Ask a Biologist vol 034   Topic: Color Guest: Peter Vukusic

Iridescence: Nature's Spectacular Colors -

You may not know the name or how it works, but iridescent color is common in Nature. From butterflies to birds and even fish you can see examples of these eye-popping colors. Dr. Biology sits down with physicist Peter Vukusic from the University of Exeter to talk about iridescence and science behind these spectacular colors.

Transcript

Dr. Biology: This is "Ask a Biologist," a program about the living world, and I'm Dr. Biology. Today we're going to be talking about color, but not just any color. We'll be talking about the amazing world of iridescence, colors that are known for their brilliant blues, radiant reds and greens that just grab your eye. Colors so vibrant that they are truly eye-popping.

In an earlier show, we had a chance to chat about color and how we see color with Kevin McGraw, who's one of our faculty in the School of Life Sciences. Today we have a special guest who's going to give us the inside story about how iridescent colors are made. In our studio today is Dr. Peter Vukusic, who's one of the speakers at a very special conference about iridescence.

This is the first in a series of annual meetings established by the School of Life Sciences called "Frontiers in Life Sciences." Dr. Vukusic is a physicist interested in how things in nature, such as butterflies and birds, produce iridescent colors. And even though he does not consider himself an artist, he's also won a rather prestigious international award, the L'Oreal Art and Science of Color Prize. He's also appeared on several science shows, both on the BBC and National Geographic. Welcome to the show, Peter.

Peter Vukusic: Hi, good to be here.

Dr. Biology: All right, let's talk about this wonderful world of iridescence and how it's different from the color I see, well right here in our studio. We have some rather bright blue and bright green colored walls.

Peter: The classic dictionary definition of iridescence is "an iridescent color is a color that changes its color with angle." So if you look at a wall straight on and it's green in appearance, it would be iridescence only in the situation that if you turned to the side and looked at it from a glancing angle, it would not be green anymore. So it would change color with that angle of viewing and that's classic iridescence.

Dr. Biology: You showed an amazing video of a car during one of your talks that had a spectacular paint job. And as it drove past, it kept changing in color. I didn't know you could get paints like that.

Peter: Absolutely. It's a very desirable paint color in certain cultures and certain countries, and it's pretty expensive too, although that price is coming down. And really the technology that we associate with color can be used and can be applied to such an esoteric thing like paint. For certain people with a little bit of funding behind them, they can pay some money and they can have someone spray a paint coating onto their car, onto their building, or onto their wall, and that paint will have amazing color properties.

Dr. Biology: We're going to talk about some pretty cool products that use iridescence and we'll do that later in the show. But right now, I'd like to get back to the basics, or maybe I should say back to nature since that's where we first learned or at least we first saw iridescence color.

Peter: Certainly that's where it first existed, 15 million years ago, 100 million years ago. Who knows really? The biologists, the entomologists and the ancient, pre-history people really can't be sure when it first evolved, but it did evolve very early on -- and by that I mean hundreds of millions of years ago.

So now we still see them. We still see them in butterflies and in fish; we still see this amazing color effect. And in a way that's why scientists like myself and other people here at the conference are studying these natural systems with great iridescent colors to try to learn from them, and try to not only understand their biology, which is interesting enough, but to understand the physics and the science that creates the color in the first place.

Dr. Biology: How is the paint, you know these screaming green and blue colors that we have on our walls different from the iridescent color of a butterfly?

Peter: That's a great question and to answer that we've got to get into the science behind these things a little bit. And to do that let's start with one significant idea and that is that there are two main categories of color production. So the sun is our light source and the light sources shines all the colors of the rainbow down onto a surface, let's say the wall of our building or the surface of our car. Depending on the category of color production, certain light will be reflected in certain ways.

The first and most everyday color production method has to do with pigment. Now a really common pigment that many of the audience might know about is chlorophyll. Chlorophyll is what makes the leaves green and the grass green. There's a biological function to the chlorophyll and that's to help with photosynthesis and the science of that is really well-established.

But as a byproduct to the photosynthetic processes that are going on -- which are really important for life and plants, flowers and grass and everything -- it turns out it is green. So chlorophyll is green, blood is red and melanin is brown because of the nature of the way light from the sun, let’s say, is absorbed by that. So we got to be really clear about this and if we're having a mini science lesson here, let's just carry on.

Chlorophyll is green because the light that hits it scatters green, so green is reflected into our eyes, but be clear about the process. Green is reflected because green is not absorbed. We're not seeing red from grass or blue from grass because the red and the blue wavelength colors are being absorbed and that's really key. So the key component, the key principle as to why grass is green or why blood is red is because certain colors are absorbed and certain colors are not absorbed.

OK, so that's pigmentation and that's the first category of color production. When we talk about iridescent color, it's absolutely not pigmentation that's the process going on. In that process, it's the exact same process as we see producing the color in soap bubbles. So if you ever do the washing up -- wash your dishes, wash your car or have a really soapy bath or shower and you get all these bubbles going on -- if you see a little bit of color in those bubbles that is a different process because the soapy water is not colored and doesn't have any pigments in it. And the process of that is a much more physics type of effect called "interference," and we could get into that right now if you'd like to.

Dr. Biology: Yes, I'd like to do that. But first let me sum up that many, if not most, of the colors we see are produced by pigments and/or dyes. So the bright red shirt is red because it absorbs all the colors except red; and the green plants, as you said, get their colors because they absorb all the colors except green. In fact, that can be a really fun biology experiment where you grow plants under different colors of light with green being one of them. The results usually surprise students, but right now, let's get back to iridescence and interference color.

Peter: Sure. So here's Interference 101. Light is amazing. We can think of it as being an electromagnetic wave, and that's a really fancy term to say it's made of electric fields and magnetic fields together, but it starts to get complicated. If we track back a little bit, we should understand that light can behave as a wave. Now we're all used to waves. If you go to the sea or the ocean, you see waves coming in and that's a really interesting example of what's called a "transverse" wave, if you looks sideways onto the direction of the motion.

So let's say you're on the beach and you see the waves coming in. But let's say you sat in the boat on the beach and you looked out sideways, you would see peaks and troughs of that wave going towards the beach. The physical distance between one peak of a sea wave and another peak of a sea wave that’s given a name, and that's called the "wavelength" of a wave. And for sea waves, it might be 30 feet, let's say, but for light waves that distance is a million times smaller.

And light waves clearly aren't made of water, they're made of electromagnetic energy. And the wavelength, the distance between one peak and another of a light wave is given a name, and it's called a "nanometer distance." It's 100 nanometers and that is a million times smaller than the size of a sea wave, let's say.

It's the wave length which dictates the color. And so, red colors, the wave length of red light, let's say, it bigger than the wave length of blue light. But again, we're getting into the physics and perhaps this isn't the place.

So, light is a wave. Those light waves interact with material. So, let's say a soap bubble. A soap bubble will be colored because when light waves hit the soap bubble, a reflection from the top surface of the soap bubble adds to the reflection from the bottom phase and they both go in the same direction. It's saying to our eye.

And depending how thick that soap bubble film is and depending on the angle. Here we're once again we're talking about angle. Depending on the angle at which you're looking at the soap bubble, the light waves add to reinforce each other to produce a bright color or they add to cancel each other. In which case we don't see that color brightly reflected.

And so it's to do with the adding of waves together which create interference colors and really that defines iridescence.

Dr. Biology: And this is one of the cool capabilities of animals, such as birds and butterflies?

Peter: Yes. Definitely. So, I said in the soap film, we've got a one film of soap. But these butterflies and birds and fish, somehow evolution has given them the knowledge and that's a really, kind of bizarre statement. But they have evolved the ability to use interference, to use the addition of light waves.

And they do that by having evolved specialized layered structures on their wing scales, in their feather barbules, in the fish scales. Wherever you see this iridescent color, you're seeing the result of a fantastic evolution of material and structured material. And it's an amazing thing as a scientist to study, really.

Dr. Biology: While listening to some of the talks at the conference, I got the impression that when dealing with iridescence, the color has a lot to do with those nanometer-thin layers and also the number of layers that impact the interference light waves and ultimately are responsible for the color.

Peter: Absolutely right. So, it's the thickness of the layers, the material that is used to make the layers, and the number of layers. You could have at least one and if you go up to 10 layers then that affects the quality of the iridescent refection. The more layers you have, the brighter that reflection is. The bigger the density of the material compared to their surrounding air, the better the reflection in a sort of developmental way.

Dr. Biology: Which is counterintuitive to me. There are more layers, the light is going further down, I wouldn't have thought light would be brighter.

Peter: A really good point but we have to remember that these materials inherently -- unless they've got some pigment to them -- these materials are transparent. For instance, the butterfly scale material, that's the bright blue morphed butterfly. That is made out of material which as transparent as our fingernail material. It's just a modified form of protein.

So, it's a really good point you make. You'd expect the more material the less would be reflected the more would be absorbed. But it's only pigmentation which it does that absorbing. And in many cases there's very little pigmentation in some of these species.

Dr. Biology: So, that's how iridescence is so unique. In this case not only does it produce color but it also becomes an amplifier?

Peter: Yes. For sure. It enhances the reflection of a particular color from a surface. But we’ve got to remember; you can't reflect more than you receive. So that's a really key, important point to science. One of the fundamental principles of all science is conservation of energy.

OK. So, let's say we get a hundred units of energy from the sun, you can't reflect back into the eye of another butterfly or the eye of a person more than that original hundred units.

Dr. Biology: Right. And the thing about color that many people may not think about is that each color has a particular energy. So, for example, blue has a higher energy level than red.

Peter: Absolutely right.

Dr. Biology: So, in this case we're saying you can't put in a red light and get a blue light out because blue takes more energy than red.

Peter: That's a very important thing to say. Each color is associated, just as you said, with a particular energy. So generally normal materials like our fingernail material, or like the butterfly, scale material, they do not change the energy of systems. You need kind of a pigment to do that. But the structure itself just does not change this energy.

Dr. Biology: All right. In case anybody's getting a little lost with this talk of color and waves and energy, on Ask a Biologist website there's an article about color. It's called "Seeing Color," and has a very nice illustration of the color spectrum including the range of energy associated with each color. So if you're a little confused, go up there and take a look at it. It will help make it much easier to understand what we're talking about.

In the meantime, just remember that different colors have different energies.

Peter: Absolutely right. Yes.

Dr. Biology: OK. Now I can't wait any longer. We have to talk about these two models you've brought into the studio. They are sitting on the table in front of us. They really look like intricate sculpture pieces but there is more to them than that. So, let's talk about what they are, what they're showing us and also how they're made.

Peter: Sure. Let me put them into context. On the table in front of me, I've got two models that are made out of a polymer material. The reason we've produced these models is as follows:

The butterfly scales are so small we can't see them with our eyes. How they're angled, all the surfaces, where they are going. So, for that reason, we tried to scale these things up instead of them being at the nano-scale, can we make them at the centimeter scale? So, to do that we take pictures using this electron microscope of these tiny scale sections. We feed those pictures into a computer using a cad package. We make 3D models of them virtually in the computer. And then we use something called a laser centering system to convert those 3D computer models of the original, real samples into real, solid materials. Things that I can just put in front of me on the desk as we have here.

Dr. Biology: Yes, and as you've mentioned, these are round discs and they are about 10 or 12 inches in diameter or 25 or 30 centimeters. They look like intricate white sculptures. But sculptures representing a nano-scale world.

How much larger are these? Can you tell me what the magnification is?

Peter: We've increased it by a factor of 10,000 times.

Dr. Biology: 10,000 times?

Peter: So, that goes from the nano level right up just to the centimeter level.

Dr. Biology: You know, I think the thing that really fascinates me the most about these models besides their beauty, is we get a glimpse at something usually only seen using very, powerful microscopes. And never at a scale that you can actually --with my fingers here I can touch it and I can feel it. Just how did you make these models?

Peter: The technique is an engineering technique and essentially it's just a big machine. So, we produce the 3D model and put it into the machine. And the machine is called a centered laser system. So, one starts with just a powder of un-polymerized material and then the 3D model controls very intense lasers which illuminate the powder in a pattern corresponding to the 3D model in the computer.

And you build that pattern up layer by layer, because when the laser's are tracked across the sample, or wherever they track, they polymerize the powder and create a hard, solid material which you build up layer by layer according to the model that you've input into the machine. It's a pretty well known technology. Unfortunately, the machines are pretty expensive to buy and each model isn't so cheap to produce but they're really, really excellent for demonstration purposes.

Dr. Biology: Give me the details. How much did they cost?

Peter: I've got a very thin, small one on my left and that is about 500 pounds, about a $1,000 and the bigger one which is a sort of more complex built is around 900 pounds. So, just short of $2,000.

Dr. Biology: OK. So not everybody's going to be making these in their garage. All right. Let's see, so what we're looking at here are parts of a butterfly scale and it's up close and personal. We get to actually touch them. What have we learned from these models?

Peter: Well we can see visually at the centimeter level the inherent structure responsible for, in one case here on my right, the blue of the morpho wing. And in the other thinner, smaller region here on my left, it's a different sample, a different build, and that's the structure responsible for a silver reflection from another butterfly from South America.

Dr. Biology: So shape has a big impact on the color of iridescence?

Peter: Shape is the responsible factor for the iridescence, yes.

Dr. Biology: So that really interests me. As you mentioned before, we all know about paint and painters that use pigments to create colors, but the idea of using shapes to create colors is really cool. And in your case, iridescence expanded beyond pure science to include the world of art, and resulted in an international art award, or prize as they call it, presented each year by L'Oreal, which is a cosmetics firm.

Peter: Absolutely. The artistic world relies on color and appearance, and the manipulation of light and color is the sole underpinning effect of painting -- not so much sculpting, of course, but painting. If artists and if the art world had the ability to further, not better, manipulate light and color from their canvas, then I'm sure they'd grab onto that ability. So a few of the things that we were able to discover with this butterfly study and this animal study have potential to be applied in the artistic world, and it was for that reason that some of our work was recognized for that award.

Dr. Biology: I also saw a few images in your presentation of some pretty impressive lipstick.

Peter: Yeah, after L'Oreal honored us with an award, they invited me to Paris to their scientific labs in which they develop and produce and research their cosmetics. And most of us are familiar with L'Oreal cosmetics, certainly on the shelf; many of the audience might wear L'Oreal cosmetics.

But their processes are underpinned by serious scientific research. It's not a bunch of models in a room somewhere dreaming up new colors to wear, absolutely not. It's a very serious and a very strong scientific effort. So they wanted to try to limit -- for a line of products -- the amount of pigment that is used to produce the color, and indeed, that would help international resources too. Pigments rely heavily on natural resources, natural minerals and they're expensive to transport and they produce CO2 during that transportation process.

Dr. Biology: All right, let's weave back into the world of butterflies. There were some very cool, color butterflies shown during your talk and some other people talked about them as well. But the one that was very interesting to me was the one -- as I said at the beginning of the show -- that had an eye-grabbing green. But in the case of this butterfly, microscopically, there was more to this green than say - meets the unaided eye.

Peter: Absolutely right. What that butterfly is relying upon is the idea of "color mixing." Now many of us will have and will indeed continue to mix paints for their artwork. Generally mixing paints involves mixing pigments and when pigments mix together, you get a third pigment -- so two separate colors produce a third color. That process is called color mixing, but in the case of mixing pigments, it's called "subtractive color mixing." It's one of the methods of color mixing and it's limited to pigments.

And by subtractive it's really important to get the idea right. The absorption we described before for pigments and the absorption of both pigments when they mix, subtract further light from each other and that's why it's called subtractive color mixing. But what would happen if instead of mixing pigments in a pot, you painted a dot of one pigment in one place and just moved a millimeter or two across the page, and put the dot of the other pigment next to it -- say a yellow and a blue next to each other, rather than mixing them together?

What you'd get then, if you stood back from it, is that our eyes would create the stimulus of a mixed color. So our eyes would additively mix the blue and the yellow -- and in that case that would be different from the subtractive mix -- and it would give the appearance of third color, an additively-mixed third color. So that's color mixing: subtractive color mixing on the one hand and "additive color mixing" on the other. And the science of that is really well-known and it's taught in schools really well.

But butterflies we found out - a certain specific range of these butterflies use this additive color mixing and produce this pointillism, and indeed in the art world, pointillism is superbly well-known. An artist at the end of the 19th century called Georges Seurat he invented this artistic movement called Neo-Impressionism. The Neo-Impressionistic painters used the technique of pointillistic color mixing. So he's got a really famous picture. The classic Neo-Impressionist picture is a painting of a lot of very abstract men and women and children walking on an island in Paris. Its style underpins the whole idea of color mixing.

But if you could zoom in and get right in a centimeter from that canvas and you had a magnifying glass, you would see lots of individual color points. So the artistic world knows pointillism really well. It turns out that was invented a hundred years ago, but nature has been using this for 30 or 40 million years. This particular green butterfly produces on its wing scales different microscopically-sized points of yellow and blue color, which in our eyes and in the eyes of another butterfly, produce the effect of a third color and in this butterfly's case, it's green.

Dr. Biology: Now we've been talking about butterflies and other animals that make these iridescent colors and how they require some rather elaborate layers and shapes, and each takes a lot of energy to make. My question is why would a butterfly or any animal that uses iridescence take the time and energy to make iridescent colors?

Peter: Great question. What's the advantage? That's the key biological question to these things. So let's examine the potential advantage offered by a structural color over that offered by a pigmentary color. Well there are many answers, potentially, structural colors offer you brighter colors and a much more intense reflection. Whereas pigments actually work by absorption and therefore the intensity, the brightness of the reflection can be reduced and is limited. Structural colors offer you really intense reflection and that may be useful of course in certain situations.

Morpho butterflies, for instance, are visible over a quarter of a mile away because of the intensity of their reflection. And also as a matter of fact -- and it's important to say this --

because on the wing when they're flying, they're flickering. They're flashing on and off this bright, blue signal, and that's a conspicuous attraction signal.

Dr. Biology: Kind of a strobe effect.

Peter: Absolutely right. Our eyes are drawn to a flashing, to a flickering strobe light or moving signal. So that's one, sheer brightness. Another one is the fact that, as we've said, angle dictates the color that's reflected to a certain extent. So if it is of potential use to the species -- to the butterfly or the fish -- to have an angle-dependent color, which changes from blue at straight on to violet at grazing and that is an advantage to it, then the structural color is great; it's useful.

In addition to that and we're starting to get more complicated now, we've got the idea of "polarization." Now light waves, just like sea waves, can be polarized. So let's just think about polarization. Let's say, Dr. Biology, you go on one side of a long room and I go on the other side of a long room, and we are each holding the end of a long piece of string, like a skipping rope.

To demonstrate polarization, let me send a wave down to you and I do that by just waggling my hand up and down, up and down. And you can imagine that movement of my hand will send a wave with vertically-oriented peaks towards you. In fact, that is a polarized wave and the polarization will be vertical because the peaks are vertically upwards and downwards.

The alternative to that would be to polarize it horizontally. So instead of moving my hand up and down, I'd move my hand from right to left. Those are the two different polarizations oriented at right angles to each other.

Now, light can behave in just the same way. Light can be polarized vertically or horizontally, in addition to several other ways. And the structure that we see in some of these butterfly scales has the ability to offer polarized light signals. And we know full well from biological studies that insects largely are sensitive to polarized light.

So in that sense it can be another channel for communication between the male, let's say, in one species, to the female in the same species. Or between males in the same species. Or even between a species and its predator. All these sorts of variables have to be considered when trying to understand, trying to work out the reason for the evolution of the systems.

Dr. Biology: Right, because sometimes the coloration of butterflies I've seen allows them to disappear into their surroundings.

Peter: Yes, as humans who are appreciative of beautiful things with bright colors, our eyes are always attracted to the bright blue colors which stand out. But let's not miss the fact that manipulating light and color for appearance can be applied to the purpose of camouflage, just as you say. So we've got to keep our eyes open as potential scientists, and as good scientists.

Dr. Biology: OK. For humans, besides lipstick and some pretty cool car paints, where else are we going to be seeing iridescence in the future?

Peter: We are used to communicating via, if you like, electrical signals up and down wires. And indeed our computers are based on electrical connections between tiny little things called transistors within the computers, which do the processing, and which play our games, or run our Excel sheets, or write our Microsoft Word essays. Now, we know as scientists that an electron traveling from one part of a circuit down a wire to another part of the circuit actually travels pretty slowly. And when it travels, because of the resistance of the wire, it produces heat. That's inefficient. The speed is slow, relatively speaking, even though these new computers are really fast.

Imagine getting rid of the electricity and replacing it with something which travels at the same speed as the fastest thing in the universe. And we all know what is the fastest thing in the universe. It's the speed of light. And in fact, potentially that's what we'll be able to use in the future. Imagine connecting one transistor to another transistor via a light wire down which we send pulses of light at the speed of light. Imagine how much more powerful this sort of thing is going to be.

So on the one hand we are superficially talking-in detail, but nonetheless superficially talking-about structural color in animals and insects, and the biology of that. And that's really exciting. But let's not miss where the potential application of this is. That's in technology. That's in communication. Potentially in a few tens of years optical computers will exist which work on the principle of light signals, as representing the light bits of information, at such amazing speeds that we just can't even begin to understand how powerful they're going to be. There are people right now throughout the U.S., throughout the world, who are working on developing these sorts of things already.

Dr. Biology: I'm sitting here and my mind is just thinking of all the possibilities with light-based computers. But before we go down that path I'd like to ask a few questions I ask every scientist. These are questions that are fun, they're often revealing, and they're always entertaining and educational. To begin, when did you first know you wanted to be a scientist? What was the spark that got you going?

Peter: That's a really good question. My mother was teacher - a junior school teacher, my father worked in science himself, although he didn't stuff the thing down my throat, and I think it was just a curiosity. Each of us has a curiosity. And if we haven't, let's say the curiosity has been stifled a little bit, each of us should develop his or her curiosity. I think the drive associated with this curiosity about the world that I had early on is what has led to me sitting here next to you today.

Dr. Biology: Guess what I'm going to do now. I'm going to take it all away from you. You can't be a scientist, you have to step out of your life as a physicist and the passion you have for science. What would you be, or what would you do, if you couldn't be a scientist?

Peter: [laughs] That's a question I've never been asked before. I could give a frivolous answer that is serious on one level. I'd like to be a professional surfer, or a professional snowboarder, because there is a thrill. And, you know, it's not unconnected. There is a thrill that I think I need, and a thrill that I know everyone else needs. There's a rush of adrenaline which comes from surfing a 10-foot wave. There's a rush of adrenaline that comes from finding new powder in Val de Zere in Austria, or in France, and just losing yourself in the moment, in the thrill of an adrenaline rush.

But even though that's a physical activity, which I would opt possibly to have if you took science away from me, that really is at the heart of why I'm a scientist. There is a thrill that is indescribable, about discovering something new scientifically, about proving something scientifically. That's why many scientists go to work every day, because of that thrill. Not because of a wage, not because of a paycheck, or the need to prove yourself, or anything. It's just the reward associated with understanding a bit of science.

Dr. Biology: Wow. I have to say, you're the first to come up with that as an answer; an adrenaline rush through science. You know, I hadn't thought about it that way, but you're right. I think many of us in science get a rush from the work we do, the experiments we design, the answers we find, and the places we get to explore.

Peter: Yes.

Dr. Biology: OK. Well, how about some advice for someone who might want to get into this adrenaline rush career? Maybe there's a snowboarder or a surfer ready to take the science plunge.

Peter: All parts of science are not for everyone. Lots of different people have different tastes, different backgrounds, they may have been brought up in one way or another, with more influence from biology, more influence from chemistry, let's say. But really I would recommend if you want to try to put a toe in the water, find a topic that interests you. Through "Scientific American," through, "New Scientist, " through one of the more easily accessible type of journals. And if something then interests you, let's say like high-energy physics, or genetics, or experimental field biology, whatever that is, then try to follow it up.

Try to find other articles that would inform you better about those sorts of things. Try to find people-scientists on the web, let's say, or good teachers that you know of who would be able to answer your questions and point you to more resources. But it's up to you. You really have to just follow your ambition, follow your interests. And,well, we're back to this word again-follow your curiosity.

Dr. Biology: You know, that's perfect, and that's what we'll leave the show with. Follow your curiosity. At least follow it to the next episode of "Ask A Biologist."

Right now, Dr. Vukusic, I want to thank you for sitting down with me and taking the time to talk about the world of iridescence. I know that I learned quite a bit today. Every time I do these shows I keep learning. And I plan to investigate more about iridescence, probably starting with your website.

Peter: Thanks Dr. Biology. It's been a real pleasure.

Dr. Biology: You've been listening to "Ask A Biologist" and my guest has been Dr. Peter Vukusic, from the University of Exeter. If you'd like to learn more about his work you can visit his website. The address is -- are you ready -- http://newton.ex.ac.uk/butterflies. We'll also have that link on our website, and it will be in the content log of this program, as well as linked from the transcript of the show.

The "Ask A Biologist" podcast is produced on the campus of Arizona State University and is recorded in the Grassroots Studio housed in the School of Life Sciences, which is an academic unit of the College of Liberal Arts and Sciences. And even though our program is not broadcast live, you can still send us your questions about biology using our companion website. The address is askabiologist.asu.edu. Or you can just Google the words, "ask a biologist." I'm Dr. Biology.