Secret Message Masks

60-minute activity by Jeff Nee

Promotional Blurb: “What does a color filter do, and how can you use it to draw and write secret messages? Explore the underlying universe of light and colors in this hands-on activity to make and take home your very own secret message mask!”

About this lesson

In this activity, students will explore light and colors, art and science. They will discover the concept of filtering out colors, as NASA does to image and study space. They will craft a mask that will filter colors, altering the appearance of their artwork, or "secret message." An alternative to the take home activity is the quick, cheaper "tabletop version," e.g. if you're working a table at a festival or STEM night, where you skip the mask craft, providing just a small, color filter square (one eye's worth is perfectly fine) or readily available "3D anaglyph" glasses for the students to take home, then focus your time on students making their artwork/messages. This activity is written for grades 1st-3rd, but the activity itself, the creation and exploration of secret messages is easily scalable to any age/level. Even professional scientists can have fun crafting secret messages with color filters, and we hope you do, too. Have questions or need more content? Email jnee@jpl.nasa.gov.

Learning Objectives/Standards:

- NASA uses color filters to take pictures and study space for a variety of reasons.
- Science is fun, creative, and helps you learn about the world around you.
- For younger children, manual dexterity of crafting a project including tracing, taping and tying knots

Relevant Next Generation Science Standards:

- Planning and Carrying Out Investigations
- Constructing Explanations and Designing Solutions
- 1-PS4-3. Plan and conduct investigations to determine the effect of placing objects made with different materials in the path of a beam of light.
- 1-PS4-4. Use tools and materials to design and build a device that uses light or sound to solve the problem of communicating over a distance.
- 4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen.
- MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.
- HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
- HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Background info:

- Article about Hubble's color filters: https://hubblesite.org/contents/articles/the-meaning-of-light-and-color
- From Space Telescope Science Institute, series of 2-minute videos about color filters and image processing for the Webb Space Telescope: https://www.youtube.com/watch?v=668mx9Ay5Kk&list=PLm0MBdI3VlBVYtifm_shSFhfICogfE91W&index=1
- WFIRST's Wide Field Instrument - 2-minute video with an animation of a NASA color filter wheel: https://youtu.be/s0jxY8MihZM
- Psyche mission's color filters: https://youtu.be/gCmIZ_sZbEM?si=PFI5Yx2xHIKkfr73&t=106

Materials/Setup:

- Media Slides - either printed out, preferably in large format, such as 11x17, or on a projector. Note that these visuals are NOT meant to be presented in a lecture-style format. They are simply visual aids to enhance the interactive discussions and hands-on activities detailed in this write up.
- Secret Message Masks Project (per student, set up at the tables now):
  - Half of a 9" paper plate with holes punched in the sides on the 4th ridge from each cut edge (i.e. about eyebrow height for students)
  - ~3x5" **dark** red filter gel rectangle
    - So-called "medium red" works best, do **NOT** buy "light red," "fire red," or even just "red" for this project. Reputable companies will publish their spectrum and other data. You'll want transmission of less than 5% with as much red and as little any other color as possible.
    - As an extra caveat, it's always best to test the exact filters you're going to be using with the exact markers/screens/projectors/printers that you'll be using for your event.
      - In this day and age, every device manufacturer, every printer, every marker, has its own special color gamut, i.e. one company's "red" is not the same as another companies, and even the smallest difference in color choices can ruin your secret messages.
      - The good news is that it's also easier than ever to fine tune at least your examples to specific shades, hues, and devices as the real "wow" factor that will engage students and show them what's possible. If you need assistance or tips, please email jnee@jpl.nasa.gov.
    - Note that they're usually sold in single sheets. For just a few students, that should be fine (say, $8 for 30 students, or ~$0.25 per student). However, online stores sell it in bulk on large rolls for cheaper if you plan on serving lots of students (say, $140 for 48"x25' rolls, or 960 students, at ~$0.15 per student). Include taxes and shipping in your budget, though many online sellers offer free shipping with larger orders.
    - Optional, maybe get a few other color filters like blue and green for comparison and for older students to explore. See the extensions section below.
    - 3x5" is the recommended size for younger children who are still working on basic dexterity skills. Cutting smaller squares just for eyes (say 1 to 2 square inches) can save money, of course, down to literal pennies per student. They can also work for older students to make the mask crafting extra challenging, e.g. measuring distance between one's eyes, or incorporating other color filter squares into their mask, allowing them to switch between different color filters, just like NASA missions do.
    - See the "Color Filter Gel Alternatives" section if needed.
  - (2) pieces of yarn/string, ~3 feet long. For younger kids, just make sure the string is long enough to reach around their head, even if they tie it right in the middle.
  - One pair of kid safe scissors
  - GOOD roll of tape (i.e. Use the translucent tape that is easy to tear if possible, and only use the stronger transparent tape with metal teeth dispensers so it's easy to tear. I can't tell you how many younger students got frustrated with tape that was too difficult to use, and it's completely avoidable for a great learning experience. Also, since children often have trouble sharing, especially at younger ages, it's just an easy way to improve campers' experience if you give people their own tape, or at most one roll per pair, if sharing is one of your learning objectives.)
  - Assorted Markers - make sure there's a lot of red/orange/yellow/pink/etc.
    - markers work better than crayons or colored pencils, usually,
    - BEFORE your event, experiment with whatever you have, and just make sure you do have a good assortment of colors that will appear/camouflage as desired

- One set of the above materials ready at the carpet/circle time for demo
- Scrap white paper ready for secret messages (give students half sheets of printer paper to start)
- Secret Messages Examples printed out, set to the side, and/or taped up around the room.
    - BEFORE your event, be sure to test the filters you have with the patterns you've selected for demoing.
    - Adjust colors digitally until they appear/camouflage as desired. Remember that printing will look different from a screen!
    - You may also wish to simply run this digitally, say showing on a projector and having students in a computer lab as a digital art activity, but remember that even different monitors can vary in their color reproduction, so still test them!
- Different colored construction paper taped up around the whiteboard/room (to look at with masks later)
- Optional - dark, possibly "blackout," curtains for any windows if you're choosing to do the filter activity of shining red/green/blue light around the room. Note any emergency lighting that you might also want to temporarily cover up for this activity.
- Optional - white board and several dry erase colors
- Optional - You may wish to wear some sort of "secret message" clothing this day. For example blue jeans and a red shirt, or some color patterns, etc. Try the filters you have on pieces of your wardrobe.
- Optional - especially if you can't get any red color filter gels, consider using just a red "party" light bulb found in many stores, or a computer projector, or big TV monitor showing a solid red image (like in the powerpoint, then just turn off/block all other lights/windows). You should experiment as to which lights/projectors/images give the best results in terms of your secret messages.

Presenter Script

Introduction (5 min)

Hello! My name is Jeff, and welcome to this lesson we call “Secret Message Masks.” Whenever we look at anything, there’s a whole bunch of information that we can gather just by looking. However, that information is very often hidden; it’s a secret, but we can use science to see those secrets more clearly. We’re going to learn about one particular tool that NASA uses to look more closely at the universe: color filters.

Optional Alternative: Let me tell you a story. NASA and JPL have always liked to take pictures of things in space, and NASA is very old (started on October 1st, 1958; 65 years old in 2023), with JPL even older (started on October 31st, 1936; 87 years old in 2023). Back when NASA first started, all they had were black and white cameras (or at least the BEST cameras were black and white). So when they sent robots to space, they only sent black and white cameras, but is Mars black and white? The universe is full of color! So how would you make a color picture out of black and white cameras? [Pair-share and take any ideas.] NASA uses something called color filters. Note that even in modern times, NASA still uses black and white cameras with color filters for a variety of reasons.

Have you ever wondered anything about colors or light? Or how NASA takes pictures in space? [Normally we would include a question of “what have you heard about…” but the topics of color and light may be a bit too basic/broad for such a conversation to be meaningful at this stage. And learners may not actually have any “wonders” about this, but this is also a good assessment time to see what interests and prior knowledge your audience has.]

Here I have a quick drawing that I’ve made. Take a look and share with a neighbor what you see.

[Take a few seconds to allow pair-sharing, and get some students to share with the class, if desired.]

Well, there’s a secret message here, and we’re going to use color filters just like NASA does to learn and see more clearly.

Filters (5 min)

What kind of filters have you heard about or do you use at home? How would you describe what filters do? What do you think color filters do? What questions do you have about filters?

[Pair-sharing opportunity or have a broader class discussion. Notice the specific wording of the questions so that there are NO wrong answers! Techniques such as “thumbs up if you agree” or using the silent sign for “me, too” can help every learner feel included in the discussion even if only a few students get to verbally share. Writing questions/ideas on the board can also help. Remember to give proper wait time before calling on someone to share out with the whole group.

Often students will have heard of air filters, as in heating/cooling systems or cars, or water filters such as for drinking water and aquariums. Show the stock images from the media collection and connect those with color filters.]

All filters let some stuff through, the stuff that you want, like air or water, and the filters catch or absorb things you don’t want. Color filters are the same; they let the color you want through but catch or absorb others.

Optional (if you can remove most/all external light and have colored lights or are using a computer projector): We can approximate color filters by simply shining one color at a time. Here, I’m shining just a red light. Take a look around. Does the room look the same or different? Take a look at your clothes. Do you remember what colors you were wearing today? Does it look the same or different? Do you remember what colors I was wearing? Did anything happen to the colors of my shirt/pants? I had put up some different pictures and sheets of colored paper. Do they look the same or different? [Give students a few minutes to look around, encourage sharing with neighbors and with the class as desired. Repeat for green and blue light, if possible.]

So the universe looks different depending on what color light, or what color filter you use. This is how NASA views the universe even today. Here are some images taken by one of NASA’s Mars rovers. They’re all the same picture, but do they look the same? They’re all black and white pictures, but they each used a different color filter. Take a minute to share some observations with your neighbors; what do you see is the same or different? Can you imagine what the real colors are? [Give a minute for sharing.]

Here are those same pictures, but tinted in their respective colors. To get a true color picture, you can combine the different color filter images together, like this. [Repeat with the Jupiter images if desired.]

So why separate the colors? Looking at this color picture is like listening to a song: it’s beautiful and wonderful, but if you want to truly UNDERSTAND a song, say to use it or play it yourself, it’s much easier if you can separate out different instruments and voices to study each component.

One more note before we make our secret message masks: raise your hand if you’ve ever mixed all the different colors of paint before. Keep your hand up if you remember what color you got? It’s usually some form of brown, but here we’re mixing colors of light, not paint. Going into the details is a whole separate lesson, so just know that mixing colors of paints is different from mixing colors of light.

Making Masks Demo (10 min)

Our secret message masks work on the same principle as NASA's color filters. Using only one color at a time will help reveal secret messages that are otherwise hidden. I'm going to demo how to create our masks, and then you'll get the chance to make your own to take home.

At the tables, you will find all the materials you need for your mask: Half a paper plate with some holes, a color filter, and two pieces of string. You'll also find all the tools you need, including scissors, tape, and markers. If you find that you're missing something when you get to the tables, just let me know. To make a secret message mask is pretty easy, only about five or six steps. I'm going to take just a few minutes to show you all the steps here, then I'll send you to the tables to do it yourself.

[Note that the paradigm of demoing a project in a focused, circle-time-style environment BEFORE students have materials/distractions in front of them is simply one way to execute this activity. You could, as another example, do this step by step with students at the tables immediately. However, we prefer this method for this particular activity because 1) it's a relatively easy and straightforward project, with a very large margin for error, as it's almost entirely aesthetic, i.e. the color filter already works entirely as-is, unlike, say, an electromagnet or solar oven which requires a lot of precision work in order to function at all. 2) Any time you can have younger students practice active listening is time well-spent. 3) Explicitly knowing the number of steps they'll be doing in just a few minutes can help those who are usually challenged by sitting still, as opposed to asking students to sit and listen to a pure lecture for some indefinite length of time. Feel free to truncate or even entirely omit the introduction sections if you're worried about your students being able to sit still for a full 20 minutes before they start doing the activity. Simply saying "let's make secret message masks!" and leaving all the explanations for later is totally fine depending on the students and your own timing. You'll notice that at each step we include asking questions and engaging the students at least a tiny bit so they're not ONLY sitting and listening. One final note is that as you're demoing, just be aware of who can see what, especially those students sitting on the fringes. Hold up and show around each step so that all the students feel involved, engaged, seen, and heard!]

Step one, because this will be your mask to take home: write your name! Be sure you write it somewhere along the edges of the plate. Don't write it in the center. You'll see why that's important in just a minute. Your plate might be bumpy there, but just do your best. Do you think I have to write my name perfectly on this project? No, not at all. This is just for you, so do it how you want. It doesn't even really matter which side of the plate you write, but keep in mind that the curve of the plate is going to go against your head, like this. So, for example, if you want to hide your name while you're wearing it, you write it on this side, where the plate is curving upwards. We'll call it the "face side" because this is the side that will go against your face. However, if you do want people to see your name while you're wearing it, you write it on the other side where the plate is curving down. We'll call this the "outside" because it'll be facing out while you're wearing your mask. Might sound a bit confusing, but like I said, it's entirely your choice and either side is okay.

Step two: You'll need to take your filter. You might be able to just look and see what color is this filter for? Red! This filter will mostly just let red light through, and it will catch or absorb all the other colors. Feel free to take a quick look through it once you get to the tables, but to make your mask, you'll need to place it on the paper plate. Align it about in the center, along the cut edge of your plate. Then take a marker, and with one hand holding the filter in place, trace out the shape and size of the filter onto your plate. As with your name, it doesn't matter which side you draw it really, but I personally find it easier to do the tracing on the "face side" because the plate lies flatter this way. Do you think it has to be perfectly straight and traced? No, it doesn't need to be perfect. I will ask that you please double check that your name is outside of what you traced, because the next step is to cut out a viewing area for your mask.

Step three: Now we're going to cut out a section so you can actually see through your mask. The part that you traced is just a guideline to help make sure you don't cut too much. You can cut out whatever shape or size you want INSIDE the area that you traced. Don't cut ON the line; that's too much. Also, make sure you'll be able to see through it, of course. You can cut out small eye holes if you wish, but that's a bit tricky because you have to measure your eye holes carefully. I like cutting out a larger area so I can see more through my mask. You can cut straight, zig zag, curved, whatever you want as long as you stay inside the lines. What pattern do you think I should cut for mine? There, so now I've cut out a section and I'm going to hold it up to my face to make sure I can actually see out of that area. Any questions so far? [Remember wait time!]

Step four: Once I'm happy with the pattern I've cut out, it's time to tape on my red color filter. Just like before, place the filter onto your plate. I'm going to place mine on the "face side" so that the cool pattern that I cut out is visible on the "outside" of my mask. Align it with the lines you traced earlier, and then I need my tape. Remember when you're trying to rip tape, it's best to hold the tape close, but not too close, to the teeth, and then pull it downwards to let the teeth rip a piece for you. I like to use three pieces of tape, one along the top, and one on each side. Try to keep the filter inside the lines that you traced, and try to keep it as flat as you can, but remember that it doesn't have to be perfect. Once you're happy with it, hold it up to your face again and test it out. The next step will be to tie it into an actual mask.

Step five: Now we're ready to tie it! I've already punched two holes into your paper plate, and we're going to start by taking one of your strings and tying it to one of the holes. Raise your hand if you've tied knots before. Raise your hand if you haven't. Now raise your hand if you can't remember if you have or not. That's okay, we're going to go over it now, and it's not too complicated. All you have to do is put one string through one hole to start.

[Note that your strings should be measured so that even if the students tie the strings exactly in the middle, it should still be enough to tie around their whole head. For older kids, you certainly can introduce the concept of offsetting the string to give more slack at the other end for tying around their heads. Note that if you punched holes too high or too low, tying around the head will be difficult, so be careful in your prep! This is actually a very good exercise in topology (the math of how shapes are connected), and an important life skill, especially in this age of velcro shoes, where kids can grow up without ever tying even a single knot.]

Then you take the two ends, and cross them. Here, take a look, what shape does that look like? I think it looks like an "X." Take one end of the string (it doesn't really matter which one) and put it through the hole you made. Then you pull the ends tight. It SHOULD make a knot! If it didn't work, try it again and this time try the other end of the string. At any rate you just do it one more time for a strong, double knot: make an "X," put one end of the string through the hole, and pull tight. We'll do the exact same thing with the other string and the other hole. Make an "X." One end through the hole, and pull tight. Make an "X." One end through the hole, and pull tight.

To tie it around your head, you're going to need some help. When you're ready, you can ask a neighbor, or you can ask myself or one of our adult helpers, to tie the two strings together behind your head. Your job is to hold your mask to your face, like this. Would you mind helping me, please? Then your helper is going to tie it behind your head with the exact same steps. Make an "X." One end through the hole, and pull tight. Make an "X." One end through the hole, and pull tight. Not too tight, of course, don't hurt yourself, just enough to keep the mask on when I let go. You should be able to lift up your mask onto your forehead, like this, and then bring it down again when you need it. Mask off, then mask on. Off. On.

You're technically done, but if you finish before everyone else, and you want to, you can slip the mask off and go back and draw or decorate it as you wish. For example, I have these paper plate scraps from when I was cutting, and I'm going to use mine to add ears and a horn to mine to make a unicorn, or you can make it into robot antennae, or whatever you want. Markers are here too for any drawing you want to do on your mask.

Hopefully it doesn't seem too difficult, and again, does it have to be perfect? No, it's your project and you can make it how you want. So step one: write your name. Step two: trace the filter. Step three: cut out a pattern. Step four: tape the filter on. Step five: tie the strings. And maybe step six: decorate if you have time. Name. Trace. Cut. Tape. Tie. Decorate. Any questions? [Remember to give proper wait time for any questions. If there's a question that doesn't seem relevant to everyone, you can feel free to release the rest of the students to the tables to start their project while you answer the individual questions/comments.]. Okay, let's walk to the tables, please!

Making Masks (15 min)

[Send students to the tables to make the masks. Keep an eye on younger students and help and/or assign helpers as needed. Encourage older/faster students to help others.

Also DISCOURAGE overly-anxious adults from helping TOO much! One of the objectives is to give kids practice crafting their own projects. A good suggestion is to simply be an extra pair of hands for students. For example you help hold the plate steady while they write their name on the bumpy part of the plate, holding the filter while they trace, holding the X while they thread the strings through, etc.

When fast students are totally finished, encourage them to look around the room and outside windows to see what they notice about the red filter with both masks on and off. Encourage them to decorate their mask with whatever they want (robot parts, animal parts, etc.). Encourage students to help each other tie their mask on (gently). Point out all the things you put up around the room, special clothes that you wore, and encourage them to share observations with each other.

Specific encouragement can go a long way. "I really like the pattern that you cut." or "Great job helping your neighbor!" can help. Remember to encourage the effort just as much as the results: "I really like that you kept trying to tie the knot!" or "I'm proud of you for not giving up!"

Make sure to give accurate 5 minute and 1 minute warnings for time (set a physical/digital timer if you need one), and reassure students that they'll get more time to finish later. Even if there are some stragglers at the end, have them bring what they have so far, which is usually a mask that just needs to finish tying the strings. They're going to need their color filter for the next section.]

Secret Message Demo (5 min)

Alright, welcome back. As I mentioned, not to worry if you didn't get to finish. You'll have time later. However, I wanted to pause you to show you the secret messages. First, I'm interested in hearing what you observed looking through your masks. What looks different? Does anything look the same?

[Pair-share and/or call on students to share out with the class. Encourage students to be as specific as possible. "What do you mean it disappeared? Oh you mean you can't see it anymore! Look more closely; can you still see it, even a little bit?" and "What color does it look like through the mask?" Validate and encourage other students to look through their masks to share the experiences as people are sharing. The following assumes you have some sort of white board or large chart paper with markers that you have personally tested to actually work with your filters, but the discussion should be adaptable whether you're using a blackboard or using a projector and the relevant slide.]

So let me write a few words on the board: red, orange, yellow, green, blue, purple, pink, brown, black… I've written each word in that color. Take a look at them with your masks. What do you observe? [Pair-share or with the class. Remember to call on students that haven't gotten a chance to share out yet!]

Okay, so now I have a very simple drawing, just some red and white stripes. Take a look through with your mask. Does the red REALLY disappear? Can you still see the colors if you really look closely? What's REALLY happening? So it only makes some colors HARDER to see. What would you call it if something is hard to see? Some animals can do this; they can blend in with their surroundings, and make it harder to see them. [Give proper wait time! It's a good bet that at least some kids know "camouflage."] Camouflage means to blend in with your surroundings. So the colors I drew are still there, they're just blending in and making it harder, sometimes very hard, to see. Some colors blend in by appearing lighter, and some colors appear darker. That's how all color filters work: they let some colors through into your eyes so those appear brighter, in this case reddish colors, but the filter absorbs all the other colors, stopping them from getting into your eyes, so those appear darker.

So how can this help us make secret messages? Let me show you. I'll start with a simple drawing of a blue bird. Now, I'll draw this around it. Okay, masks off? Take a look, what do you see? A bird in a cage. Now, masks on! What happened? The bird is free! Okay, masks off. Let me try drawing another one. Here's a person inside a dungeon. Masks on! She's free, yay! There are an unlimited number of possibilities you can create with your own secret messages now that you have your mask. Let's take a look at my secret message from before. Masks off first! Everyone ready? So this is what we saw at the beginning of the session. Now…Masks on! Can you read the secret message now?

[Read for them as needed. Repeat with as many examples as you want/have time for. Remember to check that everyone's mask is off before you show examples. You may just want to stop at just two or three examples to let kids have more time creating. You can always put up more examples around the room and at the different tables to provide inspiration. Depending on the level of students you might wish to explicitly go over which colors do/do not camouflage.]

So all you have to do is remember that some colors get lighter and some colors get darker to camouflage. As you're creating, if you're not sure about a particular color, just put a small dot on a small corner of your paper and test it with your mask! Remember, does it have to be perfect? No, just do your best and keep trying and practicing. Walking to the tables, please!

Secret Messages (15-20 min)

[Give students half sheets of paper, purely to save paper without limiting creativity. Encourage students to test, practice, and persevere. Ultimately anything they draw is a “secret message” as anything they draw will appear different in the mask. Encourage learners by pointing out interesting effects from whatever they draw: “I like how all the blue and all the purple you drew blends together now!” Again, remember to validate effort, not just results: “I like how you tried this again, and you didn’t give up!”

Also remember to encourage sharing, especially with the coveted markers that camouflage. If you haven’t already, you can put up the graphic detailing which colors camouflage and which don’t, and instead of answering “yes” or “no,” you can point them to the graphic, or even better you can ask them to test it out themselves. Giving students a dedicated “testing” paper can help.

Note that some students will want to outright copy the examples, and that’s totally okay! If multiple students from different tables want to copy the same one, feel free to shift people around at the tables depending on your space available and viewing angles. Remind students that they’ll get to take their mask home, so they will be able to practice and make as many secret messages as they wish.

As elaborated upon in the extension section, this activity of creating secret messages is truly scalable to any age. Of course anyone can find crafting a fun and interesting mask worthwhile. However, even veteran professionals of any discipline can find creating secret messages to be both challenging and rewarding. In addition, the artistic science and scientific art of color filter secret messages hold depths that almost anyone can dive into to find gems of new understanding and appreciation of the universe around you. This activity falls at the convergence of physics, biology, chemistry, psychology, geometry, aesthetics, pedagogy, and even some philosophy. The extension section has a list of potential topics and resources to broaden anyone’s horizons. From simple drawings like kids do, to digital masterpieces, and even professional graphic design, go as far as your audience wants to with this.]

Conclusion (5 min)

[Conclusion is optional. If you wish to simply give learners more time to work on their messages, feel free to do so and end with a simple “Thanks for coming and have fun making more secret messages at home!” Here we simply provide some culminating ideas and food for thought about the activity and its application in “real” science. Note the quotation marks because the students exploring and discovering ideas and functions of their mask is, with great sincerity, as real as science can ever get.]

So we’re using our color filters to read secret messages that we drew, but NASA scientists use color filters to read secret messages, or hidden information throughout the universe, like Mars, Jupiter, other places in space, and even here on Earth!

Here are the images we saw before from Mars and Jupiter. Take another look at them. What do you notice is different from one color filter to another? What details can you see in one that you can’t see in the others?

[Depending on timing and level of the students, this can just be rhetorical or you can actually dive into the images and go over them in detail in small groups and share out. Anything they observe is valid.]

The point is that just looking at one color at a time is useful for noticing different features and discovering different patterns. In addition, scientists can even filter out colors, or “wavelengths” that are invisible to the human eye, in order to reveal even MORE of the secret universe. Here are some pictures that used invisible color filters, such as infrared, radio, ultraviolet, X-ray. This one on the bottom is using a special device called a spectrometer to find harmful methane leaks in California!

So as you take your masks home to make even more secret messages, just remember that you’re doing the same basic science as NASA researchers do when they’re studying the universe! Thanks for coming today, and I hope you continue exploring color science and more throughout your life!

Extensions and More Information

The preceding script was really written for younger grades, around 1st through 4th. However, keen-eye readers will note that there are actually more Next Generation Science Standards that are relevant to this activity at the Middle and High School levels.

With extra time and/or more advanced groups, you can explore and discuss the underlying science behind how color filters and the secret message masks work as well as related concepts. Do note that exploring all the various concepts (e.g., light, optics, color mixing, transparency/transmission, chemistry, biology, neuroscience, psychology, culture, etc.) can be advanced enough to engage even professional scientists. So go as far as you want with it!

Color Filter Gel Alternatives

As stated in the materials section, the color filter gels are easy and affordable to purchase online, ranging from $0.25 down to literal pennies per student, depending on the precise application. However, for those who aren't able to get filter gels for whatever reason there are several alternatives:

1. Your organization might already have red/cyan/blue "3D" or "anaglyph" glasses. While not as good as dedicated medium/dark red filters, they can still work for some secret messages. The cyan/blue can also be used, though, again they don't work as well. Specifically if you have access to a NASA center, there might be an old stash of them gathering dust, (3D images were relatively popular a decade or two ago) just ask the education and outreach team.
2. Note this JPL article specifically cites colored cellophane: https://www.jpl.nasa.gov/edu/teach/activity/the-science-of-color/. Again, doesn't work as well, but if you already have it (e.g., it's popular among those who like fancy gift/party decorations), you can test it to see if it will work for your needs.
3. Food coloring in water or gelatin can also work, but requires you to find just the right ratio for your needs. For gelatin, make it a very thin layer, letting it dry out completely to make a transparent sheet.

Cautions for Virtual Presentations

Because it's 2023, virtual presentations and workshops must be addressed. If you're doing this online, simply beware that video compression for streaming live video can destroy color contrast, which normally isn't a problem, but can be disastrous if you're trying to show precise colors, say in secret messages. The best workaround is to record high quality video ahead of time, and then share the videos directly to your audience (e.g. sent ahead of time, downloading short clips, etc.) instead of trying to do it live on camera right then. Essentially don't assume that your online audience is seeing what you see as a general rule. At the very least check in with them to make sure, and if possible have a partner online who knows what things are supposed to look like just to ping you if things go awry.

General notes, ideas, and resources:

1. Note these materials and setup are targeting grades 1st through 3rd, so a lot of prep is done for the students. You can feel free to adjust the prep more (for kids who need more help or for shorter sessions) or less (for more advanced groups or longer sessions). That could be all the way from having masks entirely pre-made so students just focus on the decorating and secret message making, to only providing the raw materials and having students make it entirely from scratch.
2. Slide 40: As a quick demo for the invisible wavelengths of light, you can grab any IR remote (TV, Blu-ray player, even some home appliances like remote fans or A/C units have them), and almost any digital camera (smartphone, laptop webcam, etc.) and show the IR LED bulb flashing in the digital camera. Note that not all cameras will work that well; some cameras ship with IR filters that will block the IR light, most notably, modern iPhones. This of course could work in your favor for this particular activity since, if you have one phone with the IR filter and one phone without (perhaps ask for volunteers in the audience who have different phones than you do), you can show the difference side by side.
3. **For 4th grade Next Generation Science Standards**, explore more how the filters prevent light of a certain color from reaching your eyes, thus preventing you from seeing them.
4. **For Middle School Next Generation Science Standards**, explore light as a wave and how white light is a mixture of many different colors, many different wavelengths of light, and how the filters work just like air/water filters to filter out unwanted things and allow just what you want to be transmitted. You may wish to include diffraction gratings and/or prism explorations.
5. Other advanced concepts and ideas:
    a. Discuss contrast as a necessity of how the secret messages work. White letters on a white paper, or Black letters on a black paper, are unreadable. The filters make the white paper appear red, which camouflages some colors. The filter also makes some darker colors appear the same dark color, eliminating/enhancing contrast there as well.
    b. Give students different filters (like the 3D glasses above) and see if they can make secret messages or observations using green/blue filters (note that, in our experience, green and blue filters don't work as well for secret messages as red filters, but they can still be interesting to explore.)
    c. Discuss red, green, and blue as the primary colors of light which almost all digital displays use to "trick" our brain into seeing the entire spectrum of color. Use the color filters and a few light bulbs/flashlights to mix and match different colors of light to see what happens (making cyan, magenta, and yellow). Contrast that with the Cyan, Magenta, and Yellow in printers/newspapers as the primary colors of pigments.
    d. Discuss the concept of individualized experiences, i.e. that what one person sees is not necessarily what other people see. Your "red" could be/is probably different from what other people see as "red." We at least know that different people can discern different shades of colors, but the extreme would be that there's no way to prove, one way or another, that what you see as red isn't what I see as blue, and so on.
    e. Examine and dissect your "color filter technical data sheet" (a cheat sheet of which colors camouflage and which don't) which shows transmission of each wavelength of light, and discuss how that translates to what the students are seeing in their drawings.
    f. Challenge students to create a "Secret Alphabet" where each letter or combination of letters turns into something else under the red filter, to truly craft a secret message (see the "Boys/Girls" example above). Assign each student to design one letter at a time. Experiment and be creative! If someone comes up with a really good one, feel free to share it with us: jnee@jpl.nasa.gov.
6. Other resources, videos, and concepts for extensions/enrichment include:
    a. An image processing curriculum using real, color filtered, space images and free image processing software, email jnee@jpl.nasa.gov if you need assistance or a write up. You could also use digital image editing to create digital secret messages.

b. PBS It's Okay to be Smart: "How to see colors that aren't real" 10-minute exploration of colors.
c. PBS Physics Girl: "Does this look white to you?" 5-minute exploration of color mixing.
d. Physics Online: "Colour and Colour Filters - GCSE Physics" exploration of using different color filters starts at ~2:30
e. VSauce: "Is your red the same as my red?" 10-minute exploration of individualized experiences
f. About invisible colors:
    i. Veritasium UV: "The World in UV"
    ii. Physics Girl: "Sunscreen in UV"
    iii. Okay to be Smart IR: "What if we could see Nature in Infrared?"
g. About Color Synesthesia:
    i. Numberphile: "Synesthesia - Numberphile"
    ii. DiscoveryVR: "What's It Like To Hear Colors? - A VR 360° Synesthesia Experience"

Mask Making

Some educators may even wish to omit the mask portion entirely, to simply give older learners the filters outright. However, we would encourage such educators to give crafting a mask a fair try before unilaterally skipping it. Note the second learning objective stated at the beginning: "Science is fun, creative, and helps you learn about the world around you." As we mentioned in the general notes above, there are several ways you can adapt the mask crafting for, say, middle and high school students. To expand further, ideas could include the following:

- Provide the raw materials and tools (and more of them), such as
    - A stack of paper plates
    - Scrap cardboard
    - box cutters
    - Spools of yarn/thread
    - Hot glue
    - Hole punchers
    - More advanced materials/tools such as paper mache, plaster, plastic bricks, clay, ceramics, wood carving, 3D printing, etc. While some of those materials would certainly require more time than the 15-20 minutes allotted for making masks, remember the goal is to engage students in a fun and creative STEM activity, and perhaps spending more time on the masks or even doing multiple sessions is okay.
- Connect the mask crafting to various cultures and traditions around the world (hopefully from some of the students' own culture, if possible). Include imagery from various masks from around the world, as well as their history for students to draw inspiration and relevance. From the ancient masks of early Neolithic tribes to the modern burqa or even the culture around healthcare face masks, there is a rich, complex story that could be told around covering human faces and especially eyes. Consider this example of an activity to make snow goggles from the the Museum of the North: https://science.nasa.gov/learn/heat/resource/make-snow-goggles/
- Provide a wide range of color filters. Make sure students know that the primary filter they will need to use is the medium red, but incorporating different color filters could even turn this into an engineering design challenge. Remember the color wheels that NASA spacecraft actually use, and challenge students to make a mask where they can switch from one filter to another. Alternatively, the challenge could be to design and craft a working color filter wheel for the camera on your smartphone.

Advanced Secret Messages

Exactly like how Mask Making can be expanded and interpreted in many ways, so can the secret messages activity. Beyond the straightforward challenge of hand drawing more complex and intricate secret messages (e.g. nicer artwork, calligraphy, words, etc.), the primary way to take secret messages to the next level is through digital image processing. Some concepts/topics that might be beneficial to cover:

- Basic "photoshop" skills: selections, cut, copy, paste, transform, and most importantly color. You may be interested in our Stories from Space lesson plan detailing using free and open source software.
- Color mixing:
  - Primary colors of RGB for digital displays
  - Primary colors of CMYK for printers
  - Contrast with traditional art RYB primary colors, and discuss the concept of different color gamuts derived from different primary colors
  - This is important for advanced secret messages especially if you provide different color filters. You can use the concepts of digital versus print color mixing and different color gamuts to fine tune messages to react to different filters, displays, and printers. See this slide in the media slides as an example.
- Color depth
  - Digital bits and different base counting systems
  - 16-bit color hex codes, great for fine tuning secret messages for different displays/filters
- Formal Steganography, the study of secret/hidden messages: https://www.nasa.gov/wp-content/uploads/2016/10/02-05_multimedia_steganalysis.pptx
- HTML
  - Teach coding a secret message website, with a very simple example (tuned for 3D glasses-red-only on Macbook retina display): Secret Messages HTML (0 KB)

```
<html>
 <head>
  <title>Secret Message</title>
 </head>
 <body style="background-color:#0000ff;">
  <h1 style="color:#2200ff;">Can you read me using a red filter?</h1>
  <h1 style="color:#1c2e48;">Welcome to my secret message site!</h1>
 </body>
</html>
```

  - Consider some simple JavaScript, e.g. for loops to fill a pattern, accept user input, and/or randomize output. One example: Secret Message Inputs HTML (1 KB)

```
<html>
        <head>
                <meta charset="utf-8">
        </head>
        <body style="background-color:#0000ff;">
        <h1 style="color:#2200ff;">Welcome to my secret message site!</h1>
        <h1 style="color:#1c2e48;">Enter your hex codes, Red, Green, and Blue: </h1><br>
        <input type="text" id="redField" class="redField"><br>
        <input type="text" id="greenField" class="greenField"><br>
        <input type="text" id="blueField" class="blueField"><br>
        <input type="submit" value="Submit" class="colorSubmit">
        </body>
        <script>
                //only chooses the first h1:
```

```
            var myHeading = document.querySelector('h1');
            var colorSubmit = document.querySelector('.colorSubmit');
            var redField = document.querySelector('.redField');
            var greenField = document.querySelector('.greenField');
            var blueField = document.querySelector('.blueField');
            redField.value = '22';
            greenField.value = '00';
            blueField.value = 'ff';
            function clicked()
            {
                  //Get the user's input value
                  var redValue = redField.value;
                  var greenValue = greenField.value;
                  var blueValue = blueField.value;
                  //Changing the header
                  myHeading.style.color = '#'+ redValue + greenValue + blueValue;
            }
            colorSubmit.addEventListener('click', clicked);
      </script>
</html>
```

- Regardless of exactly what and how you explore, the science of colors, perception, and aesthetics is a worthwhile activity in any endeavor
  - **Myth** of the Left brain vs. Right brain, aka Creativity vs Science:
    - Blog from Harvard Health, including links to research, search for “Right brain/left brain, right? March 24, 2022 By Robert H. Shmerling, MD, Senior Faculty Editor, Harvard Health Publishing; Editorial Advisory Board Member, Harvard Health Publishing”
    - 4-minute Ted Ed video about the myth search “The left brain vs. right brain myth - Elizabeth Waters”
  - “Arts and sciences are part of one, common creative culture”
    - 2004 Research paper: Root-Bernstein, Robert & Root-Bernstein, Michele. (2004). Artistic Scientists and Scientific Artists: The Link Between Polymathy and Creativity.. Creativity: From potential to realization. 10.1037/10692-008.
    - 2008 Research paper: Root-Bernstein, Robert & Allen, Lindsay & Beach, Leighanna & Bhadula, Ragini & Fast, Justin & Hosey, Chelsea & Kremkow, Benjamin & Lapp, Jacqueline & Lonc, Kaitlin & Pawelec, Kendell & Podufaly, Abigail & Russ, Caitlin. (2008). Arts Foster Scientific Success: Avocations of Nobel, National Academy, Royal Society, and Sigma Xi Members. Journal of Psychology of Science and Technology. 1. 51-63. 10.1891/1939-7054.1.2.51.
    - 2015 Research paper: Scheffer, M., J. Bascompte, T. K. Bjordam, S. R. Carpenter, L. B. Clarke, C. Folke, P. Marquet, N. Mazzeo, M. Meerhoff, O. Sala, and F. R. Westley. 2015. Dual thinking for scientists. Ecology and Society 20(2): 3.
- You might also consider mentioning color blindness and synesthesia as neuroatypical experiences of the above topics, jumping into inclusive and accessible design, which is just as important for scientists as it is for any human being living in the modern world.

GUSTO Background information

- Fast Facts:
  - **G**alactic / Extragalactic **U**ltra-Long Duration Balloon **S**pectroscopic **T**erahertz **O**bservatory
  - ~21 miles up, 3x higher than passenger jets, for ~100 days around Antarctica
  - $50 million, almost 10x a typical balloon mission (NASA generates more than 300% in economic output!)
  - Infrared telescope studying interstellar medium and stellar life cycle in the Milky Way and the Large Magellanic Cloud, a satellite galaxy
- Official NASA mission page: https://www.nasa.gov/event/gusto/
- Detailed 2023 article: https://www.nasa.gov/wp-content/uploads/2023/11/critical-path-23fall.pdf#page=7
- Johns Hopkins University Video: https://www.jhuapl.edu/news/news-releases/230717-gusto-balloon-mission-ships-out-for-antarctic-launch
- NASA Balloon Science with a shout out to GUSTO: https://www.youtube.com/watch?v=ATTJ8y6W0xM
- March 2023 Science Briefing Presentation Slides: https://science3.nasa.gov/science-pink/s3fs-public/atoms/files/Walker_GUSTO%20APAC_23March23.pdf - "GUSTO will serve as a Rosetta Stone for understanding the inner workings of the Milky Way and LMC"
- Why not use JWST?
  - Far Infrared (63 - 205 microns), Near Space
  - 55 days, over 1,300 hours, of observation to meet threshold
  - Essentially, GUSTO doesn't need to us JWST for its science, thus JWST is better utilized doing other observations

Infrared and Invisible Colors

- https://stemgateway.nasa.gov/connects/s/article/Exhibit-Ideas-extra-visible-light-exhibit
- Relate wavelengths/frequencies to colors
  - https://informal.jpl.nasa.gov/museum/sites/default/files/ResourceLibrary/EMSPosterfinal.pdf
  - Some notable relations to draw (perhaps literally draw on the above poster):
    - Car radio stations are shown in MHz for FM (e.g. 89.3), and kHz in AM (e.g. 650)
    - TV and other radio communications are in the hundreds of MHz
    - Cell phone signals vary by carrier, but in the US are usually around 0.6 to 1.9 GHz
    - Wifi is 2.4 to 5 GHz, creeping up to 6 GHz these days
    - GUSTO is looking at ~1,400 GHz to ~5,000 GHz (the "T" in GUSTO)
    - Human body emits on the order of ~30 THz
  - Or use this one: https://science.nasa.gov/wp-content/uploads/2023/08/ems-introduction.jpeg, though the atmospheric opacity might add irrelevant information/confusion since GUSTO is purposefully going above the atmosphere.
- Commercially available "Thermal Imaging" cameras are looking at frequencies around the human body range, about one order of magnitude above GUSTO. If you have or are interested in getting a thermal camera for IR demos:
  - Note that "IR" cameras are often not what you'd want for such demos. That wording typically refers to grayscale security-style cameras or baby monitors. While essentially the same, scientifically speaking (and perhaps even MORE accurate since all astronomical IR detectors only see in grayscale), for education and outreach, the ability to map IR frequencies to visible color ranges is simply more engaging and instructive for most audiences, similar to how NASA processes IR images for public release.

        - You can use this short video series from the Space Telescope Science Institute on how they process JWST images to help audiences understand what goes into such images.
        - https://youtube.com/playlist?list=PLm0MBdI3VlBVYtifm_shSFhfICogfE91W&si=gTCh43rkOi6Fe6hS
    - Have students use their hands to warm up different objects to see how they change in IR. With some materials, it can be possible to write a secret IR message this way.
        - Use ice cubes, warm water, and/or reusable cold/heat packs
        - Use different materials from plastic to glass to metal
        - Beware of one of the biggest misconceptions regarding thermal conductivity versus temperature, i.e. just because something "feels" cold or warm doesn't always correlate to its actual temperature. Namely, touching an object that feels cold actually increases it's temperature
    - Have students use different materials (such as glasses or plastic bags) that are opaque to IR yet transparent to visible light, or vice versa.
        - Eye glasses
        - Acrylic
        - Water
        - Window panes
    - Need more reasons to get your own Thermal Camera?
        - Thermal cameras are practically useful in personal/professional life -
            - Inspecting your own house/equipment, e.g. electrical shorts, "vampire" plugs, HVAC, insulation, and plumbing leaks, etc.
            - Note that even if you personally don't want to get one, ask around in your personal/professional network. Any friends or colleagues who are electricians, plumbers, other contractors, or who do similar work, perhaps even as a hobby might have one or be interested in getting one, which you can then borrow for the occasional educational event.
            - Case in point, JPL has several thermal cameras that JPLer are welcome to borrow. For educational outreach, the JPL Education Office has one, and for more technical work, the Microdevices Lab has one (though they also use it for the occasional outreach event).
        - Thermal camera pictures are great to take for your events because people usually aren't recognizable
        - If applicable, printing out pictures as souvenirs make easy, personalized, and valued takeaways. It's better than a random sticker or flyer, because it's of that person. Consider creating an easy-to-use printing template with your organization's logo or website.
    - Beware of using the term "true/false color." While arguably innocuous in the past, between social media filters, generative AI, and even politics, current times hold a veritable minefield of misconceptions, miscommunications, and mistrust. Remember that ANY picture can never be 100% "true" color; the human eyes and brain are simply not a digital camera. You can try using instead "natural color" and "representative color". Some reference articles:
        - "Recast as 'decoration' rather than 'knowledge,' these images—which all represent invisible forms of light—appear to audiences as willfully misleading."
            - "Pretty Pictures": The Use of False Color in Images of Deep Space
            - Invisible Culture, Issue 19, by Anya Ventura 2013
        - ""We actually try to avoid the term 'true color' because nobody really knows precisely what the 'truth' is on Mars," said Jim Bell, the lead scientist for the Pancam color imaging system on the Mars Exploration Rovers (MER). In fact, Bell pointed out, on Mars, as well as Earth, color changes all the time: whether it's cloudy or clear, the sun is high or low, or if there are variations in how much dust is in the atmosphere. "Colors change from moment to moment. It's a dynamic

thing. We try not to draw the line that hard by saying ‘this is the truth!’"...Bell likes to use the term “approximate true color” because the MER panoramic camera images are estimates of what humans would see if they were on Mars. Other colleagues, Bell said, use “natural color.”...Zolt Levay of the Space Telescope Science Institute produces images from the Hubble Space Telescope. For the prepared Hubble images, Levay prefers the term “representative color.”

        - True or False (Color): The Art of Extraterrestrial Photography
        - Universe Today by Nancy Atkinson 2007
    - It is also worth noting the long-standing debate and research regarding the misuse of color in science communication, e.g. for your next research paper. However, in this particular use case, we don’t worry too much about it because a) we’re not trying to relay any specific scientific data or conclusion, b) “rainbow colour maps might reflect aesthetic attractiveness” which is indeed important in public engagement, and c) in the practical uses of thermal cameras it’s actually quite beneficial to have such contrast, where “the yellow is the brightest colour and attracts the eye the most” because you want to easily and quickly find the hot spots in your view. That being said, if you’re someone who feels strongly about it, your commercial IR camera likely has viewing modes that are more aligned with the best practices in science communication.
        - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7595127/
        - Crameri F, Shephard GE, Heron PJ. The misuse of colour in science communication. Nat Commun. 2020 Oct 28;11(1):5444. doi: 10.1038/s41467-020-19160-7. PMID: 33116149; PMCID: PMC7595127.
- IR astronomy Images
    - https://esahubble.org/images/opo0429g/
    - https://blogs.nasa.gov/webb/2022/08/22/webbs-jupiter-images-showcase-auroras-hazes/?linkId=177177185
    - https://blogs.nasa.gov/webb/2023/06/30/saturns-rings-shine-in-webbs-observations-of-ringed-planet/
    - https://www.eso.org/public/images/comparisons/eso1205a/