomena related to catalysts, students should ask what the role of each chemical is and how they interplay to create the observed effects.

Investigations: Students will carry out one of four investigations, all which illustrate these properties of catalysts. Some investigations cater more readily to different areas so we will want to make sure the students get the main point for each investigation when it comes time to sharing with their jigsaw. The investigations will include esterification of salicyclic acid, redox reactions of thiosulfate, photochemical decomposition of DCIP dye, and starch metabolism.

Thinking Tool:

Beakers of water with students. This activity will demonstrate a chemical reaction pathway with students taking the roles of reagents, intermediates, and products. We'll introduce a tool that make a step easier or faster, causing the "reaction" to be faster.

Bridge from Investigation to Culminating Assessment:

Jigsaw: Inquiry groups will be divided up and distributed into one jigsaw group per instructor. Groups will be formed such that each jigsaw group is composed of at least one member from each of the inquiry groups. In the jigsaw group each student will share what they learned from their individual inquiry activities. The jigsaw groups will then try to synthesize all of the content to come to a more complete understanding of the commonality between these experiments with the goal of using the information from all group to help them more thoroughly interpret their own experiments.

Culminating Assessment Task – Making Meaning:

Students will use their observations and synthesized information from the jigsaw activity to make a poster and give a short presentation to the class. The prompt will be as follows: “Integrate your observations of catalyzed reactions and explain, using a diagram, the significance and role of a catalyst in a reaction. Keep in mind what you have learned from the exchange of information with your classmates.

Detailed Documentation

Overview of Activity Components:

Day 1
Introduction to the activity (Robert: 15 minutes)
Safety & Technical Skills (Chris: 20 minutes)
Chemistry Review and Stoichiometry Demo (Robert: 45 minutes)
Starter (Robert: 20 minutes)
Forming groups (Megan: 15 minutes)
End of Day Wrap Up (Chris: 5 minutes)

Day 2
Finish anything not covered in day 1
Contexting Investigations (Chris: 10 minutes)
Investigations (All: 100 minutes)
End of Day Wrap Up and Cleaning (10 minutes)

Day 3
Thinking Tool (Megan: 55 minutes)
Investigations (55 minutes)
End of Day Wrap Up and Cleaning (10 minutes)

Day 4
Finish investigations (70 minutes)
Jigsaw (40 minutes)
End of Day Wrap Up (10 minutes)

Day 5
Contexting Poster Prep (5 minutes)
Posters Prep (50 minutes)
Poster presentations (Max: 45 minutes)
Synthesis (Chris: 20 minutes)

<u>Introduction to the activity (outside):</u>
(Robert, 15 minutes)

Introduce facilitators and the schedule

> Hey everyone, we are [Introduce facilitators]. We're here to make sure you have a fun, interesting, and productive time in our class. Over the next five Saturdays days you'll be carrying out an inquiry based investigation to learn about sustainable chemistry. We have a pretty packed schedule so get used to this sound. [Ring bell] This will be used to signal when it's time to transition into the next activity.

Discuss inquiry (Chris)

> "I'm sure many of you have not been introduced to the process of inquiry learning before so I think it's important that we discuss what that is exactly. The process of inquiry is based on the idea that knowledge is best gained by participating, by doing, by being involved in the process. It rejects the idea that we can just stand here and talk at you for a hour and you will learn and understand everything perfectly. In this activity there are no grades and no way for you to fail, but we do expect you all to participate in the process. You'll all be engaged in simulated scientific research to teach important concepts. When you are engaged in scientific research the answers don't always come easily, so although you are welcome to ask questions of the facilitators, we won't always give you answers right away. You will have an opportunity to share your discoveries with everyone at the end."

Icebreaker (Megan)

> "Since you will be working in groups and giving presentations, it will be important to feel comfortable interacting with us and your peers so we are going to do an icebreaker to help everyone get to know each other."
>
> [Students will stand in a circle and toss a ball to other students, when the student catches it they will answer the question closest to their right thumb until every student has had a chance to speak]

<u>Safety and Technical Skills:</u>
(Chris, 20 minutes)

Discuss safety

> "You will be using chemicals to perform some laboratory experiments. As such, it is very important that we follow the guidelines for laboratory safety. We are providing all of you with lab coats and safety goggles. It is important that you keep these on at all times."
>
> Ask the class if they think there are any other safety topics they have learned that we should address then add:

“ Additionally, we are providing you with gloves that we recommend you use whenever you handle chemicals. In the unlikely event you spill chemicals on yourself we have safety showers and eyewash stations.” [*Indicate locations of safety showers, eyewash stations*] “We’ll only use the fire extinguisher if it is safe to do so, in the case of an evacuation the gathering point is in front of the building on the lawn” [*Indicate locations of fire extinguishers.*] “For your safety, you aren’t allowed to use your phone or eat in the lab, feel free to go outside if you need a snack or have to take a call. Finally, since we’ll be working with chemicals for the next three weeks its important that you wear closed toe shoes and long pants.”

Discuss techniques

Ask the class for any techniques they may have learned (in general). If any of the following topics come up let the students explain. Otherwise explain to the class and let them know they will practice the techniques in setting up the demonstration

lab notebook - We will provide. One of the most important things is keeping a good record so you can repeat results and accurately report what you learned, how, and why. When making measurements it is more important to record the actual amount than to worry about trying to hit an exact number

weighing out chemicals - Scales should be tared first using either a weigh boat or weigh paper. It is important to clean up the scales after use for the next group. Also allow the scale to equilibrate before writing down final measurement.

measuring volume - Draw out a graduated cylinder and indicate meniscus and where to read volume. Point out that its typical to estimate one unit past the markings.

waste disposal - Especially when considering green chemistry we want to make sure no chemicals go down the drain. Probably the easiest method is to collect a small waste at your bench in a beaker and transfer it to the waste bottles in the hood as it is getting full or at the end of the day. Chemicals can be dangerously incompatible so we will have a waste bottle for organic waste and aqueous (in water) waste.. Check how full the bottle is before adding anything to it, make sure to use the funnel, and close the bottle when you are done. (show exploded waste bottle)

cleaning - Part of a complete experiment includes cleaning up when you’re done, at the end of the day we need to make sure all of our equipment is clean and put away. Rinse contaminated glassware out into waste first then clean with soap and water in the sink.

<u>Chemistry Review:</u>

(Robert, 25 minutes, powerpoint)

Discuss relevant information (chemical reactions, stoichiometry and sustainability)

Before we get any further, we need to discuss a few concepts that are important to your investigations throughout this course. First, we need to discuss sustainability. You are all here for a sustainable chemistry activity. What does this phrase mean to you? What are some things that can be done in order to be sustainable? [*write down student ideas for future reference*] These are are all good ideas, keep them in mind as you continue with this activity.

So we just discussed sustainability a little bit, but we're here to investigate sustainable **chemistry**. How many of you have taken chemistry before? Alright, so how about we transition into discussing chemistry by talking about S'mores. How many of you guys have had s'mores before? What ingredients do you need to make one? Right, graham crackers, a marshmallow, and chocolate. We can represent this as an equation where we have a starting materials leading to our final product. But this is incomplete. It's kind of like a recipe but, right now, it doesn't tell us how much of each thing we need… let's add in that information. Alright, now this is better. We can even add more information over this arrow here, like that we need to use a campfire to heat this. Excellent. How many S'mores can you make here? 4, because after that, we'd run out of chocolate and have left over or excess marshmallows and graham crackers. What if I was like, "Oh no, 4 smores is not enough!" and I ran to the store to get 36 more pieces of chocolate. How many s'mores now? 7, exactly. Now I'm limited by the number of graham crackers I have. This informative equation is exactly how chemists look at chemical reactions. We don't always use pictures like this so let's represent this like a chemist might.

Now I have a question for you guys again… what is a chemical reaction? Turn to the person next to you and come up with and idea of what a chemical reaction is. [*add student definitions to poster*] A chemical reaction is a process that transforms one chemical substance into another. You have reactants or reagents that undergo a chemical reaction to form some sort of product. It's as simple as $A + B \rightarrow C$. This is how we will represent chemical reactions. This tells us that it takes one molecule of A and one molecule of B to make a single molecule of C. I'm sure almost all of you have seen an example of this before and maybe even does this at home. When you mix baking soda ($NaHCO_3$) and vinegar (CH3COOH) you generate CO2 gas, water, and sodium acetate. Now, **let's investigate this reaction a bit further**. I want you to keep this chemical reaction in mind.

DEMONSTRATION (http://pubs.acs.org/doi/pdf/10.1021/ed085p1382)

During this demonstration, we will have students practice some of the safe lab techniques that they were just taught to help weigh out our chemicals that we need. The extremely visual nature of this demonstration will give them a memorable experience to link with the information they just learned. The demonstration will end with a small discussion of how this is relevant to their experiments and will lead nicely into the next demonstration of catalysis.

Let's discuss what we just observed… I want you to spend the next few minutes discussion with a few people around you. The questions I want you to answer are__________. Think back to the s'more slide and draw a parallel with what we just observed. Remember, how you went about answering this question too. Alright, let's discuss what happened...

Stoichiometry is the calculation of reactants and products in a chemical reaction. It's founded on the **law of conservation of mass** where the total mass of products equals the total mass of the reactants. Basically, you have to end with the same amount of mass that you started with, you cannot create or destroy matter in a chemical reaction. You can't make your s'mores if you're missing a graham cracker. This is a very important concept that will be coming up throughout this class. In your investigations you'll be looking at reactions that seemingly violate this principle.

Starter Component:

(Robert: 20 minutes)

Decomposition of H_2O_2 with MnO_2:

(http://pubs.acs.org/doi/pdfplus/10.1021/ed4006826)

Using 1 liter bottles containing 50 mL of 30% hydrogen peroxide, ~1g of Manganese dioxide will be added to catalyze the decomposition of hydrogen peroxide. This will produce a small plume of steam as the exothermic reaction gives off water vapor and oxygen gas.

I will have three 1 liter bottles with 50 mL of H_2O_2 prepared for this demonstration. I will tell all the students that "if you leave one of these out in the sun for a few days, it'd all turn into water. The combination of light and heat will cause the hydrogen peroxide to decompose to water and oxygen. But we don't have that kind of time today, so we want to help this along. Here, I have some manganese dioxide…" I'll weigh out ~1g of MnO_2 and add it to the 1 liter bottle. and step back. I'll point out that this is the same process as leaving it out in the sun just ~1000x faster. I'll also add 100mg of MnO_2 to the second bottle to demonstrate that, although the reaction is slower, the same process is occurring. Lastly, after the first reaction has finished, I'll filter out the MnO_2 and add it to the last 1 L bottle to show that it'll still work (isn't consumed).

Hopefully this activity show the students that the MnO_2 speeds up the reaction, one that would occur regardless of it's presence. I also want them to notice it's possible to reuse all the catalyst without loss of activity. Lastly, I hope they pick up on how I carried out my experiment, changing one variable at a time, and use similar tactics during their investigations.

Include discussion of stoichiometry.

Investigation Group Formation:

(Megan: 10 minutes)

We will set out sign up sheets corresponding to each investigation and have students sign up for their number one and number two choice. We will then divide the students into groups, trying to have at least two groups for each investigation area.

We expect to have ~28 students in our activity for our four experiments: Starch (Max), Light (Megan), Iron (Chris), and Wintergreen (Robert). It will be useful to give students an idea of the scope of each activity so that they will not feel over or underwhelmed. For example say:

- The starch experiment investigates this phenomenon using (mostly) household items.

(i.e. I&E for “non-STEM identifiers)

- The Light experiment examines environmental factors other than chemistry on this effect (i.e. multidisciplinary integration)
- The Iron experiment allows students to easily “see” the reaction progressing rather than infer start/stop times (i.e. different learning styles)
- The Wintergreen experiment involves higher-level chemistry--it will be more difficult but will bring deeper understanding (i.e. plays to differences in background knowledge)

The group of 24 students will then break up into eight groups of three, with no more than two groups examining one experiment. Each sign up sheet will look something like this:

EXPERIMENT NAME

1A ___________
1B ___________
1C ___________
1D ___________
2A ___________
2B ___________
2C ___________
2D ___________

The 1’s and 2’s will be group 1 and group 2 for the experiment. When Jigsaw occurs, all A’s will form a jigsaw, all B’s will form a jigsaw, etc.

(Note, to ensure equal distribution in jigsaw, experiment 1 signup should read ABCDABCD, 2 should read BCDABCDA, and so on)

<u>Contexting Investigation Component:</u>
(Chris: 10 Minutes)

Four separate investigations will be presented, with student groups carrying out one of the investigation activities. Instructors will focus their facilitation on the two groups investigating their particular activity. Instructors will also provide support to other students and facilitators as needed. Each catalysis investigation has the potential to illustrate all aspects of the content goals but tend to be better at highlighting different components (given in individual descriptions). The idea is that during the jigsaw, students can be “experts” at their own activity and work to put together a solid idea of a catalyst as a group. Contexting for the investigations in general will be a brief introduction:

“Today we will start our investigations. We will be doing what is called an inquiry based activity where you are given tools to generate and explore your own questions related to a particular topic. We will then help you design and interpret your own investigations and we will later come together as a group to share what we have learned. The idea behind this type of activity is that it is a more realistic model of what it is like to do actual research than a more typical “cookbook” style lab class. We understand this type of activity can be frustrating due to the lack of structure but it can also be an enjoyable challenge to come up with your own ways to investigate a question.”

“Will will be here to help ensure a safe environment and help you with your design and ideas, but we will not “give you the answer” as these will be for you to discover and demonstrate. If you feel like you are “done” we can help you test your answers or come up with new types of questions to investigate”

Facilitators will context their own specific investigations with a demonstration of the components available in the investigation activity.

Individual Investigation Areas:
(All instructors: 240 minutes total)

Esterification of Salicyclic Acid and Catalyst Recovery

Section Author: Robert Lewis

Materials (per group):

Equipment to set up ~4 reactions

(4)	22mL vial with cap
(4)	small magnetic stir bar
(2)	Hot plate stirrer
(2)	Water/oil bath
(4)	clamps
(2)	spatula
(1)	Buchner funnel
(2)	10mL graduated cylinders

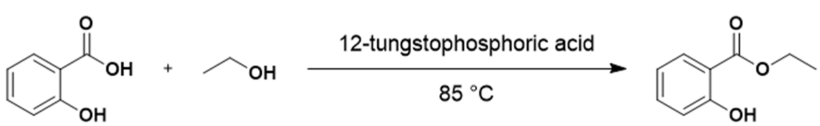
Chemicals for up to ~4 reactions:

(4mL)	absolute ethanol
(2g)	salicyclic acid
(200mg)	12-tungstophosphoric acid hydrate
(200mg)	cupric nitrate trihydrate
(88mg)	benzene-1,3,5-tricarboxylic acid (BTC)
(60mL)	decane

Miscellaneous materials:

Disposable pipettes, pipette tips, weighing paper, filter paper,wash bottles of acetone and DI water, and access to scales.

Chemical Description and General Methods: The esterification of salicyclic acid with ethanol is performed in the presence of 12-tungstophosphoric acid, a Brønsted-Lowry acid catalyst. The product ester smells like wintergreen and the reaction can be monitored with smell. Student will also notice a color change from clear to yellow as the reactants dissolve.



The acid catalyst can be recovered by encapsulation into a metal-organic framework (MOF). This encapsulation process can be monitored by sight since it changes the solution from green liquid to a suspension of blue catalyst-containing particles. This catalyst can then be recovered by filtration, dissolved in a new batch of reactants, and reused.

The encapsulation and reuse of the catalyst was never carried out due to time constraints. Therefore, students were not able to come to the content goal of catalyst regeneration. If the time constraints are unavoidable, it might be a good idea to demonstrate this for the group and let them draw conclusions on their own.

Possible Investigation Routes: Students may choose to see how the reaction proceeds without the addition of the catalyst. By setting up a two reactions, one with and one without catalyst, the students could have a direct comparison. They would not notice the wintergreen smell developing in the reaction with no catalyst and could conclude that the catalyst **facilitates** the esterification. Additionally, student will notice that the reaction with the catalyst shows a color change which can indicate catalyst **participation** in the reaction.

Students might also ask if the catalyst is consumed in the reaction. The added steps of encapsulating the catalyst in a MOF gives students a visual indication that the catalyst was **regenerated**. To add to this effect, the recovered catalyst can be reused in another esterification to show that it is indeed still the same catalyst and has not lost its reactivity.

Content Goal Challenges: This experiment clearly shows that catalysts **participate** in reactions and are **regenerated**, but getting students to see that they **facilitate** the reaction may be a bit of a stretch. For the uninformed observer, it might just seem that the catalyst is a necessary reactant rather a participant that facilitates the reaction without being consumed.

Facilitation moves to elicit learners' thinking: I hope to elicit thinking by simply asking the students to explain what they are doing and what they hope to learn from it. As the experiment progresses, I'll have them tell me all their observations and ask them to use this data to try and explain what their experiment and give a reasoning for what they will do next.

Facilitation moves to reach content goal: While using the moves mentioned above, I will be listening for the use of words related to the content goals (catalyst, participation, facilitation, regeneration, etc.). If I hear one I'll encourage that avenue of thought/explanation. If more work is needed to reach an understanding or provide an adequate explanation, I'll subtly hint at or push them towards experiments that can provide the data they need. If they correctly identify the catalyst in the reaction, I'll ask them what they think it means and how they can prove that with experiments.

Practice Goal Challenges: Students may be reluctant to offer up explanations for their observations, give only explanations based off of partial results, or interpret results incorrectly.

Facilitation moves to reach practice goal: Main facilitation move for this will be to ask them to explain their results and what they think they mean so far. Repeating their analysis back to them will help highlight inconsistencies in their explanations. Subtle suggestions of possible experiments to put them on the right path might be used if they continue to misinterpret data or have an incomplete picture.

Supporting Equitable Learning: Since student are working in groups there's the chance of one student taking charge and giving orders rather than letting each person contribute. Through questions and observation I can determine if someone is being given the opportunity to contribute. If the situation seems more one-sided, directed questions and facilitation moves, such as eye contact, will be used to bring the less involved person into the discussion and pull out their opinion/hypothesis.

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Reaction of Fe(III) with Thiosulfate:

Section Author: Chris Bernt

Materials:

Dissolve all solids in distilled or nano-pure water. The amounts listed are per group

(2)	10mL graduated cylinders
(3)	very small beakers or 3 small test tubes
(10)	disposable pipette
(1)	wash bottle
(1)	large beaker (for waste)
(1)	stopwatch or other timer

(200 mL)	1mM Iron (III) nitrate	(8.08g of hydrate salt)
(200 mL)	1mM Sodium thiosulfate	(4.96g of salt)
(20 mL)	1mM Iron (II) sulfate	(0.56g of salt)
(20 mL)	1mM Copper (II) sulfate	(0.50g of salt)
(20 mL)	1mM Nickel (II) sulfate	
(20 mL)	1mM Cobalt (II) chloride	(0.48g of salt)

Chemical Description and General Methods: The reaction of iron(III) with thiosulphate produces a deep violet complex anion, $Fe(S_2O_3)_2^-$. This decomposes slowly with the fading of the violet colour:

$$Fe(S_2O_3)_2^- (aq) + Fe^{3+}(aq) \rightarrow 2Fe^{2+}(aq) + S_4O_6^{2-}(aq)$$

Other metals can also oxidize the thiosulfate more quickly and then in turn can be reduced by the iron(III) to give the same overall net reaction at a faster rate, hence a catalytic process.

Students can then test different mixtures of the solutions and make observations. When the Fe(III) is combined with the thiosulfate the mixture should become dark purple and slowly change to clear. Adding different amounts of the other metals will affect the rates differently. For consistency, students should place a specific volume of Fe(III) in one of the reaction vessel (beaker or test tube), add a controlled amount of catalyst (none or a counted number of drops), and then add measured volume of thiosulfate. As soon as the thiosulfate is added they should start to time their reaction. Another option would be to set up reactions side-by-side and see which goes clear faster. Using the grad cylinder and DI water, the students could also possibly make their own dilutions.

Possible Investigation Routes: Students may decide to investigate how the addition of the catalyst affects the speed of the reaction. One of the ways they might go about doing this is by adding controlled amounts of the catalyst solution and using a stopwatch or side by side comparison to see how the quantity affects the rate. For this particular experiment they would observe that more catalyst has a linear effect on the reaction rate. This directly addresses the aspect of the content goal that catalysts ***facilitate*** reactions.

Students might also ask whether or not the catalyst is used up during the course of the reactions. They might try to see if they can observe the catalyst color after the reaction has completed. Perhaps a more apparent way would be to re-use the final solution in another reaction (since it contains regenerated catalyst, it will speed up that reaction as well). This would strongly reinforce that catalysts are ***regenerated***.

Students might be able to even nail down the mechanism by testing the catalyst without the iron, in which case it should work stoichiometrically but not be regenerated without iron.

Content Goal Challenges: While this experiment clearly demonstrates that catalysts facilitate reactions, getting to catalysts participating is more of a conceptual leap. The experiments mentioned above can demonstrate this but students may need some encouragement to pursue this line of inquiry.

Facilitation moves to elicit learners' thinking:
Ask students to explain what they are doing and why. Ask students to describe what they have seen, encouraging objective responses before asking them to infer what it means "What do you think makes the solution change color?", "What do the different colors represent?", "What affects how long a color is observed?" Ask students to keep notes on their observations and ideas in their notebooks

Facilitation moves to reach content goal:
In addition to above, encourage students to draw a representation for what they've observed. If they suspect the metal is the catalyst, ask them what they think this means and how they can test it. Getting them to reuse a solution can help them understand catalyst is regenerated.

Practice Goal Challenges: The biggest challenge will be getting the students explanations in the graphical form we are looking for at the end of the activity

Facilitation moves to reach practice goal: Ask the students how their observations translate into an explanation. Encourage the students to draw a representation of their observations, based on what they saw in the introduction.

Supporting Equitable Learning: Encourage all group members to offer up explanations. If necessary direct questions at specific members.

<u>Catalyzed Hydrolysis of Starch by Alpha-Amylase</u>

Based on http://www.nsta.org/highschool/connections/200809ASalivatingInquiryExperience.pdf

Section Author: Maxwell Fisch

Materials (Per Group):

(Several)	Large test tubes
(1)	Water bath at 37°C (via hot plate or bunsen burner)
(1)	Water bath at 100°C (via hot plate or bunsen burner)
(3)	disposable pipettes (for water, iodine, and amylase)

Approximate chemicals for one (1) reaction:

(2mL)	Saliva
(¼ to ½)	Corn starch packing peanuts
(2 drops)	Lugol's iodine solution
(2mL)	Benedict's solution

Chemical Description and General Methods: Alpha-amylase catalyzes the hydrolysis of starch molecules into maltose. Lugol's iodine solution functions as an indicator for starch; it is dark blue-black when starch is present and turns light yellow when starch is absent. Amylase is added to a solution of starch and Lugol's iodine. Students will note that over a period of a few minutes, the iodine indicator will turn from dark blue to clear, which indicates the catalytic hydrolysis of the starch to maltose. Students can then add more starch to solution and will find the catalyst to still function.

Possible Investigation Routes: A solution of DI water mixed with iodine and a starch solution with iodine will be used as reference samples. Students may alter three variables in this lab; the concentration of starch, the concentration of amylase, and to what extent the reaction can be repeated.

Students will find that without amylase, starch will not break down on a reasonable timescale. Thus they can deduce that catalysts **participate** in the reaction. Students will notice that should more starch be added to the solution, the new starch will be hydrolyzed without the addition of extra amylase. There is a bit of a jump to make here, but one could argue that this suggests the catalyst is **regenerated** in the reaction.

Content Goal Challenges: This experiment shows that catalysts **participate** in reactions and, through critical thinking, that they **regenerate** as well. Because starch does not readily break down on its own, observing the facilitation aspect will be more difficult if not impossible.

Practice Goal Challenges:

Supporting Equitable Learning: Experiment uses mostly household items and therefore eschews the connotation of chemistry as an otherworldly entity.

Facilitation move to elicit learners' thinking:

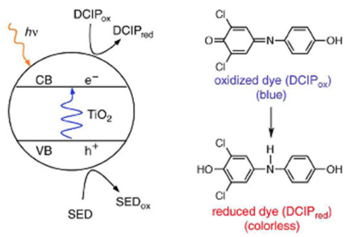
Facilitation move to reach content goal:

Photocatalysis using Sunlight
Megan Chewy

Materials
Per group

(12)	test tubes (4 sets of 3)
(12mL)	DCIP (2,6-dichlorophenolindophenol sodium salt hydrate)
(60mL)	water
(2.7g)	glycerol
(40mg)	TiO2 (~21nm particle size)
(40mg)	SiO2

Chemical Description and General Methods
Students will experiment mechanism of DCIP dye degradation by a phtocatalyst TiO2. Upon irradiation, an electron is promoted from the valence band into the valence band, which are then used to reduce the DCIP. The students will observe in 30 minutes, the blue dye will turn into its clear reduced form. The demonstration will show the degradation of the dye is dependent on both light and catalyst.



Possible Investigation Routes
Students have several paths to towards understanding the mechanism of the dye degradation. Students can study the effect of light by placing their test tubes in varying amounts of sunlight to dark, and monitor the color change of the DCIP. Students can also change the amount of catalyst used in the reaction and monitor the rate of the reaction. Students should determine that catalyst loading is directly proportional to the rate.

Content Goal Challenges
This experiment demonstrates that catalysis **facilitate** chemical reactions. However, the understanding of concept of **participating** in the chemical reaction will most likely be achieved though facilitation of the team!

Practice Goal Challenges

Supporting Equitable Learning
Unless you're blind, everyone can participate. (i.e. WEAR YOUR SAFETY GLASSES, CAROL)

Thinking Tool:

This activity will demonstrate a chemical reaction pathway with students taking the roles of reagents, transition states, and products. We'll introduce a change that makes a step easier or faster, causing the "reaction" to be faster. The students will be engaged in a relay race where they will have to transfer 2000 ml of water. The students will be broken up into four groups of six (if some students don't attend then students can be given multiple beakers to hold).

"Hey everyone! I hope you all had a lot of fun last Saturday exploring your different chemical reactions. Like we said last week, there is a general unifying theme to all of the experiments, and we wanted to do a fun exercise that may also be helpful when you're thinking about what could possibly be happening in your experiments. We are going to be doing a fun relay race where the goal is to transfer 2000mL of water into this bucket. We will be giving you one 50mL, 100mL, 600mL beaker and one 125mL erlenmeyer flask. For the first time, you must stand in a specific order. You will have the opportunity to change order after this, so pay attention to what is happening, what is making you successful, as well as what is causing your group difficulties.

Great! Now discuss with your group how you want to rearrange and we will do this again!

It seems as though you figured out that no matter where you place the 50mL beaker, it takes the longest and is determining how fast you can transfer all of the water. So now we are going to help you guys out a little more. Each group will be given two 250mL beakers. You may put these in any location you choose but there can only be maximum two people side by side. Each beaker must be used and be poured into individually.

Good luck!!!!

Exercise 1 - basic reaction and learning the task: Each group will be arranged in this order (students holding beakers or timer)

[Water Bucket] (100 ml) (50 ml) (600 ml) (125 ml) (2000 ml) (timer) x 2

let them rearrange any order x2

Then we'll

[Water Bucket] (100 ml) (50 ml) (600 ml) (125 ml) (2000 ml timer)
(250ml x 2)

Next, we will introduce these "intermediates" by changing the size of the beakers. This will demonstrate that not all parts of the reaction are equal. There is a rate limiting step; one one part of the reaction determines the speed of the reaction.

Finally we will introduce a catalyst to the reaction. This can be done in multiple ways. We will provide other materials, such as additional beakers and rubber bands. Other variables that can be changed are the placement of students. They could potentially stand closer together, or have another student help at one step. These "catalyst" would facilitate the faster transfer of water.

To me, this was the biggest shortcoming of our activity. Although students were engaged and many enjoyed this activity, I think the opportunity to use it to teach something was lost. Many students didn't know *why* we had them do this and never made the connection from this activity to their own investigations. The initial contexting was intentionally left unclear so the students could focus on the activity and having fun, but I feel as though a little more could be said. The biggest issue with this lies in the discussion that followed the activity. There needs to be a better way to bridge from the activity to their own investigations. I think it'd be good to related this back to the s'more analogy and the two demonstrations we showed them on the first day. Not only would it build upon something they have seen already, but it would give them a clear indication of what the thinking tool was supposed to relate to.

Bridge to Culminating Assessment Task: Jigsaw

Students are broken up into their four Jigsaw groups according to letter (A, B, C, or D). Each jigsaw should have 6 to 8 people and no two people should be from the same experimental group. One person from each experiment should be represented in the jigsaw. Students and one facilitator gather in a circle and the facilitator begins the conversation. An example prompt is given below.

Contexting: *We are going to participate in what is called a "jigsaw discussion". In real academic and and industrial settings, professionals must be able to share and discuss information before results are conclusive. This allows us as scientists to brainstorm and to* ***explain phenomena using evidence****. The purpose of this meeting is to share our experimental observations (what we did, what we saw, what we expected, etc) and integrate those observations into a framework that may be used to explain the strange chemical phenomena we saw yesterday. Everyone will have 2-3 minutes to summarize what they did and what they saw. Afterward, we will discuss similarities and differences and begin to explain these phenomena. Each person in the group has one piece of the total picture so you will all need to work together and contribute to come to a greater understanding of what you all observed.*

Question for Group to Discuss: *How do you think a catalyst works? What did you do or see that supports your explanation.*

Visual aids like chalkboards or giant post-it notes may be used to facilitate discussion. Encourage students to address each other by name. Make sure students criticize ideas and choices and do not criticize people. (e.g. Don't say "I think Max is wrong", say "Max's explanation is insufficient because…") After the 40-minute session, students should have at least one working model of how catalysis works so that they may bring that/those model/s back to their experimental group for the culminating assessment task.

At the end of the session have one representative from each of the four jigsaw groups share a few sentences with the room about what their jigsaw group found and concluded before regrouping.

Culminating Assessment Task:

As a culminating assessment task, the students will synthesize their observations from the experiments and jigsaw and make a poster that explains their findings. The poster will then be presented to the rest of the class.

Contexting:
There are three sections of active learning in this lesson. Explain to the students that first, we explored phenomena through experimentation, found empirical evidence, and used that data to inform future experiments. Next, we corroborated information from others in the jigsaw, as real scientists integrate new information from others to reevaluate their hypotheses. Finally, as a scientist, one must **synthesize** their thoughts, ideas, and observations and **communicate their findings** effectively, as information that is not communicated does not exist, for all intents and purposes. Therefore, the students must find a way to explain their particular chemical reaction and disseminate their findings to the rest of the class.

Content Prompt:
The prompt should indicate:

- Students are to return to their original experimental groups
- They are to make a poster that explains their particular experiment using the concept of a catalyst
- The presentation MUST include
    - Scientific observations from their own experiment
    - Aggregated data from the jigsaw
    - Corroboration of their experience, others' experience, information given in background lectures, previous knowledge, analogy from the thinking tool
    - An explanation of how a catalyst works supported with evidence
    - Words
- One poster is presented per group, and EVERY student must present at least one part of the poster
- Each presentation should last 3? minutes, with 1-2? minutes for questions.

An example prompt is given below:

"As your scientific exploration culminates, you, as a scientist, must be able to communicate your thoughts and ideas effectively. Science that is not communicated does not matter. Hence, we will all regroup into our original experimental teams. In your team, discuss the ideas that were shared in the jigsaw. Next, thinking about your personal experiment, the jigsaw, the thinking

tool, our lectures, and any prior knowledge you may have about chemistry or catalysis, make a poster to summarize your current explanation of how a catalyst works with an emphasis on how your specific reaction works. Your group will make a 5 minute presentation with your poster, and every group member must contribute to a scientifically rigorous part of your presentation (Sorry, just saying the title of your poster does not count.). As a scientific researcher, you must make sure all of your explanations can be supported with experimental evidence or evidence from your jigsaw. To test the strength of your explanation, try asking "how do we know that?" or "why do we think this?" after every step of the explanation. You will have about an hour to make your poster with your group, so plan accordingly. If you would like any clarification or input, please contact a facilitator. Have fun!"

Useful poster-making tools include

- Large pieces of paper or giant post it notes
- Sharpies and highlighters of various colors
- Rulers and/or straight edges
- Hands with opposable thumbs

Synthesis:

(Chris)

Contexting

The goal of the synthesis will be to bring together everything the students learned, make sure that the students can again hear and see the content and practice goals, and to bridge the lesson to the broader impact of catalysis in daily life and sustainability.

"Thank you for sharing your posters and everything you all learned with us. To wrap up this activity I will be giving a short presentation, reviewing what you discovered and showing the applications of catalysis"

Presentation

The body of the synthesis will be delivered by a powerpoint presentation. The first slide will go over the key points of catalysts as per our content goal (catalysts **facilitate** chemical reactions, **participate** chemically, and **regenerate**). During these slides we'll reinforce that these are the topics the students learned and that they came to these conclusions using the practice goal of **constructing explanations** via **identification, assimilation,** and **inference**.

The next four slides will go over the reactions that occurred in the individual investigations, pointing out the aspects each team discovered and showing the complete chemical reaction. This will allow us to also reinforce each teams individual contributions.

The next three slides will give examples of real-world catalysts to show how this knowledge is applied in very wide range of fields: an example in industrial chemistry, medicinal chemistry, and daily life.

This will segway into the next two slides about sustainability and the role of catalysis in green chemistry. This will allow us to also reinforce that constructing explanations will be a part of furthering this important field to develop new, more effective, and greener catalysts.

Equitable and Inclusive Design and Facilitation

List a component of your activity that you have decided to consider from an Equity & Inclusion point of view:

Jigsaw and poster session

How might differences in learners' background have an effect on how they engage with this component?

Gender - Gender will always play a role in science education. Science is largely seen by society as male dominated and, because of this, women are entering the classroom with poor self-efficacy and are therefore less likely to participate.
Cultural - Some learners may be less likely to question their peer's opinions, beliefs, or observation due to individual cultural norms.

How have you designed this activity component to maximize equity and inclusiveness?

During the jigsaw activity, we have decided to give everyone the opportunity to talk by having them go around the circle and state their name, the experiment they worked on, and any important observations they made. After making their way around the circle, they could start discussing their results and, as a facilitator, we could encourage each person to contribute. For the poster session, we'll give everyone the same time limit and ask that everyone in the group are given equal time to present.

How do you plan to facilitate this activity component to maximize equity and inclusiveness?
See above.

Assessment

Content learning outcome (see Goals "Four Filters" Design Tool):
Students will be able to identify a catalyst as a chemical that **facilitates** chemical reactions, **participates** chemically, and is **regenerated** so that it is not consumed. Each of the starters and investigations are specifically designed to highlight each of these points. By demonstrating proper experimental technique with the starter, students will be able to design their investigations accordingly to discover the content goals.

Content prompt for culminating assessment task:
Integrate your observations of catalyzed reactions and explain, using a diagram, the significance of a catalyst in a reaction. Keep in mind what you have learned from the exchange of information with your classmates.

Rubric:

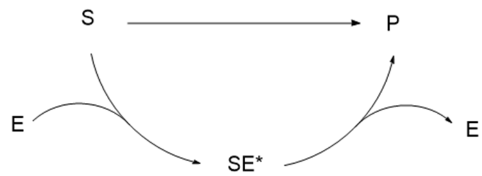


Diagram A - Example of Student reaction network

Evidence of understanding	0 (didn't show)	1 (partially shown and/or partially correct)	2 (showed correctly and completely)	3 (showed with some extra nuance)
Diagram with substrate, product, and catalyst		Missing anything, incorrect relationships, extraneous info	see diagram A above	Energy diagrams
Catalyst participating and being regenerated		Catalyst shown to be regenerated but not active, or vice versa	Catalyst is shown participating and being regenerated	
Students should be able to verbally explain the proper relationship between the components		Explains mostly in layman's terms, little scientific language.	Uses correct terminology, makes connection between observations and explanation.	Uses concepts of activation energy, multiple reaction pathways,

Practice learning outcome (see Goals "Four Filters" Design Tool and Articulating Practice Goals Design Tool):

Students will **construct an explanation** (practice #6 from the framework) of catalytic mechanisms by assimilating observations and data from catalyzed reactions. More specifically, students must **identify** pertinent aspects of reactions, **assimilate** new observations with previous chemical knowledge, **infer/postulate** unseen steps, (and **construct** a coherent framework to **explain** a reaction.)

Observations:

Practice: Constructing Explanations	**Example of what it looks like when a learner needs to work more on the practice**	**Example of what it looks like when a learner is proficient with the practice**
Specific aspect of practice your students will engage in: Identifying pertinent data to create an explanation	Prior to Teaching: Students present results but do not provide an explanation. Students include steps that disagree with observations or previous knowledge. After Teaching: Students presented observations as if they were explanations. Ignore previous observations or focus on observations that were unimportant.	Prior to Teaching: Students use data to present an explanation. Explanation makes sense based on data. After Teaching: Students took all of their previous experiments into consideration when trying to explain what they were observing.
Specific aspect of practice your students will engage in: Assimilating previous chemical knowledge to inform explanations	Prior to Teaching: Students base explanations solely on observations. Students ignore physical laws (e.g. conservation of mass) After Teaching: Data from previous experiments was forgotten/ignored when setting up next experiment or forming explanations. Many students didn't draw upon lessons from thinking tool/lecture to explain things.	Prior to Teaching: Students accurately use general chemical knowledge to explain specific situation After Teaching: Some of the students with previous chemistry experience were able to use terms accurately in their explanations. Students also were able to use terms introduced from the initial lecture within their discussions.
Specific aspect of practice your students will engage in: Infer and postulate unseen steps	Prior to Teaching: Students do not acknowledge holes in explanations. After Teaching: Explanations were had a few holes in them but were not acknowledged by the groups.	Prior to Teaching: Students use inference to form hypotheses about unobservable phenomena After Teaching: This was not truly seen in this activity.