TRANSCRIPT

Key Conversations with Phi Beta Kappa

How Mathematics can Solve Real-World Mysteries with Ingrid Daubechies

In this episode, Fred Lawrence speaks with Ingrid Daubechies, James B. Duke Distinguished Professor Emerita of Mathematics at Duke University and a National Medal of Science recipient. Daubechies takes us from her childhood fascination with calculating multiples to her groundbreaking work on wavelets—mathematical building blocks that have revolutionized image and signal analysis. She talks about how her research helped the FBI compress millions of fingerprints, analyze seismograms, and even distinguish authentic Van Gogh paintings from forgeries. She also tells the story behind the whimsical Mathemalchemy Project, a collaborative art installation that celebrates the pure joy and creativity of mathematics.

Fred Lawrence: This podcast episode was generously funded by two anonymous donors. If you would like to support the podcast in similar ways, please contact Hadley Kelly at hkelly@pbk.org. Thanks for listening.

Hello and welcome to Key Conversations with Phi Beta Kappa. I'm Fred Lawrence, Secretary and CEO of the Phi Beta Kappa Society. Since 2018, we have welcomed leading thinkers, visionaries, and artists to our podcast. These individuals have shaped our collective understanding of some of today's most pressing and consequential matters, in addition to sharing stories with us about their scholarly and personal journeys. Many of our guests are Phi Beta Kappa Visiting Scholars who travel the country to our Phi Beta Kappa chapters, where they spend two days on campus and present free public lectures. We invite you to attend. For more information about Visiting Scholars' lectures, please visit pbk.org.

Today, I'm delighted to welcome Professor Ingrid Daubechies. Professor Daubechies is the James B. Duke Distinguished Professor Emerita of Mathematics at Duke University. Her recognitions are many, including receiving the National Medal of Science this year, which is the highest recognition the United States can bestow on scientists and engineers. Her academic work focuses on mathematical methods for the analysis of signals, images, and data with applications in many directions. Most recently, she has led a collaborative mixed media art installation that celebrates the beauty, creativity, and fun of mathematics called the Mathemalchemy Project. Welcome, Professor.

Ingrid Daubechi...: Thank you very much for welcoming me, but please call me Ingrid.

Fred Lawrence: Delightful to be with you today. Thanks for joining us. Let's start with a little bit of your background, which may or may not have been the obvious beginnings for a mathematician and a PhD physicist. You're born in Belgium, the daughter of a criminologist and a civil mining engineer, that doesn't seem to be the most likely background for a prize-winning mathematician, theoretical physicist. Can you tell us a little bit about your childhood and where you grew up and were you always interested in math?

Ingrid Daubechi...: Well, I was always interested in understanding why things work and understanding, seeing things, connecting them with other things I knew. And so yes, I was always, I think, interested in mathematics and for instance, understanding how it could be that when you saw a cube, it didn't look like a three-dimensional object. It looked just like two almost squares connecting in the middle if you just put yourself at the right height and things like that.

I don't really view my interest in mathematics as different from wanting to understand things. Of course, once you want to understand, you start seeing that some arguments that you figured out in one situation also apply in a completely different one, and that's all that mathematics does is it defines concepts that are useful. It gives them names, it studies them, it then looks at connections between them, and of course, you can take this very, very far and mathematicians do, but that's what mathematics is.

Fred Lawrence: So Galileo said that math is sometimes translated from the language that God used when he created the universe, does that relate to what you're saying?

Ingrid Daubechi...: It's the language that we certainly use when we want to understand and connect things. I do believe that the mathematics we use is mathematics we make with our minds. I believe it's something we observe and our observations are based on the world around us. So in a sense it's not independent of that, but it certainly also has to do with our brain. We see certain connections and we explain to others who may not immediately see those connections, but we then use lots of arguments and metaphors and so on. So we teach each other, and so as a community we get further than each individual can, but it's a very human activity.

Fred Lawrence: So then does mathematics actually help us understand how things work or is it just a description of our understanding of how they work? That is to say, is it intrinsically how they work or just our understanding of how they work?

Ingrid Daubechi...: It's certainly, I believe, our understanding of how they work, but we are part of this world and so we try to make sense of everything around us and we hope that we understand a lot and we are very ingenious about thinking of ways in which we can understand things that are not immediately obvious to us. That's what scientists do and so on, and then on all that we apply again, those principles of mathematics and we name concepts, we reason with them. We hope that pure mathematicians have already studied something that might be very useful for us, which has happened many times in physics and is now happening in biology. So we are very good at teasing out things that might not be immediately obvious to our senses, but they rely on experiment and so on.

Fred Lawrence: Now, I do want to go back to your path a little bit. So I have to ask, is this story about the little girl who puts herself to sleep doing not just numbers, but multiples? Is this true or is this an apocryphal story?

Ingrid Daubechi...: It's absolutely true. In fact, my husband, we laughed a lot when we first met. We quickly discovered that he had done the same. There's a phase that almost all children go through where they try to name numbers higher and higher and higher, and they're fascinated by the fact that they have discovered that they have understood the rule, which is that you make bigger and bigger numbers, and so then they enumerate them, 131 and 132 and so on. Once you've understood that it's kind of boring, the number, X number, it's a very fixed rule.

And then you learn about multiples 2, 4, 6, 8. But again, it seems, the evens, I don't know when this happened, but certainly it was when I was fairly little, six or so, taking the double every time and numbers get quick so quickly. So they get big.

Fred Lawrence: Yes, you're up to 512 and 1,024 before you know it.

Ingrid Daubechi...: Exactly. And that's just the 10th number in the series at 24. So then I would try to manipulate those in my head and go back, have I made a mistake and so on. In a sense, it makes you realize, exponential growth I know is something that goes very fast because I did those early computations when I was a little girl.

Fred Lawrence: And of course, when you were doing that as a little girl, you couldn't remotely have thought of it as academic work, which is precisely the point for you. It was a mixture of fascination and fun. It was a pleasurable experience to do this in a way that shows that what children innately understand and what sometimes as adults we have to recapture is this connection between academic inquiry and just the sheer delight of discovery.

Ingrid Daubechi...: Yes, absolutely. And I remember, well, the intellectual part of childhood was discovery all the time and discovery of what one could do, what one could find in books, what could read, what one could understand, what one could connect. I loved learning. I still to this day love learning new things. I'm the kind of person who, not always but on a plane when I get to choose something to watch, certainly about half the time I choose documentaries because I love learning these things about nature usually. But it's fascinating too, and then usually, you see, you have these aha moments of, oh, I actually knew that, but I didn't know that was underlying it.

Fred Lawrence: Right. Or even that experience of I knew that, but I didn't know that I knew that until I heard that explained that way. In some ways the definition of true genius, even something, elements of the special theory of relativity - I don't want to suggest that you could put the special theory of relativity on a matchbox, but on some level, some of it does have that sheer moment of saying, I think I kind of knew that, but I didn't know that I knew that until I heard it explained to me that way.

Ingrid Daubechi...: And about special activities. So people see this enormous, this brainchild of Einstein, which it was, and this enormous revelation must have come to him from, and people describe his gedankenexperiments of sitting on a light ray and what would happen if you did that and so on. But at the same time, he was then working at the Swiss Patent office, and one of the patents that he worked on was schemes that different railway systems in Europe, which were starting to have to connect well with each other, had to try to synchronize all the clocks of the different systems. Because to have a schedule, you have to be on the same clock. So the idea that you had to be able to send signals from one to the other to help you then both have synchronous clocks from then onwards. Now it's so obvious once you learn that that must have had an influence on how he thought of special relativity.

Fred Lawrence: That's right.

Ingrid Daubechi...: So what I love about that story, which was uncovered by a historian of science at Harvard whose name escapes me right now, but it's fascinating is that it connects with this very different preoccupation, this bread-winning occupation at the time, impulses then influenced his very deep intellectual thinking. I think that happens to us all the time.

Fred Lawrence: So tell us a little bit about what field that discovery is about, and if you can mix both the math and science with a little autobiography in terms of your journey to this discovery. How did you find your way into it and what is it you found your way into?

Ingrid Daubechi...: For my PhD, I worked with Alex Grossmann on mathematical techniques that turn out to be really useful in semi-classical approximation. So what you dare try to do is you are sitting on the bridge between quantum mechanics and classical mechanics. Classical mechanics is the one described by Newton's laws and late developments in the one which we are familiar with in our everyday life.

Fred Lawrence: And answers most of the questions that most of us would have in our everyday lives given that we exist on earth not in outer space, and given that we travel well below the speed of light.

Ingrid Daubechi...: And that mechanical engineers use all the time and with which a lot of our technology is built except electronics. But then in quantum mechanics, which applies to atomic physics and nuclear physics and so on, you find that in the realm of the very small, which is what they discovered about, well, a hundred years ago, that physics doesn't apply. There seem to be only certain energy levels, for instance, at which electrons live within atoms, not the whole continuum as you might, if you have the model of something turning around a nucleus electron turning around or nucleus, there's no reason why in principle, in classical mechanics, that would only be possible at certain energy levels as we have found experimentally is the case, and so quantum lives in a different realm and it's governed among other things by this uncertainty principle that you cannot, with high precision, no form of particle, both its position, its momentum at the same time.

Fred Lawrence: Right. Heisenberg's great discovery is giving us both a physical principle, but a philosophical principle of what we can know and the literal limit of what we can't know, sort of an anti-enlightenment principle, that it's not about just continuing to apply ourselves and then we'll know everything. There are some things that actually are not knowable or at least in tandem, they can't both be known.

Ingrid Daubechi...: It applies to sound waves also. We are all familiar with this idea that a wave through a medium can be visualized on a computer screen as this undulating shape that goes up and down in a very nice, smooth, regular way. We're thinking about just a simple sine wave here, not something very complicated. Often when I give a talk about this, I show people a sine wave and then I show another one that oscillates just a little bit, but significantly that you can see. Instead of having all these four oscillations on the screen, I have five full periods. So people see and I say, this oscillates a little faster. It's a higher tone. You would hear that difference.

But when we hear things, we hear actually many, many, we hear a short time instant that is many of these oscillations because we actually hear at thousands of oscillations per second. That's kilohertz. If instead I heard only a tiny little bit, something that's maybe, I don't know, an eighth where the wave is going up from what I was showing on the full screen. If I show that for both those waves, you can't make a difference. You cannot tell.

If you want to know very, very, very precisely in time, then you will not know very precisely in frequency because it doesn't give you enough information, and that's actually all that Heisenberg's principle is. Then there's the fact that microscopic physics can be described by things like waves. That's a very spectacular thing. It's the wave mechanics of Schrodinger and so on, and once you have that, you also have the Heisenberg uncertainty principle.

In any case, I was working on this correspondence to classical and quantum mechanics and a tool that you use there is essentially understanding things in terms of waves, which is called Fourier analysis, and standard tools that are used in this correspondence turn out to be useful to understand lots of things where you use waves. For instance, signal analysis, which has nothing to do with quantum mechanics.

Fred Lawrence: I understand what grows out of all of this work then has application in what seems like an astonishing range of circumstances.

Ingrid Daubechi...: Of course.

Fred Lawrence: This helped the FBI compress millions of fingerprints and computers, analyzing seismograms from earthquakes, working with fossil experts, distinguishing true Van Gogh works from forgeries. Can you take us through just a couple of those and tell us how your work has elucidated what seems like an unconnected set of projects?

Ingrid Daubechi...: So wavelengths decompose into building blocks that localize in both time and frequency, but they do it over a very short time when the frequency is high and longer times when the frequency is low. And we were talking about some signals and there are many other signals that depend on just on time. But if you think of it in two dimensions, it turns out that in images, this is very much the case as well. In images, if you just think of any image, a snapshot of the surroundings where you sit now, then there are places, if you took a high resolution snapshot where all these pixels live, then in many places the pixels would be very similar to their neighbors because there's a gradual change in light or color or intensity in the image.

But at any place, because it's not preordained where you have sudden transitions, you might also have a sharp transition between light and dark. And so that's very short-lived, especially in your image. And you need something very tiny that can have big changes to describe that. So you will need big wide stretches where not much is happening, and also the ability to pinpoint small changes, and that's what wavelengths allow you to do. Because they have a fast way of decomposing things in such building blocks, they have so many applications because there are many applications where that's exactly what you want to do. You want to have the sharp delimitations of objects that are moving in the field and not care about things where not much is happening.

In fingerprint compression, you want to know both the location of the big swirls, but you also want to know the location of small sweat pores on the lines or small little islands between the lines. So you want things at different scales. Whenever you are interested in things that happen at different scales in your data, something like wavelets is a good idea.

Fred Lawrence: So talk to us about the Van Gogh forgeries, which I'm sure for many people will be as fascinating as it is for me. How does it apply?

Ingrid Daubechi...: Well, so first of all, I'd like to say, to have a preamble here, that we have worked on applications of wavelets and other techniques in image analysis to a whole range of different art topics, and the distinguishing forgery from a real one is my least favorite of the whole time. But I'm still happy to tell you about it. It's the first one we were asked to do, and so that was introduced because when we first started with people in museums, they wanted to convince them that image analysis could be useful for some of the questions they were interested in, they didn't really know what questions to ask us.

And so that's a question they ask, and so what happens is that when you start looking at things over many different scales, you can look at how much fine scale information there is compared to things at much coarser scales, and you typically find that the fine scale information is very different in something that's not drawn freehand, and many forgeries are drawn much more meticulously or painted much more meticulously by somebody who's trying to make a forgery than the freehand artist would do, and so you start distinguishing that in these very, very fine details.

Now, I consider this only as a possible additional tool for art experts to have in their toolbox to make such attribution decisions. They have many other tools that they typically use, and I actually know of no case where wavelet analysis was decisive in making an attribution decision or not, and the reason it's my least favorite topic is that I do get contacted by people who believe that they picked up at a flea market or inherited from their Great Aunt a true Van Gogh, and could I please pronounce on that? And I don't touch things like that with the stick.

Fred Lawrence: That's not what the work is designed to do.

Ingrid Daubechi...: No.

Fred Lawrence: Tell us about the Mathemalchemy project, which is, I understand it began in 2020 as a collaboration with a fiber artist, Dominique Ehrmann, and a number of other artists and artistic mathematicians as described on the website, and you built a large multimedia installation that, I'm using your words now, "Celebrates the creativity and beauty of mathematics." So tell us about how this all came about and what its impact has been?

Ingrid Daubechi...: So I've long been fascinated with objects, beautiful objects that delight many people in mathematics as well as many laypeople because of their symmetries there and sometimes of the slight ways in which they deviate from symmetry. I mean the combination of. So at the joint meetings of the American Math Societies, there is always an exhibition space where mostly mathematicians, but also artists have, it's a juried exhibition, where they expose objects that they have made that illustrate something interesting mathematically or that are just delightful.

I had wondered how combinations of these could work, could act, and in 2019, I saw a work by Dominique Ehrmann, who I didn't know then, which was textile based art, but it's called Time to Break Free, and it shows a quilt that gets contorted because it's being aspired by a kind of steampunk machine that is then, the whole thing is static, but it suggests that time will then take these ingredients of the quilt and process them and transform them and out step out of a big horn step the characters that were just appliquéd on the quilt as 3D characters, confidence stepping into the world. I thought, oh wow, this transformative effect, maybe we can make something like that.

Together with all these people because I could see this was hours, thousands and thousands of hours of work, and of course I was not going to ask her to do something like that, but maybe we could work together and make something that showed the transformative aspect of mathematics. I contacted her and she was just thinking of what she would do next, and she was game, and we talked about it, and then we proposed it to the next joint meetings in 2020.

And we said, "Okay, if this is a collaborative project, if people don't step up, then we've had fun and that's it. But if you do, then let's do it. Let's work on it. Let's design it. Let's make a scene that tells stories in which math plays a role, and mathematical customs are magical." So it became a magical world in which critters live in a different world with objects and customs that are very mathematical, and that refers to many mathematical things.

So it's beautiful because it enchants children because they're chipmunks and squirrels and a turtle and an octopus. It's also, when you look further, you see mathematical things illustrated, and so it was a full range from elementary school kids to research mathematicians. So we were going to build it in workshops where we would come together, and I had found funding from the Simons Foundation for the travel that was necessary to bring us together in these workshops where we were going to physically make things, discuss and physically make things, and the first workshop was the third week of March 2020. And of course that…..

Fred Lawrence: Well, that was bad timing, wasn't it?

Ingrid Daubechi...: Yes, exactly. And we decided to not let it interrupt us. We decided we're not going to postpone. We're not going to cancel. We held our first meeting the third weekend of March in 2020 on Zoom. That's when we all learned Zoom and breakout rooms and all that, and we designed something. Over the next three months, we met weekly, and some groups met more frequently and reported them at the weekly meetings on the weekends. And after three months, we had designed the whole thing and Dominique put the brakes on and she said, "It's time to start fabricating." And then we started making things at home.

Fred Lawrence: Great project. I always ask my guests on Key Conversations to help our listeners build their book lists and their bookshelves, and I wonder if you could help us with a couple of suggestions, both for those for whom these concepts are either new or maybe some mathphobes who I hope you have brought around to thinking you're not really math phobic at all, and it's never too late to start, as well as some folks who have some background in the area, but would like to learn more about kinds things we can talk about.

Ingrid Daubechi...: Absolutely. I think a wonderful little book is a book that's called *Mathematics: A Very Short Introduction* by Tim Gowers. Tim Gowers is a very high level mathematician. He got a Fields Medal and so on, but he also really believes in bringing mathematics and explaining mathematics to lay people. He actually, during the pandemic, saw it as a very important part of his job to make people in policy circles understand exponential growth. Somebody else who's written a number of different books, which I think are absolutely wonderful, is Stephen Strogatz, who again, is a very high level mathematician. He's a member of the National Academy of Sciences and so on. But he has a podcast, actually, which I think I would recommend to people. But he also has written books, *Sync: How Order Emerges From Chaos*.

Fred Lawrence: Emerges From Chaos. I love that.

Ingrid Daubechi...: Yes, and *Infinite Powers*. And then there's one book, actually, which is a lovely book for people who are interested in how mathematics can be a background in a mentorship, in a friendship, and so on, which is called *The Calculus of Friendship*, which is a book in which he talks about his long time correspondence with his own calculus teacher. So these are books I think that will, first of all, illustrate to people who are mathphobes, that mathematicians are people with interesting and lovely emotions, but also introduce them to concepts and to mathematical thinking that is so different from what they may have remembered from math at school.

Fred Lawrence: Well, it's clear that in your time with us as a Phi Beta Kappa Visiting Scholar, you have communicated not only great stories, but also just the sheer enthusiasm for trying to understand the world and the ways in which mathematics has helped you do that, and in fact, I venture to say that most people have intuitively done as well, but not labeled it that. And so in some ways, what you're really doing is unearthing for them their own background in mathematics.

Ingrid Daubechi...: Absolutely.

Fred Lawrence: So I'm so grateful for you playing that role for us as you have in so many other campuses, but you did for us this year as a Phi Beta Kappa Visiting Scholar, and thank you so much for joining me today on Key Conversations with Phi Beta Kappa.

Ingrid Daubechi...: You're very welcome. It was a pleasure.

Fred Lawrence: This podcast is produced by Phantom Center Media and Entertainment. Kojin Tashiro is lead producer and mix this episode and Hadley Kelley is the Phi Beta Kappa producer on the show. Our theme song is Back to Back by Yan Perchuk. To learn more about the work of the Phi Beta Kappa Society and our Visiting Scholar program, please visit pbk.org. Thanks for listening. I'm Fred Lawrence. Until next time.

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