

GOOD PRACTICES FOR ONLINE SCIENCE CLASSES
WITH EXPERIMENTS

by

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ABSTRACT

Research into the question of what makes good online science classes with labs is the basis for this paper. Good online science classes are organized carefully and clearly. They find ways to adapt and apply all the principles of good science education including making predictions, considering outcomes, asking questions, and testing novel ideas. Finding and guiding students in activities with real physical objects, using technology to pause the students and enable them to make predictions, and providing vibrant, active discussion boards can make these classes as effective and interesting as live classes.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

Online Teaching

Walking across campus as a new student, you hesitantly look at every building. When you think you have found the right one, you walk all the way around it, looking for the entrance. Once in, the long hallways and endless doors look overwhelming. When you finally find a door with the number on it you are expecting, the lights are off and the chairs are all stacked along the wall. You enter and see a pile of syllabi on a desk near the front. You pick one up and wonder what to do next (Darby, 2019).

This would never happen in a traditional, in-person class, but it is often the feeling students get in the online environment. Even when you have taken a few classes and have become more acclimated, the next class can be completely different, throwing off your newly acquired rhythm.

Online classes are becoming increasingly popular. They are crucial to the success of many students who have jobs or families or other responsibilities that make traditional classes difficult or impossible. They have been incredible for me. I could not have done this degree without them. We are very fortunate in the MSSE program. We have teachers who have taken the task of teaching online seriously and set a great example for how it can be done.

A lot of what this paper will do is point out the things we have already seen, helping us see the work behind what we experience as well as providing examples and samples of ways to

do this for high school or undergraduate classes. Good online classes are not that different from any good classes, but sometimes the steps to get the results are different.

Background and Purpose

I currently teach math and science classes for an online private school. We have students from 5th through 12th grade. One distinctive aspect of our school is that we have live class twice a week for a total of three hours. Most new online classes, especially for the college level, are asynchronous since students are not able to attend at scheduled times. These classes need to be first of all good classes, then good online classes. They also need to be good science classes, and for many of them, good science lab classes. To be the latter, including inquiry and experiments in the classes is imperative, though difficult. To really learn science, the students must do science.

Not all of us will teach online, but looking at what makes a good online class has had me looking more closely at things that can help any class. There is a growing body of literature on studies with online classes. We will look at that in the broad context of good teaching, online and in person, then narrowing to specific options for good online science teaching with labs.

CHAPTER TWO

CONCEPTUAL FRAMEWORK

Best Practices for Online Classes

At its core, online teaching is no different than any other teaching. How the class is organized, how the teacher connects with the material and the students, and the ways resources are used all affect the quality of the class. According to a recent study, there are four major indicators of the quality of an online class: the course organization, the alignment of course objectives with the actual materials, interpersonal interaction, and technology (Fischer, McPartlan, Orona, Yu, Xu, Warschauer, 2022). We will look at each of these areas.

It is hard to underestimate the importance of how an online class is organized. Students in traditional classrooms have the familiar pattern of entering the room, sitting in a desk facing the front, and expecting a teacher will tell them what they are to do. Students in online classes often have trouble accessing the classroom and are still lost once they get there. Careful, complete organization to help them find their way is a crucial foundation for a successful online class.

Steven Nagel, an online class designer for Ohio State University, encourages teachers to think about the layout of their course pages like they would think about the layout of a physical room and carefully consider how to make it most accessible and helpful to students. He also encourages laying out a map of the course content using infographics (Nagel, n.d.). Even if the students never see it, they will feel the clear path of the course. This example is one I developed for a section of a physical science class.

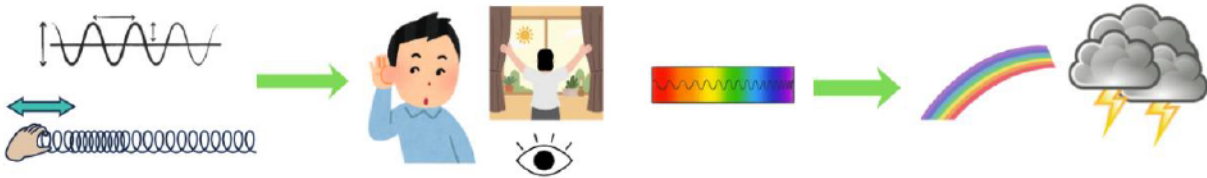


Figure 1. This infographic depicts how a section of a physical science class will go from the types of waves to sound and the ear and light and the eye, then to light from the sun and applications in weather.

Part of organizing the course with clear direction is developing clear objectives. Some of these will come from the institution and text, but it is important that you as the teacher make them your own. “Especially in online learning environments, where students are expected to study more independently, carefully choosing and presenting a course’s learning objectives is important.” (Fischer, et. Al., 2022, page 3). Continue by showing all along the way how the course content ties clearly to the objectives. Having a clear path in your mind as the teacher is crucial, but not enough on its own. Showing the student the connections between what they are doing and the goals of the class helps them stay on track and make the important connections on their own. Precisely stating the objective tied to each activity and making assessments align with these objectives contributes to students’ success. This is so important that there is even a website available to help evaluate how you are doing on this alignment which leads you through the process of making sure you have clear objectives that carry through the class, providing a strong structure for learning (Quality Matters, n.d.).

In looking at the physical science section pictured above in Figure 1, the first objective is seen in the first image: students should to be able to differentiate between transverse, specifically electromagnetic, and longitudinal waves. This is a valid objective and can be tied directly to

providing information about the differences in construction of the types of waves. It can also be tied to activities where the different waves are modeled with slinkies.

But why do we care if a wave is transverse/electromagnetic or longitudinal? This first objective needs to lead to other objectives that have some bigger purpose in the end. One over-arching objective I chose for this particular class was for students to see connections between the principles of physics and the way they experience things happening in the world. Physics is very useful! Getting students to see that is an over-arching goal for me.

With this bigger objective in mind, we move on to examples of each type of wave: visible light for transversal/electromagnetic and sound for longitudinal. The energy that comes in the form of a light wave has a very different effect than the energy that comes from the compression/longitudinal wave through the medium of air that is sound. The back-and-forth movements of the molecules of the medium make sound waves transfer energy in very specific ways. A simple lab or demonstration can be made using a plastic bottle with the bottom cut off and replaced with rubberbanded plastic wrap. Holding the open end of the bottle towards a candle flame and flicking the plastic bottom will make sound/compression waves travel through the bottle, and if all goes well, put out the flame. This lets the student see the effect of a sound wave and helps lead to the next step in the objectives. Details of this experiment are in the chapter on experiments and sample lesson in Appendix A.

Sounds waves are what we hear. Understanding them better lets us look at our own experience more deeply. Our hearing is an amazing mechanism that starts with the eardrum vibrating with the compressions of the sound waves. When we start thinking about all the things we can distinguish in sounds like pitch, volume, length of a tone, we can tie that back directly to

the construction of the wave that we started with. Different amplitudes give us different volumes; different frequencies give us different pitches. That all leads us to the importance of the speed of the wave, which also impacts the frequency. Sound can travel at a lot of different speeds depending on the medium and the speed of the object emitting the sound.

So now we have gotten to hearing music, understanding words, why the pitch of a siren changes as the vehicle passes you all from understanding somethings about longitudinal waves. We can do a similar trail with visible light and our eyes, then extend that to non-visible light. The last picture on Figure 1 shows a way to bring the waves back together. The rush of negative charge to positive charges that happens in a thunderstorm sends out both visible light waves and audible sound waves. Because of the different characteristics of those waves, they reach us at different times. Knowing that time difference, and the temperature of the air, can give us a very accurate calculation of how far away the lightning strike occurred. Interesting, but also potentially lifesaving.

Good objectives, well communicated lay a firm foundation. Building on that with as much personal interaction as possible makes the class stronger. When a class is completely asynchronous, this must be purposeful. Flower Darby in her book, *Small Teaching Online*, points us to research about the value and importance of learning together, from each other, as well as from our instructors (2019).

Messages sent before the beginning of the class offering helps to getting started well in the class initiate a good connection. Having places for students to interact with each other and demonstrating that you are engaged with that as well helps create a connected, supportive environment. The tried-and-true method for this is discussion boards. Thinking through the

prompts carefully and encouraging debates, opinions, additional insights and personal experiences can give students ways to respond that engage them. Being present often and thoughtfully, responding to what students have said and with knowledge of who they are, helps students want to engage as well. In some ways, online class discussions can be even better than live classes. The problems of time limitations, dominating students, and large classes can be avoided (Darby, 2019).

The last element identified as crucial for a great online class is the technology. What you have to work with will depend on what platform the institution you are creating the class for uses. This paper will not address specific platforms but will address helpful technology things specifically applied to science labs in the next sections.

Best Practices for Online Science Classes

Having a good online class is a great start, but not enough. It also needs to be a good science class. Science is something we do, not just learn about. One of the weaknesses of online science classes is the limitations for labs. However, there are some good options. There are a lot of lab things that can be done with everyday materials. The advantage of this is it brings science into real life. Fancy lab equipment has its place, and science students should learn about it and have opportunities to use it when possible. But science is a human endeavor to know about the world we live in. Using everyday items keeps this before us. Science is for everyone, not just white coats in labs.

Seb Falk in his book *The Light Ages* reminds us science has always been a human endeavor and not clear-cut. “Understanding the history of scientific ideas in their proper context – seeing the science first through the eyes of the people who made it – allows us to appreciate

that science does not progress in a straight line.... Scientific understanding has sometimes hit a dead end, or taken a step sideways, or backwards. And it still can.” (p. 9).

Mostajo-Radji (2025) lists several studies and points out a clear pattern of students being able to learn science content, but not learn to think and problem-solve like scientists unless they are involved in direct experimentation. Observing the scientific process is just not the same as doing it.

When possible, directing our online students in real experimentation with real objects is best. There are, however, some online lab connections that give students real data and experiments to work with, as well, that are proving beneficial to students. Some of these are listed in Appendix B, along with other sites for lab ideas and other demonstrations. The next chapter gets into the specific strategies and resources that make our online classes also good science and good lab experience.

CHAPTER THREE

INSTRUCTIONAL STRATEGIES AND RESOURCES

Science Inquiry

Science is about inquiry and exploration. This is one of the reasons why actual experimentation is important. Science is something we do. Not everyone will be a scientist in the modern sense, but everyone lives in the world science explores. Trying to understand and appreciate the world we live in is part of our heritage as humans.

Michael Faraday was one of the most eminent scientists in history. He grew up in a poor family and had very little formal education. He began working at a very young age but was fortunate to work for a book binder. He read every book he could and make notebooks of the things he learned. A wealthy patron noticed the detail of his notebooks and felt that anyone trying that hard should have a chance. He got him a ticket to lectures given by Sir Humphrey Davy, one of the great scientific minds of the day. Seeing the notes Faraday took on those lectures convinced Davy to hire him as a bottle washer in his lab. Faraday absorbed all that was going on around him and was soon a prominent scientist himself. His discoveries in electromagnetism were instrumental in changing the world (Michael Faraday, n.d.).

But Faraday never forgot where he came from. His heart was for everyone to have access to the understanding he and others were finding. He started the Christmas Lectures at the Royal Institution in 1825 as one way to bring science to everyday people, especially young people.

They have continued to this day, only missing a few years during WWII (History of the Christmas Lectures, n.d.).

Faraday is a great inspiration and reminder that though most of our students will not make science a profession, they will live in the world that science explores. Learning to think in ways that scientists do, having a curious interest in how things work and what will happen when we try things differently enriches any life. And no one knows when the next Faraday will show up in one of our classes.

There are specific things we can do as teachers to help students learn to be inquisitive as well as retain what they learn better. In talking about small changes that can have big results, Lang talks about the power of predicting (Small Teaching, 2021). He encourages teachers to stop in a video or demonstration or introduction of a new idea and ask students what they think is going to happen based on what they already know. The effectiveness of formative assessment and checks for understanding apply online as well. One study showed a statistically significant increase in test scores when formative assessment strategies were used in an online accounting class (King, 2023). It takes a little more forethought and creativity, but most online platforms have a way to force a response to a prompt before students can move on. Choosing where to put these and how to word the prompt is worth the time invested. The University of Massachusetts offers several other methods for formative assessment and predictions for online classes (University of Massachusetts Amherst, 2024).

One place I have done this in my live online classes is with kinematics and motion. In Physics 1 we start with basic motion problems. After learning about displacement, velocity, and acceleration in horizontal motion, we start dropping things and tossing them straight up in the air

and learn about the acceleration of gravity and what it does to the motion of the object going up and coming down.

When we have reviewed these things, I ask them what will happen when a ball is shot straight up in the air, but from a cart moving at a constant velocity horizontally. We talk about the possibilities for where the ball could land: behind the cart, in the cart, in front of the cart, somewhere else. Volunteer students advocate for different options, applying ideas from what we have already learned and their own understanding and experience. This is one place where having class online is an advantage. In my live class, I wait until everyone has chosen an answer in the poll box. This can be accomplished in a classroom with clickers or even colored index cards. According to research Lang reports on, it is better if the votes are not seen by other students so each person can evaluate the ideas on their own and not be overly influenced by others' votes. Total anonymity, so not even you as the teacher know who is voting for what, can make some students feel better about venturing a guess (Lang, 2021). I do broadcast the anonymous votes after everyone has entered a prediction so they can see what the spread is before we find out what is correct by doing the actual experiment.

My experience aligns with the research Lang includes in his original book, *Small Teaching*. Students remember better when they have tried to predict what will happen even if their prediction is wrong, maybe especially if their prediction is wrong. Lang points the reader to Stanislas Dehaene's research in his book *How We Learn; Why Brains Learn Better Than Any Machine...for Now*, that concludes that the basic model for any learning is making a prediction, finding the error, and correcting oneself. Allowing students to do this before we just tell them

that correct answer is a gift for their learning and enjoyment, but also for their growth as scientists.

Some of the best discussions we have after making predictions and seeing the actual results are about our surprise at those results. Students always have a model of what they expect to happen, though they may not be conscious of it or able to articulate it well. We all have preconceptions about how we think the world works. These intuitive ideas about natural phenomena are often inconsistent with scientific concepts and even with each other. They are usually resistant to teaching interventions and require identification to aid in the acquisition of scientific concepts (Vosniadou, 2019). Making a prediction and seeing things happen very differently often is the key to revealing those preconceptions so they can be corrected. The unpredictability of so much of what happens in our world is one of the joys of science. The complexity of the interactions of multiple phenomena happening at the same time opens all kinds of questions for investigation. When is friction actually negligible? How does motion in one dimension affect what is happening in other dimensions? What causes the period of periodic motion to change? Cookbook-type lab experiences can give students the illusion that science is straightforward and predictable. More open exploration gives a better taste of reality.

Science Experiments at Home

This leads to the question of how we as teachers, and specifically online teachers, can assist in this curious engagement. Guiding inquiry when students are together in a classroom and you as the teacher have complete control over the order in which they do activities is one level of challenge. Doing these things online adds another layer. Fortunately, the platforms used for online classes offer some helpful tools. The teacher can put a stop in a video whether it is of

themselves leading the discussion or a demo video from someone else. At that point, the student must enter a response to keep going. This response could be a blank to fill in with a short answer or a multiple choice question. Ideally, if the question is multiple choice, you would also add a prompt to ask why they chose what they did. Research shows coming up with their own words is best for learning (Lang, 2021). It doesn't matter if the prediction is wrong. What matters is the thought that went into it, and the element of surprise when the true answer is revealed. Even if the person guessed right, it will still be a surprise. If it wasn't a guess, then they didn't need this learning experience. It is important that the true answer be revealed as possible to the predictions as possible.

Websites for Content and Exploration

There are many places to find ideas and interactions for students. A lot of them are videos or simulations that give information. These can be very helpful and interesting, but are not usually designed for predictions or inquiry. As noted before, an online platform that allows for stopping videos and forcing a response before continuing can turn these demonstrations into more prediction and inquiry activities. Simulations can be set up with guiding documents that have the student trying specific tasks and answering questions about what happened. Some of our MSSE classes have done this very well. Ben Spicer's physics GISEs are a great example of guided learning using simulations.

There are other sites that have activities that involve asking questions and trying different things to answer them with real objects. In the section on objectives, we talked about an experiment with sound waves. There is an especially good way to do this explained on frugalfun4boys.com. The original setup has you cutting the bottom of a plastic bottle off and

replacing it with a piece of a plastic baggie. The baggie piece is then flicked to make a sound wave while the top of the bottle is held close to a lit candle. If it is close enough, the flame should go out. But the website author points out if you are watching carefully, you should note that there is a puff of air, raising the question that maybe it isn't the sound waves that are affecting the candle. She encourages trying the same thing again, but this time replacing the baggie with cardboard over the bottom. Setting up a guided experiment something like this could be an excellent inquiry lab for students. Details on a lesson plan for this are in Appendix A. The following photos illustrate this possibility.



Figure 2. Plastic bottle with the bottom replaced with a part of a plastic baggie being flicked to put out a flame with sound waves.

This next picture shows how observations can lead to a question and the opportunity to try something else.



Figure 3. Plastic bottle with the bottom replaced now with cardboard and being flicked again to put out the flame with no air puff.

This particular resource is from a homeschool mom. Often homeschool websites are excellent resources for online class options. The activities are designed specifically to use common items to demonstrate important science phenomena.

Another excellent source for meaningful labs without elaborate equipment is the website Science Buddies, sciencebuddies.org. They have over 150 different activities across all science areas. Since I teach in the physical sciences, my search focused on those. Science Buddies has some different options for creating roller coasters to explore energy exchange from potential to kinetic and the effects of friction. They offer a paper option that just uses cardstock and tape. There is another that uses foam pipe insulation for the roller coaster. There are many ways to use inquiry with these. How high must you drop the marble from to make the loop? Who can make the slowest roller coaster?

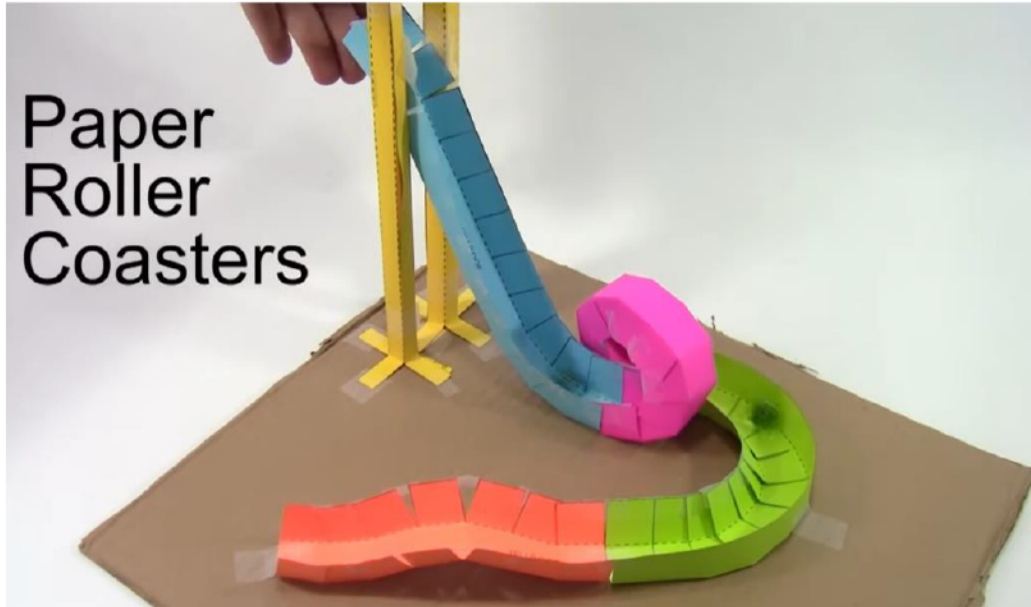


Figure 4. Paper roller coasters from sciencebuddies.org. Different heights and loops can be compared. The goal is to see the effects of potential energy converting to kinetic energy and friction.

Simple materials that can be manipulated, chosen with your students in mind, give good options for questioning and testing.

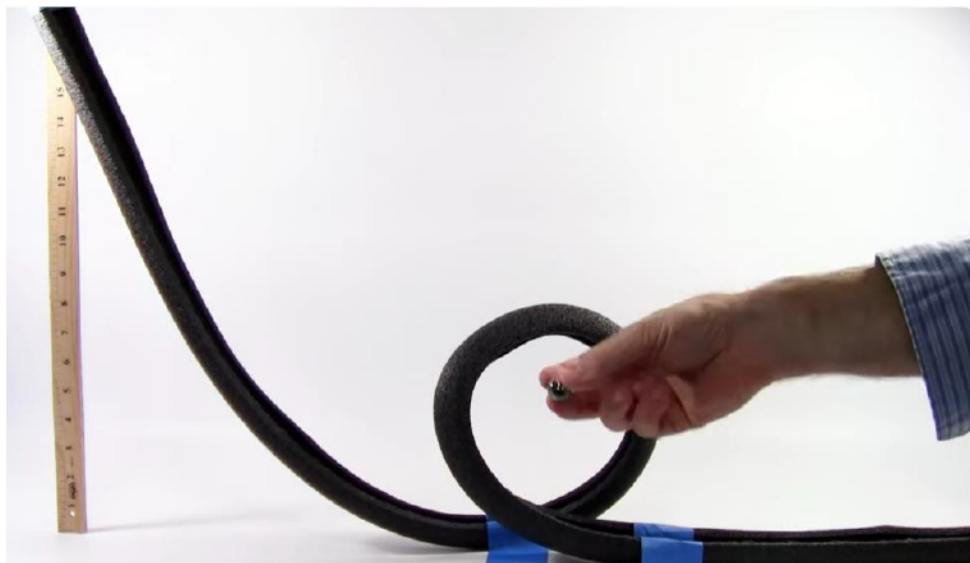


Figure 5. This is another option for roller coasters. How high does it need to be to for the marble to make the loop?

It is good practice to use as many real experiments as possible, but adding demonstrations and more cookie-cutter activities has its place. These are especially effective if there is an opportunity to apply already acquired knowledge to a prediction of what might happen next.

CHAPTER FOUR

VALUE: REASONING AND REFLECTION

Summary and Changes to My Teaching

We have looked at the importance of organization, community, and technology on our online classes. We have considered the crucial pieces to include to make them truly science classes with inquiry and predictions and questioning built into the activities.

This has caused me to reflect on my teaching and consider some ideas and options. The book *Small Teaching* has especially directed my reflections. Sometimes we do not have control over what activities and labs we do with our class, but often little changes in how we do them can radically change the outcome. Inquiry learning can be done in almost any activity. Taking the time to probe students' thinking before a new activity or concept is introduced sets them up for optimal interest and learning.

Teaching online is different. It is not as different when you have live class times. The teacher can still easily direct inquiry, and lab activities can be done together with conversation along the way. Teaching online asynchronously is more challenging. However, there are a lot of resources available for lab activities that can be done with just household objects. Carefully timed interactions can enable the student to still enjoy the benefits of prediction and consideration of expectations before doing or seeing the final outcome. Organizing the class well and considering how the pieces on the screen fit together as well as the way the science ideas

flow together, then making these things clear to the student will greatly enhance their success in the class.

Science is constantly surprising us. We can be confident in some things that just aren't true. If we knew which ones they were, we would change that! At best, even where what we know is correct, our understanding is always incomplete. This world is beautifully complex. Helping our students experience the surprise and explore the complex interactions can prepare them to be the discoverers of the future. It can also help those who will not pursue careers in anything science related. Better understanding of the world we live in is a privilege all humans should have.

Where Can You Go From Here?

If you have the opportunity to teach an online science class, I recommend you take it. It is different and takes a little getting used to, but the ability to connect with and help students who would not be able to attend a regular class is exciting. As you start looking at some of the options listed here, exploring other websites, and rethinking the activities you already know and have, you will find many things that can become wonderful inquiry activities with just a little tweaking.

Taking the time to think through your big objectives, breaking them down into the pieces needed to accomplish the big goals, organizing those objectives and the activities into a clear sequence, and showing the path clearly in your syllabus and learning management system will set both you and your students up for a profitable and enjoyable experience. As you continue to engage as much as you can personally and optimize the tech to your advantage, you will build a quality addition to the growth of your students and your institution.

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APPENDICES

APPENDIX A: SAMPLE LESSON PLAN

Lesson Plan: Physical Science Waves, Lesson 4

Lesson Overview

- **Objective:**
 - (1) To help students see connections between the principles of physics and the way they experience things happening in the world
 - (2) To
 - **Standards Addressed:**
(Identify relevant state or national standards that this lesson meets, ensuring alignment with curriculum goals.)
-

Materials Needed

- **Supplies:**
 - plastic bottles
 - scissors
 - ziploc type baggies
 - tape
 - small candles
 - matches
-

Lesson Structure**1. Introduction:**

Can you blow a candle out with sound?

Review waves – specifically longitudinal/compression waves; sound is a compression wave

2. Procedure:

- **Cut the bottom off the plastic bottle**
- **Cut a large circle from the baggie and tape around the bottom of the bottle**
- **Hold the bottle with the opening towards the lit candle**
- **Flick finger on the baggie cover**

- **Observe what happens to the flame**
 - **Hold the bottle at various distances and compare the effects**
3. **Consider what is happening and why:**
- **At what point does the candle go out (if it goes out)?**
 - **What else do you observe?**
 - **Is it possible that it is not sound waves but rather the puff of air that comes out of the bottle?**
4. **Consider other options:**
- **Replace the baggie piece with a piece of stiff cardboard and repeat the flicking and observations**
-

Evaluate:

- **What are sound waves like?**
- **Why could they blow out a flame?**
- **Consider what other implications those characteristics of sound have**

APPENDIX B: ONLINE RESOURCES

Websites for Simulations and Experiments

<https://www.fizzicseducation.com.au/science-at-home/>
<https://fizzicseducation.com.au/category/150-science-experiments>
<https://sciencebuddies.org>
<https://frugalfun4boys.com>
<https://www.science-sparks.com/>

<https://phet.colorado.edu/>
<https://gizmos.explorellearning.com/>

<https://www.biointeractive.org/>
<https://www.labxchange.org/>
<https://praxilabs.com/>
<https://www.labster.com/>

Sources for Video Demonstrations and Explanations

– with pauses for responses, many can be made inquiry activities

<https://www.veritasium.com/>
<https://www.smartereveryday.com/>
https://www.youtube.com/channel/UCY1kMZp36IQSyNx_9h4mpCg (Mark Rober)
<https://www.youtube.com/c/physicsgirl>
<https://www.bozemanscience.com/>
<https://www.nasa.gov/>
<https://www.flippingphysics.com/>