**INTERVIEWER:** Today is December 7, 2015. I'm Joe McMaster. And as part of the MIT Infinite History project, we're talking with Dr. Erik Demaine, a professor in the Computer Science department at MIT, a career he began at age 20. Demaine's research interests range across the field of algorithms, from data structures for improving web searches to the geometry of how proteins fold and the computational difficulty of playing games.

He's also a pioneering computer science theorist and an artist. In 2003, Demaine received the MacArthur Fellowship as a computational geometer, tackling and solving difficult problems related to folding and bending, moving readily between the theoretical and the playful with a keen eye to revealing the former in the latter, in the words of the Foundation. Together with his father and lifetime collaborator Martin, also at MIT, Demaine explores and celebrates the connections between mathematics and art.

Museum exhibits and film documentaries showcase his collaborative origami and glassblowing creations, which themselves are intricately related to his mathematical studies and research. He's the co-author of several books, including one on geometric folding algorithms that is considered the leading authority in the field of computational origami, which he started. Demaine has received world wide recognitions, including a Guggenheim Fellowship and numerous teaching awards.

After being home schooled during a peripatetic childhood, he received his Bachelor's degree from Dalhousie University at age 14 and his Master's and Doctorate from the University of Waterloo at age 15 and 20, respectively. Welcome, and thanks for talking with us.

**DEMAINE:** Thanks. Pleasure to be here.

**INTERVIEWER:** So computational origami-- maybe we can just start there. That sounds fascinating.

**DEMAINE:** Sure.

**INTERVIEWER:** And for someone who doesn't know really what that is, what is it?

**DEMAINE:** Well, in general, computational origami is the fusion between computer science and I guess the originally art form of paper folding. And there are a lot of different goals. But the initial goal was to advance the frontiers of what is possible artistically with paper folding, using mathematical and computational tools to aid the design to automate some of the harder geometric aspects.

I got interested in origami because it offered such a cool geometric playground where you have pretty hard constraints, which is usually one square of paper, no cuts, just folding. The material can't stretch. That's the mathematical model. And what can you do with just folding? It's a neat challenge. And the mathematics turns out to be surprisingly deep and surprising.

You can make pretty much anything just by folding. And then that's fed into the art side. And then more recently, it's fed into a lot of different engineering and scientific applications, too. So it's grown into this world of geometric folding in general. What can you do not just by folding sheets, but folding mechanical robot arms and proteins and things like that. So in general, it's all about what you can do by reconfiguring an object, how it can change in its geometry and morph from one thing to another.

**INTERVIEWER:** So what got you interested in origami originally? Was it the mathematics, or just--

**DEMAINE:** Yeah. I was just starting out as a grad student. I knew that I liked computational geometry. I came at it from a physical simulation world. As an undergrad, I worked at an oceanography department simulating plate tectonics. And that led to a whole bunch of questions about meshing and computational geometry in general. I took a computational geometry class. It seemed really neat.

But I needed some new ground to explore something that no one had looked at before. And computational origami was just getting started. There were two papers on the topic. And it sounded like fun. So we started working in it.

**INTERVIEWER:** And the computational side is enabling you to visualize and then do things that you couldn't?

**DEMAINE:** Ideally you have algorithms to design form sort of from scratch. You say I'd like something that looks like a bunny. And then it says here's how you fold it. And there are different versions of that problem. The first problem that we started looking at is the fold and cut problem. So the challenge is I give you a piece of paper and I draw a shape on it, a polygon.

It could be New York skyline or the silhouette of a swan or something. And then the challenge is can you make that shape by folding the piece of paper flat, making one complete straight cut, and unfolding the pieces. And you want to get the swan and the complement of the Swan, or cut exactly what you want with one cut. And that we ended up solving. It turns out it's always possible. But it took a couple of years to prove that.

So there are a lot of design challenges like this and you want to automate that process. So there's an algorithm, there's a computer program that you can give a shape and it will tell you exactly how to fold it. You do it. Make one cut. You have your magic trick, essentially. Harry Houdini used to do a magic trick where he'd fold a piece of paper, make one straight cut, and make a regular five pointed star. That was in the '20s. And it goes back even hundreds of years before that. So it's really neat to see what's possible in general.

**INTERVIEWER:** Yeah. That's great. And so tell me a little more about what some of the applications are or other ways this has been taken up actually.

**DEMAINE:** Well, the fold and one cut problem turned out to have applications in airbag folding. So if you have a three dimensional airbag and you want to collapse it flat so that you can store it like inside a steering wheel or the side of the car, how should you collapse a 3-D surface into a flat thing? And airbags fold kind of like paper, although they're a little smoother. You still have no stretching.

And so we didn't work directly on that application, but other people applied our techniques and other techniques to do that. So that was a fun surprise. We were motivated by magic tricks essentially and we ended up impacting safer car designs. And other origami design problems-- like more recently, we've been looking at folding robots. So in general, we have a lot of tools for manufacturing two dimensional sheets. Laser cutters, water jet cutters.

It's really fast and easy to make a 2-D cutout. But it's still pretty slow and tedious to make 3-D stuff like 3-D printing. And it's more expensive and so on. So we've been looking with Daniela Rus's group at MIT and Rob Wood's group at Harvard how to manufacture three dimensional robots that function like regular robots, but just using sheet materials. So there's a big folding component there where you want to cut out your robot, fold it up out of a flat sheet-- fold it up into a 3-D thing, and it locks together and then you drop in a motor and it starts walking around or doing whatever the robot's intended to do.

And this is really exciting, because it becomes both fast and cheap to make custom robots. You can make a robot that no one has made before in a couple of hours by hand with $10 or $20 worth of materials. That's the sort of target. And so that's really exciting. And folding is a big part of that. Another context is in nano assembly. So we can also make robots fold themselves into the 3-D structure.

We had a paper last year about where we cut out a robot-- you know, assembled just flat things, drop in a motor and a battery, and tell it to turn on. And then the whole thing folds into the 3-D thing and walks away without any human intervention. So self folding is another cool direction. And that has applications in the nano manufacture world where you can't get your finger so small that you can manipulate your nano structure.

And again, we're really good at patterning 2-D nanostructures, like when you do chip fabrication with lithography. We can make really intricate and incredible 2-D things, but 3-D is a lot harder, especially at that scale. And so folding-- this is still more in progress, but folding is a way to take those 2-D nanostructures and fold them into interesting 3-D structures. So it's been exciting to see.

I mean, when I started in the origami world, it was just a few people. And most questions were open. So it was really exciting. But we had no idea what the applications we were. We were just motivated by it's cool and art and so on. And in the last five years especially, there's been a big push for origami based engineering. There's a big NSF program to fund a lot of different groups who were interested in origami and now they're pursuing it as a big thing.

How can we use folding to make new engineering structures? Another classic example is if you have something big that you want to make small, either for transportation or storage-- like in medicine, you want a stent that can go through smaller blood vessels and then expand when it gets to a big blood vessel and remove clotting in your arteries. Or if you're sending something out into space, you need to make something small so it fits in the space shuttle and then it can expand when it's out in space.

Those are deployable structures. So there's all sorts of different contexts where you want to change your geometry somehow. And so it's been fun to be at the center of the mathematical and the computational piece, and then that has grown into all these different applications.

**INTERVIEWER:** Yeah. And you mentioned protein folding, too. So where does that come in?

**DEMAINE:** Right. Protein folding. So that's a more one dimensional folding structure. Instead of a 2-D sheet, you have a chain of amino acids. And it's a big mystery how they fold. It's so small that we can't really see the folding process. We can see some of the folding results and speculate about how the process happens. So that's still unsolved. But we've looked at a lot of geometric problems of if we were nature trying design a folding structure that behaves like, given what we know about proteins, how would we design something that could fold efficiently?

Because in general, folding 3-D robot arms is actually quite difficult. So there must be something special about the 3-D chains that nature produces that makes it easier. And so trying to figure out what that is.

**INTERVIEWER:** So it's obviously incredibly interdisciplinary.

**DEMAINE:** Yeah. Yeah. It's a pretty interesting. It has a lot of different people from different backgrounds interested in folding. We've grown a big computational geometry contingent. Then there's the people who started-- a lot of people start from the art side. They've been folding origami since they were a kid. Then they discover mathematics and then try to combine them. And then there's the engineering people coming in.

It's like, oh, this seems like a cool way to solve my engineering problems. And so yeah, there's a lot cross disciplinary stuff. And it's a lot of fun. I like working with lots of different people and different backgrounds. You learn a lot more that way. And you can make things that no one person with one background could make.

**INTERVIEWER:** Right. Right. Yeah and so some of your work and the work that you and your father, I understand, have done has made its way into well known museums and stuff. Maybe you can tell me a little about that.

**DEMAINE:** Yeah. So we'll talk a lot about my dad I guess, because he's been a big, big factor in my life. But his background is in visual arts. And he was following me around because I went to university really young, and attended a lot of my classes just to make sure we could still speak the same language and have someone to talk to. And then when I started getting interested in more theoretical computer science and geometry in particular, he saw a lot of connections between what he knew how to do in solving visual problems and got intrigued by solving more mathematical geometric problems.

And he saw a big connection in the kind of creativity you needed to do both of those. And so then he got interested in mathematics and started learning computational geometry. And we worked on the fold and cut problem together. And so that brought him into the math world. So it was natural for him to at some point bring me back into the art world. And we did a few experiments early on, but where we really hit it big was when we started looking at curved creases.

Curved creases are still a big challenge to understand mathematically how they work, what's possible on the mathematics side. And so we started exploring what's possible. And we were folding different models to see if we do this, what happens? If we do this, what happens? And the models turn into something beautiful. And so we started getting interested in the can we just make sculpture out of curved creases.

So it was a natural progression. Of course, my dad was really excited about that direction to get more into the art side. And almost immediately, we hit it big with-- the MoMA contacted us and they said, hey, we hear you're doing something interesting with computational origami. Do you have any pictures to send us? And we had just made, I think, a couple of examples that we thought were really cool.

And we sent them photographs. They said yeah, we're doing this show Design and the Elastic Mind. We'd like to have your pieces there. And then they later acquired those pieces. So that jump started my art career and our joint art career. And since then, we've been making curved crease sculpture pretty much nonstop. And it's been growing and growing over the years. We've had lots of exhibitions.

And it's a really exciting part of my life. And it integrates well with the math and science side as well. So we view-- especially with the origami projects, but a lot of different projects, we always think about, okay, there's the scientific questions and the mathematical open problems. What can we do there? And then there's the artistic expression questions like what could we make that would be really cool that expresses the same projects?

So they have different outputs, different potential outputs for the same project. Curved creases is that the big example of that. But it's fun, because often we'll get stuck in one direction and then we have the other output that we can explore. Like recently, we finally made progress on the mathematics of curved creases. But for a long time, it was just sculpture. And it was nice to have-- you're twice as likely to have productive results if you have two possible ways you can come up with output.

And it's just fun. You get a lot of inspiration either building something, you have ideas for new mathematical concepts, and you have new mathematical concepts that inspires new things that you can make and turn it into sculpture.

**INTERVIEWER:** Yeah. Mind and hand.

**DEMAINE:** Yeah. Exactly.

**INTERVIEWER:** Yeah. So speaking of your father, maybe you can take us back to--

**DEMAINE:** Sure.

**INTERVIEWER:** --this story we alluded to in the beginning. But, growing up and how you ended up ultimately getting to MIT.

**DEMAINE:** Yeah. So let's see. So when I was seven, my dad thought it would be cool to travel around as an alternative educational experience. He was always a little untraditional, let's say, when it comes to education. He thought it would be neat to experience more cultures around North America by living there and experiencing them. So we started in Halifax, which is where I was born, and then travelled to various places along mostly east coast of the US.

We did lots of little stops, and then the big stops were Miami Beach, Providence, Rhode Island-- near here-- Traverse City, Michigan, and Chicago I think. The longest one was Miami Beach. That was like two or three years. Anyway, so it was really fun. Got to see lots of different places, meet lots of different people. But I think the big thing was the bond that my dad and I formed during that time.

Travelling together is really, really special. And he treated me like a peer in that world. So we would decide where to go next together and when we were tired of a place together. And it wasn't like, okay, we're going here now. It was like hey, I was thinking about Miami because it's really flat and we can ride bikes everywhere. And it's like, oh, that sounds cool.

And so we've always been colleagues at many levels. In fact, before we started traveling, we had a company together called the Eric and Dad Puzzle Company. This is when I was five and six years old, I think. So I don't remember it too well, but I guess I helped design puzzles. And then my dad would make them, and we sold them to toy stores across Canada and split the money 50-50.

So it was always a lot of fun together. But then traveling, I think we got really close. And in particular, we did home school, initially because we were not stopping anywhere very long. So it was the only way to do schooling. But then home school worked out really well for us. I got to move really fast in things that came easy to me. And so we could set our own pace.

And there are just so many things we liked better about home school than regular school. We did school pretty much every day of the week and every day of the year. So including through the summer. And as a result, it was like one hour a day of school. And we could get so much more done by not forgetting everything over the summer and then remembering it again in the first half of the year.

So we could make it our own and make it really efficient, in particular. And so that left a ton of time for me to explore whatever while kids were in school. And then after kids got out of school, then I would go and play with kids. So that's where I got interested in computers, initially from playing a lot of video games. And at one point, I asked my dad-- I was, I think, seven-- how do people make video games?

I didn't know anything about computers at that point. And so he actually knew a little bit of basic programming. I don't know where he learned it, at some point. And a neighbor had a computer that had BASIC on it. It was the early PC days. This was like '89 or something. And so we started-- wrote one video game. It was very simple, choose your own adventure style game.

It used three commands-- print, go to, and stop. And that was it. No state, very simple. But it was whetting my appetite. And after that, I haven't written a single video game, but wrote a lot of computer programs and just started exploring that a lot. And so then at some point, I wanted more. And so I started sitting in some university classes. That seemed like a good way to learn more about computing stuff.

And I was just really hungry for it. And it was really exciting. Where to go next? So I guess I was 11 or so, and my dad also thought, well, for doing computers, it seems like math is a good thing to know. And so he taught me algebra. And then that was about his limit of knowledge. And so then I sat in a high school math equivalency class. They would take a remedial class at the local university-- at this point, we're in Halifax back after the trip.

And at the end of the class, the professor-- I mean, we asked permission. You know, is it okay if I sit-in? And at the end, he said oh, you should take the final exam and see how you do. I was like, okay, why not? I hadn't taken an exam in years. So I went to grade one and grade two regular school, but not since. So I was a little bit not used to exams, I guess.

And so I only got, I think, an 80%. And I was really disappointed. I was like, this should be 100. I didn't know how exams and grading worked. But the professor was really impressed and he thought, oh, maybe you should enroll. And so it was a bit complicated, because Dalhousie University, where I did my undergrad, had a rule that you had to be at least 16 to enter.

And I was only 12. So my dad talked to them a lot and there was a lot of politics and less fun stuff. But he took the brunt of that. And what they ended up resolving-- they've since removed the rule. And a bunch of students have gone younger since. But for me, they said okay. You don't have high school equivalency or anything, so why don't you enroll in the summer as a special student? And if you do okay with a few summer classes, then we'll let you in for real.

And that's what happened. I was so excited I took way more classes than I was supposed to. It was just like soaking up knowledge. At that age, you can learn a lot of stuff really fast. So it was awesome. I took almost entirely computer science and math classes and learned a lot. And then research started coming in I guess in the second half. I did everything in two years, because I was taking so many classes and summer classes and stuff.

So I started doing some research in more applied computer science and networking and supercomputing and stuff like that with-- I guess my first influential academic advisor was Sampalli Srinivas. And we wrote a few papers. And then I went to grad school at University of Waterloo, which is the best computer science school in Canada. And I actually applied to MIT for grad school also, but they rejected me.

So like many MIT faculty, a proud MIT reject. And I probably would have rejected me at that point, too. I hadn't really flourished yet. But then in grad school, I found my element by learning about theoretical computer science and algorithms and computational geometry. I took all those classes for the first time there. And that was really an aha moment where I saw, oh I can-- I was doing research in computer science, but I also really liked math. And I hadn't really found a way to combine them.

And then here, theoretical computer science is pretty much that intersection of computer science and math. So finally I could do all the things that I loved in one place. And that was my calling. And so then I slowed down a little bit. This is my last chance to be a student. So I was a grad student for like six years, I think. So by that point, I had lots of papers and lots of research and had found my niche of my style of research, which is very collaborative working with lots of different people.

And I think at that point, I had something like 40 papers and 60 co-authors. So I always try to keep more co-authors than papers. And I remember interviewing at MIT. That was one of the things-- it was like, it's not your 60 papers that impresses us. It's your 60 co-authors. We really like people who work well with others. Anyway, so then I went on the job market and interviewed at a few places.

But MIT was clearly the place for me. It's got a really nice geeky atmosphere that appealed. And it's the best place for computer science. And just got so much going on and lots of resources to do those things. And the best students, so that's pretty great.

**INTERVIEWER:** That's great. It's a great story. Yeah.

**DEMAINE:** And then all along that way, my dad was following along. Initially because I was super young. And so we lived together during undergrad and grad. Actually, we still live together here. But initially out of necessity and still raising me while I was also going to university. And also, dorms are a lot less common in Canada. And then a funny story there was in grad school, they had this residence called Married Student Apartments, which is normally for either married couples, one of whom was a student, or parents who were students who had children.

Then they could apply for this place and it was really cheap rent and really close to campus and nice apartments. So we applied with me as the parent and my dad as the child who was accompanying me. And that worked out. And they always got a laugh when we had to fill out the forms.

**INTERVIEWER:** [LAUGHING] That's great. That's great. Yeah.

**DEMAINE:** And so when I was in grad school, my dad got interested in math, as we talked about. So then he became a mathematician. And so when I applied to MIT and other places, everyone tried to encourage me to come by also offering a position for my dad and say, hey, he could do research here as well. We already had written probably 20 papers together.

So clearly, we're a productive team. And so my dad started as a visiting scientist. It was like a temporary two year position. But then he fit in really well here as well. And now he has many titles, including his original visiting scientist position. But also he's an artist in residence in EECS and he teaches at the MIT glass lab. And so he's really well integrated into MIT as well. And we've both had a ball here.

**INTERVIEWER:** Yeah. That's great. That's great. So what was it like going to university at that age? And obviously there's a big age difference. But did that matter to you? Or was it--

**DEMAINE:** It mattered surprisingly little. It was pretty cool. I think partly I had just really good cohort and all of my friends treated me as independent of my age. And so I had really good friends. They invited me to their parties. Apparently they kept the drugs in another room. I didn't even know it was there. But they drank in front of me and I wasn't into drinking, so that wasn't a conflict or anything. But yeah, it was really cool. I still have friends from those days. One of them lives here in Boston and we hang out often. So it was pretty sweet. I was certainly conscious that I was shorter than everyone else. And my voice changed pitch in the middle of undergrad. So that was awkward growing up. But it was much more interesting for me to hang out with college kids than to hang out with kids my age.

I tried a little bit. But high school drama just wasn't very interesting to me. So I quickly spent most of my time with college kids. The one hard thing was dating. I couldn't really date anyone, because they were either-- we didn't connect intellectually if they were really young or it wasn't legal if they were college age. So they weren't interested in that. So I had to wait a while to grow up.

I think a lot of my early growth spurts were because I was trying to be like my surrounding cohort. Could have been coincidence, but I grew tall and then grew a beard during grad school. But yeah, for the most part, it didn't really matter, which was really cool.

**INTERVIEWER:** Yeah. That's great. That's great.

**DEMAINE:** Other than the politics of becoming a student in the first place, because of rules.

**INTERVIEWER:** Becoming a parent in the grad school dorms

**DEMAINE:** That's right.

**INTERVIEWER:** And did you say your dad came to a number of the classes and stuff to keep up as well.

**DEMAINE:** Yeah. Yeah, I think initially he was just probably half curious, but also just wanted to know what I was learning. Because he had been so deeply involved in my education process up to that point with home school that he just wanted to keep involved and see what I was learning next. And I think he was casually interested, but not really into computer science at that point.

But it was when I entered the theoretical computer science stuff that he got really intrigued and then learned at a deeper level. And I taught him a lot. And then later he-- I mean, he having taught me a lot up to that point, and then he taught me about the art side later.

**INTERVIEWER:** Right. Right. I mean, it's obviously an unusual story of growing up.

**DEMAINE:** Yeah.

**INTERVIEWER:** I'm wondering are there things that you think other people who don't have those opportunities or whatever can take from it in some way? I mean, obviously not everyone can emulate it exactly or would want to.

**DEMAINE:** I think there are a lot of things that I experienced in my upbringing that more people should at least try. I think home school is a surprisingly easy thing to do. My dad didn't have any education background or wasn't super knowledgeable about any particular thing other than the arts that he was doing. But all you need is a desire to try it out. And there's tons of teaching manuals and so on.

You don't have to design a program from scratch. There's just so much material out there, especially these days with the internet. We didn't have it at that point, but there's so many video lectures and there's OCW, and there's Khan Academy, and lots of things you can learn from even without a teacher. When you have a parent who is interested in your education and it only takes an hour a day, it becomes pretty appealing.

I think a lot of people should at least try home school to see whether it works. There are always kinks to work out-- separation of parent from teacher that can be-- we had to jump through a few hoops to get used to. My dad used to send notes to my parent. So he would send notes to himself. So he's like in teacher mode. I would go outside the apartment and then come immediately back in and it would transform into school.

And he would send a note back to my dad. You know, it was all in jest. But it provided that separation. And I'm sure it doesn't work with all kid and parent pairs. But I think it's at least worth trying, because it can be a really powerful way to learn. When you have one on one-- the ideal teaching student ratio-- you can really explore a lot of things that you care about.

So I think home school is definitely worth more people trying, especially in countries where it's legal, like in the US and Canada. So it can be harder in some other countries. But in general, I would love to adapt that kind of flexible teaching model to even more traditional schools as well. I've seen a few schools do that rather successfully. But that's a little bit outside my wheel house. I know the university setting a lot better. So that's one thing. I thought there was another, but I'm forgetting.

**INTERVIEWER:** So are there-- I mean, have you found--

**DEMAINE:** Oh, right. Sorry.

**INTERVIEWER:** Yeah, please.

**DEMAINE:** I think I think going to university young is actually a really appealing thing as well. And certainly not everyone can do that. But I think actually a pretty large fraction of the population probably could. And you need a certain level of maturity just in how you handle yourself and being comfortable exploring things by yourself and that kind of thing. But I feel like you don't need to know much to go to university.

That you can pick up a lot as you go along. I think freshman year, a lot of it is review of high school. So I didn't know that much of high school really. And I just picked it up as I went along through the early classes. I knew a lot about computer science and math, but everything else I was starting from zero. And that seemed okay. And so I think while it sounds scary to go to college early-- in fact, there isn't that much background required because people come from all sorts of different entry points.

And assuming you can get admitted in the first place, you can pick up what you need to know, assuming you have that desire. So I hope it becomes a lot easier for kids to do that. Because there are a lot of kids who are basically learning nothing in high school and should just go to the interesting stuff, which I think is university. And as it becomes more popular, I think it should become easier.

**INTERVIEWER:** Do you think-- Does all this digital learning, which of course MIT and many others are very involved in--

**DEMAINE:** Yeah. I think that helps a lot, because you can-- I mean, on the one hand, you can build your own university environment. You can find the thing that you're really excited about and push ahead and just start taking university level classes without having to jump through any hoops. It's just available. And it probably also helps for the admissions side, because you can demonstrate your aptitude.

You can say, hey look, I took MIT's 6.001 or whatever. And now I took the exam and all that. So you can demonstrate that you're working at that level without necessarily being in the traditional schooling environment. So yeah, I think it's pretty great. It would be interesting to see how I would construct a home school now. It would probably involve a lot more video lectures. We didn't have any of that available.

**INTERVIEWER:** Right. Right. Did these experiences-- you know, now being a teacher. I mean, how have they influenced that process? Or have they?

**DEMAINE:** Yeah. That's a good question. Probably I hadn't thought about this. But definitely my dad always found-- I mean, his view was always to try to keep me entertained. So he would try-- for the stuff that we needed to cover but I didn't really enjoy, he would try to find a really fun way to cover it. Like history didn't interest me back then. So he would turn it into more of a storytelling environment, covering the same material but in a more engaging format.

And so that, I think, has influenced my teaching. I think of teaching as essentially an entertainment role, at least the lecturing part. I want students to have fun. And I think if they're having fun and they see how excited I am about the material, then they'll get excited and they'll engage with the material more. So I think there's a connection there.

**INTERVIEWER:** Yeah. How do you do that? I mean, how do you make things fun in your case?

**DEMAINE:** Yeah. How do you-- it's like how do you be creative? I try to use props. I study improv comedy. That's probably the big way for a few years. I have a diploma in improv comedy. And so I try to improvise and keep things exciting for me, and always changing lectures in little ways to make them cleaner, better, what I imagine. But also not being afraid to, if a student asks a good question, to go off on a tangent and explore that.

So yeah, I try to have fun with it. I figure that will be contagious. But fun examples-- I mean, a lot of my research is fun also. So I'm trying to bring that into the classroom and show how you can explore neat things, not just serious things.

**INTERVIEWER:** And so you say you studied improv comedy?

**DEMAINE:** Yeah. So at Improv Boston-- it's down in Central Square-- they have a series of classes. My dad and I took them all the way through. We had a show together, which was an improv reality show with our fellow students. I had later did an improv freak show. I was a bearded lady. That was fun. And yeah, so I haven't done any shows since then. But I still really enjoy improv.

And I feel like it's actually kind of a way of life. You learn a lot of neat life lessons, especially general teaching lessons and being used to thinking on your feet and that kind of thing. But the core principle of improv is called "yes and" And the idea is someone makes a suggestion to you-- like in improv, they act like you're their brother or something. Then you always accept it and then you build upon it. So like yes, I'm your brother. And actually, we're twins, and that kind of thing.

So that's actually a really powerful way to live life in general, but especially research and teaching and things where someone suggests an idea. Like, hey, I think it would maybe be interesting to look at this research problem. And then instead of saying, well, I don't know. I'm kind of busy. It's much more effective to say, oh, it sounds cool. And maybe we could bring it in this direction.

I mean, it can lead to over commitment. But it generally makes life more fun to live, I think. And so it guides the way my dad and I do art together and the way we do research together. And we try to spread it to the world. But that having both gone through that experience, we really see how nice it is to always be encouraging and building on each other's ideas. It leads down crazy paths. And we don't follow all of them, but it's a lot of fun.

**INTERVIEWER:** That's neat. So tell me about the MacArthur and-- well, I mean, people always wonder. What happens? Do you get a phone call out of the blue?

**DEMAINE:** Yeah.

**INTERVIEWER:** How does this work?

**DEMAINE:** Pretty much. I had no idea anything was happening, which is how it's supposed to work. It's a funny story. This is back when I still had a home phone. These days, almost everyone's on cell phones only. But I still had a home phone. But no one ever called it, pretty much just telemarketers. So the phone rings and I was about to go to school. I was like, oh, I don't know. I guess I'll answer it.

And it's like hello, this is so and so from the MacArthur Foundation. I'm like, oh, they're going to ask for a donation or something. But then they kept talking and it became clear I was getting some award. I was like, whoa, this is cool. I didn't actually know about the MacArthur Fellowship at that point. But I had whispered to my dad this is MacArthur. And he had been Googling it meanwhile. He's giving me thumbs up.

And so suddenly, I realized I was on the phone with the entire committee who had decided to give me this thing. So it was pretty exciting. It was basically my first big award other than becoming a professor at MIT. And to me, it was a big moment, kind of a defining moment of recognition that what I was doing was okay. Because my research tends to be a little on the recreational side, you might say.

I explore problems because I think they're fun, not because I think they're important. And often, these actually coincide. But that kind of-- it's a little risky to say, hey, I'm going to explore origami because I think it's cool. And then it turned out to have applications. That was lucky. And a lot of the things I explore work out that way where I can say, oh this is just cool.

I want to study the mathematics of magic. But only later do you see where it could be quote useful. And mathematics tends to have this role where, you know, Boolean logic-- no one knew what it was going to be good for. And then computers came along. And hey, we've got a great theory for that. But at any moment, a lot of the things I'm looking like they're just for fun.

And the MacArthur Fellowship was like, yeah, that's good. Keep doing that. And so that was a big moment for me to realize, okay, I guess people like this. I should keep going in this fun direction. And there are lots of benefits to looking at fun problems. Like it gets students excited about research at the university level, or it gets high school students excited about math or computer science.

Like hey, you can study origami and Tetris and crazy things in science. And that that's pretty cool. Or using mathematics. I can transition from video games to being a computer scientist. So I think it gets people excited and it engages the public in a nice way. For us, sculpture is a way of expressing math and science. And so that can connect to people who have arbitrary backgrounds.

They can appreciate the sculpture and say, hey, that looks cool. There's clearly some geometry or something going on in there. Maybe I should learn more. Or maybe not, but at least they can appreciate the beauty of mathematics expressed in sculpture form. So yeah, the MacArthur moment was like, oh, I guess this is an okay direction to go.

**INTERVIEWER:** So it sounds like it solidified your direction in a sense.

**DEMAINE:** Right. It did. Yeah. I was much less embarrassed about it, I guess. Before, I was like, well, you know, it's okay because these things turn out to have applications also. I mean, that's certainly a piece of it. But I was trying to justify it. And ow I just embrace it as the way I like to do things. It's still not traditional, but I think that's good.

**INTERVIEWER:** No, it certainly has worked well, obviously.

**DEMAINE:** I always encourage students to explore whatever they're passionate about, whether it's fun things or more serious things or whatever. Because if you work on things that you're passionate about and excited about, then you will do it well. It's natural consequence. You'll be fully engaged. You'll be learning all the things you need to learn in order to solve those problems. And you'll be excited about it, as opposed to working on things you think you should be because it's easier to get a job in that area or whatever.

You just won't be as excited and you won't do as good work. If you do really good work, it doesn't matter what you do. There will always be something. Or you'll find a way to make it work out.

**INTERVIEWER:** Yeah. Yeah. On your website, I guess, you mentioned you're involved in quite a few different research groups here at MIT. What are some of the other ones that we haven't touched on, and how do they fit together?

**DEMAINE:** Yeah. Let's see. Trying to remember your list. I guess the Center for Bits and Atoms is one pretty cool place that I like collaborating with. It's run by Neil Gershenfeld. And he just has a very fearless approach to tackling problems. He believes, I think, that everyone should know everything more or less. So to work with him is pretty exciting, because he and his students are all in this mode of like, oh yeah, you want to build a chip? We could do that.

Or we'll do the mathematics underlying the structure. Sure, we can do that too. Or let's write software. All of these different things come together in his group. So we've built robots together in particular. And we came up with a mathematical design and then three physical instantiations of this idea of a single chain of blocks, all connected together. Each one can rotate around the previous one.

And based on that simple actuation, if you have a big chain of these things, you can fold into essentially any three dimensional shape. So if you have some 3-D shape you want to make, you imagine approximating it by a bunch of cubes. We call it voxelization. In the same way you pixelize an image, you can voxelize a 3-D thing. And then you can route a single chain through any 3-D arrangement of cubes, we show, mathematically.

And so then you can actually reconfigure that chain from one shape to another. And so we built a bunch of robots at different scales where each unit is this big, or each unit is this big, or each unit is one centimeter. And so the idea is if you have a really long chain, you can just refold and reconfigure. It's this concept of programmable matter where in the same way that we reprogram and download updates to software on our phone or computers, you want to be able to modify your hardware and make it just as reprogrammable by changing the shape of the thing that you have.

So the dream eventually is that you have one gadget and you push a button and it becomes a chair, or push a button and it becomes a bicycle, or push a button and it becomes whatever you want--a blanket, I don't know. So that you could have universal gadgets that can play many different roles. Maybe there's different ones for different scales and so on. But that's an exciting concept motivated by science fiction, which a lot of cool research is. And so it was neat to actually realize that in some form with Neil.

**INTERVIEWER:** Right. Right. Yeah. And I guess-- well, a couple of the other things that were mentioned were the Energy Initiative and Milibiology project.

**DEMAINE:** Milibiology is actually in the Center for Bits and Atoms.

**INTERVIEWER:** That's the one. Yeah, sorry.

**DEMAINE:** We started working together in a grant umbrella which was called Milibiology. Yeah, Energy Initiative-- so this is, I think, an interesting inspiration that came from MIT. There's a big push to do energy, to solve energy, to somehow improve the way we interact with energy. And so I was always looking for interesting problems. And energy seemed like a cool one to see what is the computer science take on energy.

And there are many possible interpretations, but the one that we found really exciting is trying to answer the question, how much energy do you need to compute a particular thing. And there's this thing called Landauer's law that says essentially to throw away a bit of information requires increasing entropy of the world. And so that requires some energy expense.

And it's like 10 to the minus 80 something kilowatt hours for each bit that you throw away. And if you look at a typical microprocessor, it's throwing away probably millions of bits in every clock cycle. So a billion times a second, throwing away a million bits. So it's quite wasteful in some sense. Because you compute the next state of your machine and throw away the previous state.

And so that's why chips get hot, because they're expending entropy. And that's why the main limiting factor in computer speed is how well you can cool the chip and prevent it from overheating and melting. So there's a lot of motivation to reducing the energy consumption. Not only do you reduce energy consumption in the world-- I think computers are one or two percent of the world's at least electricity consumption, and maybe a somewhat smaller percentage of world energy consumption.

But it's only going to grow. And it would be nice if things grow more slowly in terms of the consumption side. But also, computers are already pretty efficient from an energy perspective. But it'd be great if your cell phone lasted 10 times longer or you could have a 10 times less heavy battery or you could run your computer 10 times faster with the same cooling.

That would be the benefit, if you could get energy efficiency 10 times higher. And computers have been doubling in efficiency every few years. So that side is good. But pretty soon, within the next decade or two, we're going to hit Landauer's limit where we're throwing away too many bits. Even if you throw away one bit per clock cycle, pretty soon, that will be too much. And you won't be able to improve energy efficiency anymore.

So we've been looking at the algorithmic question of I want to solve some problem, like I gave you n numbers and I want to sort them. Classic computer science problem. How much energy do you need in order to-- how many bits do you have to throw away in order to get there? And for many problems, if you reorganize how you do the computation, you actually don't have to throw away any bits.

You can do it fully reversibly. But in general, some problems require-- I guess in some sense, all computations can be done fully reversibly. In some sense, you don't have to expend any energy. And you could imagine doing it perfectly efficiently. But there's a trade off. Because you still want your computation to be fast and not use too much storage and not use too much memory.

And so we show that you can get some kind of trade off there where if you spend a little bit more energy, you can get things running just as fast as it used to run and not using too much more memory than before. And so that's been a really fun area to explore. And that was funded by a few MIT Energy Initiative seed grants. And then we have the first big paper coming out early next year.

So really excited that's finally culminated to I hope what will launch a whole new field of reconsidering all the algorithms that we know in this field, but now with an energy perspective in mind and trying to minimize energy.

**INTERVIEWER:** So is that something you had thought about before, or did it just come along because of--?

**DEMAINE:** I think it came along because of MITIE I was like, oh, I wonder are there any interesting energy problems? And I mean, the idea of reversible computing is actually quite old. It goes back to the '70s I guess. But it hadn't really been considered from an algorithmic perspective. So we're thinking about trying to characterize which problems require lots of energy to run fast and which ones can be done with low energy, but still running fast. That kind of thing.

And surprisingly, that hadn't been done before. And I think it will become more and more important as we reach this limit. But it's nice to consider it early. And my hope is it will-- because in order to actually execute these algorithms, you need to build new chips that support general purpose reversible computing. And only one family of chips has been made to do that. And it was done here at MIT a while ago in the late '90s.

But it needs to get a broader adoption before you actually see the benefit of these new algorithms. So my hope is a build it and they will come approach where we show, hey, look. If you could implement these chips, we have these algorithms that can just compute all these things, but with possibly even a million times less energy. That's a big win if you can run it a million times faster or you can use a million times less energy or whatever.

So that will hopefully appeal to people, and then of hopefully a few years down the line we'll have actual chips that we can run these programs on. Right now, we're doing everything in simulation.

**INTERVIEWER:** So how do you decide what to work on? I mean, because obviously lots of things interest you.

**DEMAINE:** Yeah.

**INTERVIEWER:** And there's only so many hours in the day.

**DEMAINE:** Right. In general, I err on the side of working on too many different things. Because it's more interesting. And so projects end up just taking longer. I can still do lots of projects. But there are just many in the background. Many are sitting and waiting for the right student who's excited about it to push it to the next level. But in general, I look for problems that are beautiful, I guess.

Usually I look for a problem that's very clean and simple, and yet the answer is not at all obvious. So the problem should beg to be answered. Like that's such an obvious question. How come no one has thought of it before? Like fold and one cut. Can you make any shape by folding and making one straight cut? Or is it possible to fold any 3-D shape out of one piece of paper?

I mean, these are just such simple questions, and yet no one had looked at them before we did. So they're just tantalizing. Those, I think, are the most beautiful problems. Or I guess in this case, what can you compute in a fully reversible way with no energy consumption. Or how much energy does it take to compute a thing. These are all basic questions, and they're ideal questions also for mathematics. Mathematics is really good at answering very precise, but very simple questions. And so that's our niche where we can do really well.

And those usually form the core of much more complicated answers to real life problems. But then you have to add in a lot more extra stuff. But mathematics is really good at those initial basic questions. And that's what I look for. But also a lot of the problems I look at are influenced by collaborators. I often ask people, you know, what's your favorite open problem. What are you curious about? Partly as a way to get to know them, but that leads to lots of interesting collaborations.

And in general, meeting new people with different backgrounds, I always wonder what are the possibilities for collaboration. That could lead to new directions. So there's a lot of sources of inspiration for new problems to consider.

**INTERVIEWER:** Yeah. Yeah. Yeah. You mentioned beauty, and mathematicians often refer to beauty in a certain sense. And for you, how does that relate to beauty in a more--

**DEMAINE:** Like artistic sense?

**INTERVIEWER:** --artistic sense and a more traditional definition, I guess.

**DEMAINE:** I think they're closely aligned. I haven't thought too deeply about this, but I think there's a lot of beauty to simplicity. And I think that's maybe the-- as a mathematician, I try to think, how would you define beauty? Simplicity is at least an approximation where, in mathematics, like what I was talking about, you want the problem to be clean, to be simple. It has a very simple statement, and yet it's surprising and not obvious what the answer is.

Because you can't figure it out and so you spend years trying to figure it out. I think at least some types of artistic beauty are also about simplicity. Or maybe minimalism or something where there's a very simple idea like let's take this medium-- and it's a very restrictive medium like paper or glass or something-- and then you explore what's possible with it. And you get surprising results out of it. So there's a lot of parallels there, but still more to be figured out I think.

**INTERVIEWER:** Yeah. And you mentioned collaborators and this idea that you like to have more collaborators than papers.

**DEMAINE:** Right.

**INTERVIEWER:** Maybe you can explain the importance of that.

**DEMAINE:** I don't know that it's deeply important. It's just once I realized that it was the case, I tried to keep it up. Because it seems cool to-- I think it's important to always be learning in addition to doing your work. You don't want to just get stuck in a rut and keep working in the same area with the same people. I think it's important to always be exposed to new ideas and new people with new backgrounds.

And so you're learning from them and seeing what kind of problems they're interested in. And so I guess it's sort of a breadth in addition to going deep into an area. It's also good to keep learning about new different things, new areas, and see what's exciting to you. Yeah. Now I have a 300 and something co-authors. One of the most famous collaborators and mathematicians in general is this guy Paul Erdos, who I never got to meet.

But I think he had around 500 co-authors. So my dream is to surpass him. Kind of like an internal challenge. But in general, I really like collaborative research because on the one hand, it's just more fun. Talking with someone about a problem is so much more engaging to me than just thinking by myself. I really don't enjoy thinking by myself. I like brainstorming with people. It's a lot more fun to be bouncing ideas off of each other.

Even ideas you think aren't going to work out, often you say them to someone-- either you figure out better what you meant or where you should go, or your collaborator does. And so that is just a much more engaging process. And you can have meals together and do fun things together while you're talking about research and exciting things. But also I think you can just solve problems that no one person could solve.

If you're working in a team with multiple backgrounds and multiple tools at your fingertips, you can solve problems that you couldn't solve with just your own tools. And so for a lot of problems, once I think through the problem enough to see what the core elements are, I'll think about hmm, maybe I should bring this person and that person in on the team, because they have these tools which would be perfect for solving these parts of the problem.

I think in general if you have a big problem, usually it divides into multiple sub problems. And for each of those sub-problems, for somebody in the world, it's really easy to solve. So maybe one person could solve all of them, but some of them are really tedious and some they're really good at. If you get the right mix of people, each piece is easy for somebody. And then you can put them all together and you solve the whole thing relatively easily. So I think you can just be a lot more efficient through collaboration. Yeah.

**INTERVIEWER:** Yeah. Yeah. So what's important or special about MIT to you? Because you chose MIT. You presumably had other choices too, and you obviously like it. What works about it or what's really important about it to you?

**DEMAINE:** Yeah. Many, many possible answers. I think a big part of it is the MIT culture. I mean, so many of these are self propagating. But there's a big culture here of being curious and really caring about the things that you do, both research and teaching. I think everybody is really passionate about that. And so it's contagious. It really gets you-- people are also excited about working really hard.

And so I feel like I fit in, because I also have those values. I really care about what I'm doing. And I really like working hard. And so it's nice to be in an environment where everyone else is doing that. But also everyone is curious about what you're doing, and it can lead to fun collaborations that you wouldn't necessarily bump into otherwise. So yeah. There's this excitement.

Especially when we were just beginning here, like getting to IAP classes. My dad and I would say things as jokes, but people would take them seriously and say, oh we should do that. We were at some point joking, you know-- a librarian at MIT libraries asked my dad to make some kind of library sculpture or something. And so he's kind of joking saying oh, well, we could use books as a medium and build some furniture out of books.

It's kind of disrespectful to books, right? But instead, they're saying yeah, that's a good idea. Maybe you could teach an IAP class about that. And so we taught an IAP class about building with books. And it turns out there's a whole wealth of disused books that libraries can't even give away let alone loan out or sell or anything. They've tried to give them away at multiple sales.

So we worked with the Boston Public Library and MIT Libraries. A simple example is phone books, which are useless the next year. So we had a ton of MIT phone books from the previous year. And so there are all these books out there. And you can use them to do interesting things. We didn't really know what to do with them, though. So early on, we met this architect, John Ochsendorf-- a professor here.

And we were working with a librarian. And so then we started to get ideas on what to build. And John Ochsendorf being a structural engineer had this idea of tension rods. So the one extra material we added was some steel bolts. And then we would take a whole bunch of books and drill holes through them. I have to say, there's no feeling quite like slicing through a book or carving a hole through it. It feels so wrong, but so exciting to do.

So we developed a whole technology of how do you cut books without them getting torn up and things like that. But then we would apply tension to these rods just by tightening bolts on the ends of the rods. And it would push all the pages together, and then you end up making really strong beams. And then we would compose these beams to make-- we made a rocking chair out of MIT phone books.

We made,there are, I think, about 10 or 20 students in the class. We made tables. We made a bed of sorts. It's a very solid bed. So we ended up making a kind of bedroom scene. We had lamps and I think a swing and benches. The bench is still in CSAIL here. So yeah. So a lot of fun. And we exhibited it at MIT Libraries and Boston Public Library. So I guess that was an early example on the art side.

But I think it's a really nice example of a kind of random group of MIT people getting together because yeah, that's a cool thing we should do. Let's do it. And in general, there's just a lot of excited people and a lot of students and faculty who are open to crazy ideas. And so doing art projects in particular is a lot of fun here. Because everyone's like yeah, let's do it. And here's money to do it.

And there's lots of resources and lots of tools for building things. There's all the laser cutters, waterjet cutters, 3-D printers you could imagine, which are for doing serious things. But you can also use for fun art projects or serious art projects or whatever you want. So that's probably the general picture. Of course, the students here are amazing and they usually come with their own perspective and sets of problems that they care about.

So I've been guided a lot by my own students and entered areas that I knew nothing about because I had a student who was really excited about it. And so they taught me to enter this world. And now it's a big, big part of my research.

**INTERVIEWER:** Right. So are there things that you and your dad are working on currently that are particularly exciting? There are probably many things you're working on.

**DEMAINE:** Many things, yeah. I think we've talked about a lot of them. But yeah. Folding robots is still a big thing. Energy efficient algorithms is still a big thing that we're exploring. I think a big direction we would like to go-- we're still figuring out the right way-- is making larger sculpture. A lot of the work we do on the art side is either folded paper or blown glass or both.

And there's an inherent size limit to both of those things. Glassblowing can get bigger, but it gets pretty unwieldy and you need more equipment. And paper folding has a limit, because the paper is only so strong. We've been able to build pretty big things, like maybe this tall. Maybe three or four feet tall. Just because they're folded, you can make them extra, extra strong.

But there's definitely a limit to that material. And so branching out to other materials like folding metal or recreating folded structures in non-folded mediums-- that's a direction we're really excited about and hope to make progress on soon. You can imagine playground size or entire buildings, or at least more installation scale versus just an individual piece.

**INTERVIEWER:** Yeah, and you mentioned the glass blowing, which is something we haven't really talked about. And where does that fit in? And your dad was into that before, is that right?

**DEMAINE:** Right. Yeah. So before I was born, my dad was the father of Canadian glass. Or that's what he was called. I think he started late '60s and then continued into the '70s. So he had the first glass blowing studio in Canada. And I think he saw some blown glass in London and then he went to school at a glass blowing place. But actually, he ended up just teaching there because no one knew anything about glass blowing.

Or learning slash teaching there. And so then he came back to Canada and started-- he had a living of making paper weights and vases and that sort of thing, and just experimenting and learning as he went along. Because at that point, everything was secret. All the glass recipes were secret. No one knew how to make color. So everyone in Canada and in the US-- a lot of people were experimenting in the early glass movement and just playing.

I mean, basically like scientists, right? They would do experiments. What if I add this chemical or this chemical. And they would get different colors, but maybe different consistencies to the glass. And they would be compatible and all sorts of crazy things. So that was his previous life so to speak. I never saw him blow glass I don't think. Maybe once as a demo when I was really young.

But basically when we came to MIT-- that whole story happens, and then we came to MIT and we discovered MIT has a glass lab. I mean, it's called a lab, but it's really an art studio. And so my dad was like oh, gee, you know I've never repeated a career before. He's had many different careers over his life. But maybe it's time to try it again. And so he ended up teaching beginning glassblowing here, having not blown glass for decades.

And just got really into it again. And at this point, he had a lot more freedom. He no longer had to make a living solely out of this thing. So he could be a lot more experimental and much more artistic and less just craft and trying to make a dollar. And then I started watching. And even just watching glassblowing it's really enticing and exciting. And so then at some point, he said you should try and see whether you like glass blowing also.

And so then I signed up for beginner glass blowing class here. And I've taken lots of classes now. And so now my dad and I have blown glass together. We work a lot with Peter Houk, who runs the glass lab. We try to think outside the box and make nontraditional glass forms. So we started out making puzzles for glassblowers-- pieces where it's not clear how they are made.

And so you have to think about how could you-- what are the steps that would lead to this process or this final result? Because glass blowing is still pretty traditional. And there really aren't that many different steps you can do. But still, there are some surprises. If you combine them in funny ways, you can get things that are just counterintuitive that you think shouldn't be makeable.

So that was a fun challenge. We made things that looked like regular vase structures, but then they also had weird topological connections inside. And how you get these weird connections and also a perfect form on the outside, it's not obvious. So I won't reveal the secret here. We have since revealed the secret to the glass blowers, and now they know how to make it. And then in the last few years, we've been exploring glass folding. Because I think folding is cool.

And of course, we've been doing lots of folding. And so a natural challenge is how do you combine glasss-- or a natural challenge for us, anyway, is how do you combine glass and folding. And there are so many interpretations to what glass folding could mean. And each of them is pretty exciting in its own right. And it's led to a whole world of different type of glass blowing that no one was doing before.

And it's exciting to be in new ground in such a traditional medium. It pushes us outside the box. We taught a class at the Pilchuck Glass School, which is one of the big glass programs out in Washington State. And so we, I think, really got students just to think more creatively about glass by using what do you think glass folding should be as a prompt. And so it's been a lot of fun to explore that.

**INTERVIEWER:** And does it relate to the mathematical and computational side and stuff?

**DEMAINE:** Yeah. It does. Glass folding, not yet. We're still trying to find the right model. I think there's still good avenues for exploration there. But it takes a while to solidify into a clean mathematical problem, because there's so much physics with glass blowing. But we have had more success in a different area of glass called cane design. So if you've ever seen a bowl or something that has lots of wiggly lines down the side, those are made by first making cylinders of glass with cool patterns of wiggly lines and then combining a whole bunch of those cylinders-- those are called canes-- into a full glass piece.

And canes go back to Roman times, like fifth century or something. So the idea of cane is very old. But the types of cane designs-- the particular patterns of wiggly lines-- have been the same for these centuries, millennia, whatever. And so we were curious-- maybe there's other designs out there. It's a very geometric process essentially. And you see it also in some kinds of candy making and so on, where you take some straight lines and combine them into a bundle, fuse it all together, and then pull and twist.

And so you end up with if a line is off center, it will twist and make a cool pattern. And when you combine them in particular ways-- like a simple one is a bunch of parallel lines, then you get a kind of ribbon of lines. Or if you put a bunch of lines around the center, then you get a whole bunch of helices geometrically. And then they crisscross and make a grid. Those are two of the most traditional cane designs.

But what about other arrangements of lines and what would you get? So we wrote a program-- it's open source-- called Virtual Glass. Virtualglass.org. And so now lots of people are playing with new cane designs. And it turns out there is zillions of designs out there that no one has tried, partly because actually making these things is a lot of work. And to perfect a particular design can take days of trials.

And hot shop time is really expensive. And so everyone wanted to make things that they knew were going to look good. So they just stuck to the traditional designs. Now you can just get out your laptop and fool around with some designs. And some of them don't look good or they look pretty much like a classic design, even though you thought it would be cool to arrange them in this pattern.

Like a square instead of a circle actually when you pull and twist, it looks pretty much the same. And the software gives you that immediate instant feedback. But then you can go and tweak and keep playing and adjust the colors and say, oh, that looks really cool. If I can make that perfectly-- the software shows you if you did it perfectly, this is what it will look like. This is the geometric ideal.

Then you have to go learn how to make it. It doesn't tell you how to make it. But it at least shows you what it will look like. And then you have the driving force and you can play. And this turns out to be-- I mean, it's kind of a small domain of glassblowing, of just cane making, but it's pretty novel in that no one has really tried to use computer tools for any kind of modeling of glass blowing before.

At least on the art side. So this is the first example of computer aided art making in the glass blowing world. And I think it's part of a bigger movement to use more computer tools and design tools for craft in general and art making in general. So I guess origami is another instance of that. But that's, by now, traditional to use computer aided tools. So for glass blowing, it's a much-- actually, they're similar age.

But it's been so traditional for so long. Origami is a little more gradual. Like three or four decades ago, people started trying to come up with new designs. And then by coming up with more complicated designs, they had to develop the mathematics in small steps in the beginning. And so there was a more gradual progression of more and more complicated things until the general theory emerged. With glass blowing, it's pretty much just been traditional. And so I think this is hopefully the beginning of a big explosion in new glass designs.

**INTERVIEWER:** One thing I was curious about is-- and this being the 100th anniversary of the Cambridge campus and the construction of the main group buildings and stuff. You're, of course, in the Stata Center I guess, right?

**DEMAINE:** Right. It's a pretty modern building by comparison.

**INTERVIEWER:** Yeah. But does the physical layout or the aesthetics, the architecture, of one type or another affect you in one way or another? Or your work? Does it--

**DEMAINE:** Yeah.

**INTERVIEWER:** --interplay at all?

**DEMAINE:** I really like being in the Stata Center. It's a Frank Gehry building, so there's all sorts of crazy angles, very little straight things. And as a geometer, that really appeals. It just feels-- it's inspiring to be in a kind of crazy building. Because I like doing crazy things with crazy geometries. And I have a diagonal column, a concrete column straight through the middle of my office.

And it's awkward, but it's cool. So I like that. And in particular, there's a lot of space in that building that just there are white boards in random places. And so you can bump into someone or just have an impromptu meeting in the middle of a lounge instead of scheduling a conference room or going to someone's office. So it can be a lot more relaxed and a nice collaborative environment.

In general, I really like Cambridge. Yesterday I went to Boston, but I hadn't been there in months. And Cambridge is just a fun-- it's very liberal and, again, people are excited about doing crazy things. And yeah. So it's just a nice environment to be in. It has all the advantages of being a big city. You can get things done. And there's a hardware store open at all times to buy a part that will help you make something.

But it also has very much a kind of community feel. It's not overwhelmingly large. There aren't super tall buildings. And so it's also easy to get around. I bike pretty much everywhere. So being in Cambridge has a lot of advantages too.

**INTERVIEWER:** Yeah. Yeah. No, I think it's made a huge difference to the MIT over the years.

**DEMAINE:** Yeah.

**INTERVIEWER:** Gosh. There's so much we could talk about. Are there other things that you're doing that we haven't touched on that would be good to mention?

**DEMAINE:** I made a list. Thank you. We've covered a lot.

**INTERVIEWER:** Yeah. Yeah. No, I appreciate it, too. It's really great.

**DEMAINE:** Oh yeah. There's one other thing I wanted to talk about. Oh, a few things. OK.

**INTERVIEWER:** Great.

**DEMAINE:** I made a list of the things we were likely to forget.

**INTERVIEWER:** All right. Excellent.

**DEMAINE:** Cool. So I want to talk about-- I'm going to say them now so we remember-- video lectures, a particular collaboration model, and games and puzzles.

**INTERVIEWER:** Yeah. Great.

**DEMAINE:** All right. So I don't know where to start. I really like video lectures. I like lectures in general. A lot of people have experimented with all sorts of different types of teaching. But I grew up in the lecture model, and I had some really good lectures in undergrad. And so I try to mimic all the good properties I see in those lectures. And I feel like just teaching the maybe even 300 students in your class is kind of a-- it feels almost like a waste if you only reach those 300.

And definitely there's a nice iteration process where each year you get a little bit better at delivering those lectures. Or things are a little different and you're always improvising and whatnot. But I feel like you can reach so many more people if you also just happen to have a camera recording you. And so with relatively low effort, you can reach a much broader audience and impact the world, especially the world that doesn't have great universities or people who can't access those universities.

So I arrived basically the moment OCW started. And so that was an appealing reason to come here as well, this idea of let's just share all the things that we enjoy so much here at MIT with the world. But actually, the details of video recording are many. And not many people record their lectures, actually, for these reasons. Partly there's the emotional aspect of oh, this is being recorded and the world's going to see it.

So not everyone is into that. But I think a lot of at least MIT professors, but a lot of professors in the world are confident about their teaching. And it would be great to get it out there. So it's more of there's a technical and a monetary barrier to doing it. So there are lots of teams who are willing to do it for a price. But you can't really afford that price for every class that gets taught.

So Open Courseware has been picking out the classes they think that here's a good one to invest in now and the world would most need. But I've tried to develop a system where for very cheap, you can do a very high quality recording. So I did a bunch of experiments with different video and audio equipment-- what are good microphones, what's a good wireless system, and what are some cameras that can capture pretty good lectures.

And initially, my goal was blackboard lectures because that's what I do mostly. And that's lucky, because blackboards are a lot easier to shoot than slide lectures. These days, even cheap cameras can do slide lectures pretty well. But when I got started-- I had to remember-- five, six years ago, the blackboard lecture was the more attainable thing. It turns out the one really hard part is having a good camera man.

That really requires a kind of aesthetic. And how to move the camera, that takes a lot of practice to learn. But I got lucky because I have my dad. And so when we were starting out, I was like oh, you know, I'll try it out. Let's see how it goes. And luckily, he has this amazing aesthetic. He had done, I guess, a little bit of camera work before. But we basically learned how to do it together.

And so I have a website which people have used as a model. Like here is some basic equipment-- I think it's around $2,000 or something-- and you can have a complete kit and you can record really high quality lecture videos. And by now, every class that I teach has been recorded at least once. And all the lectures are available on OCW and so on. And surprisingly, that's a novelty.

But my goal is to make it for a lot more professors around MIT and elsewhere to be regularly recording their lectures, especially the more special classes. It's hard for OCW to invest in this special topics class that will maybe never be taught again. And yet it's really sad to lose that class. If it only gets taught once-- there's this moment, and it's an exciting moment. And the people who are there will enjoy it, but it would be much cooler if you could enjoy it more in the future.

And compared to this project, there's a big historical element too, to see-- computer science is a young field. Almost everyone in the field is still alive. But that will not be true for much longer. So to capture different teachers' teaching style, and in general to open it up and allow-- like if you want to take an algorithms class online, you will probably see my face. And that's charming in that I go around the world and people say, hey I took your algorithms class online. It's great.

But I have one style of teaching, but there are many styles of teaching out there. It would be great to have more videos available so students could choose their own adventure and say, oh, I really like this teacher and that teacher. And different students are going to enjoy different styles. And so the more videos that are out there, the more they have the power to choose the ones that appeal to them.

Some people might like a more theoretical version of the class or some people might like a more applied version or whatever. More jokes, less jokes. So video lectures, I think, are in an exciting time and people are still figuring out the right way to do it. My approach has been minimal intrusion. Like I set things up so I don't need to edit the videos, because I don't have time to edit videos.

So it's just a single camera. But high quality audio and video seems to make something good enough that people enjoy it. Like on a good day, thousands of people watch one of my lectures. So that that's exciting. So it's this trade off between the amount of effort the lecturer has to put in and the results that you get.

**INTERVIEWER:** Yeah. Yeah.

**DEMAINE:** I tend to err on the side of let's not make it much more work, let's make it very affordable and low effort on the part of the lecturer. The one challenge is getting a good camera man. So ideally you have a father who's really good at camera work. But yeah.

**INTERVIEWER:** Yeah. Yeah. Yeah. Yeah. And you had a couple other--

**DEMAINE:** Yeah.

**INTERVIEWER:** --topics there that was--

**DEMAINE:** Let's see, what was the next one? Sorry, I forgot. Oh, collaboration. Yeah. So we talked about collaboration and how that's a really powerful way of working. But I was introduced to collaboration in a very special kind of model. And I've tried to propagate that model as much as possible here at MIT, and found a neat way of doing it. So the idea is called a problem session, where a bunch of people get together and there's an open problem on the table.

No one knows the answer. And we all just try to solve it at the same time. And this usually works especially well for a medium sized group, maybe 10 people or so. And I was introduced to this model at a place called Bellairs Research Institute, which is owned by McGill University. So coming from the Canadian world, that was a big thing there. And it happens to be in Barbados.

So through a kind of funny story, McGill acquired this oceanographic institute called Bellairs in Barbados, but then they started hosting workshops there. It's like hey, you want to host a one week workshop? Let's do it. And that had been going for at least 10 years before I got invited to my first one. This was in 1998. So I was a grad student and invited to this workshop.

And so there were 13 people, I think, solving problems for a solid week. And it's an incredible bonding experience. And it's also incredibly productive. If you have a nice set of unsolved problems, we can all work together on them. And it's like constant brainstorming. And I had done this with my advisor and with my dad in small instances, but this eye opening experience of working with a dozen other people, nonstop solving problems.

And it was so exciting, especially at a young age. It was very impressionable. So I want to recreate that as much as possible. I now run a Barbados workshop every year. So that's a big, big part of it. Now we're up to like 30 or so people. But I also try to run these kinds of problem sessions here at MIT. And I've tried it a few different ways. But the way that I found really works is in a class environment.

So every grad class I teach-- in the lectures, I'm covering what's the latest that we know in this field. You know, what have people been able to prove already. Then once a week, whoever's interested-- and it's a subset of the class and it tends to be around 10 people-- we get together and then try to push the frontiers beyond what's known. So we just learned how to solve this, but then the natural next question is this.

Let's try to answer that question. And it's great, because the students are right up to speed and they know exactly what they're supposed to know. And so the hard part for me is picking out the right open problems. You want something that's not too hard, but not too easy. But this has led to a ton of research. And I think it's gotten a lot of students excited about doing research.

UROP is one approach to doing research, the traditional one on one advisor-student model. But in this setting, it brings this collaborative atmosphere where we're all collectively brainstorming. And in the end, we solve problems and we write papers. And so you get to see this, I would call it a super collaborative model where you're not just collaborating with one other person or one other group.

It's like lots of people are just getting together. And it builds a kind of rapport. Like last fall, I taught a new graduate class. I hadn't designed a new class for a while. So it seemed time. And I taught a class about hardness proofs, proving that problems are impossible for computers to solve for various notions of impossible. Either they take a lot of time or they take a lot of space or, you could imagine, they take a lot of energy. But that doesn't exist yet.

And so this is a new field-- or I'm trying to encourage it into a new field, let's say. And it is exciting. And so I had an open problem session. And that was last fall. This fall, we're still meeting every week solving open problems. So this approach builds groups of students who are just really used to working together. And so there's a lot of rapport there and we still like solving these problems. And so we're still writing papers and still proceeding. And that's not uncommon. So I think this kind of experience of working together on problems for a whole semester really is attractive.

**INTERVIEWER:** Yeah. That's cool.

**DEMAINE:** And so it's been nice to share that and see how it works. I think there are lots of fields where you could have these kinds of problem sessions. But so far, theoretical computer science is the main one where they exist. And compositional geometry in particular has been-- its the most traditional in this field. A lot of people know about the Barbados workshops and try to replicate that model.

But I think I'm the first to have done it in a class setting. I think it's a nice pairing where you're learning material, but then also trying to push it to the next step and then learn some new material and then try to advance that. And it's a nice kind of dovetailing.

**INTERVIEWER:** Yeah. It sounds great.

**DEMAINE:** So I guess the third point was about hardness proofs. And it's something I'm quite excited about these days, partly because it's so much fun. And it combines a lot of different things. But for a long time, I've been excited about proving problems are hard. These are called negative results in computer science. So you can't solve something. And I like doing it for every day problems.

And in particular, puzzles and video games have been a common theme. So one of my first papers at MIT was proving that Tetris is NP-complete, meaning that it's really hard for a computer to play Tetris optimally. Even if I show you the board position and I tell you all the pieces that are going to come in advance and you can think about it a long time, it turns out you have to think for a really long time to figure out whether you can even survive the level, let alone maximize your score.

So that was an early-- that was sort of the beginning to a whole world of results. More recently-- and all of these are with MIT students-- more recently, we analyzed Super Mario Brothers and Legend of Zelda and all of the classic Nintendo games, which are the video games that I grew up with. So it was really exciting to prove that those are all really, really hard even for computers to solve.

And I think these are illustrations of why humans like to play these games is that they're actually provably really challenging. And humans like a challenge. You don't want it super hard, but you want it not to be like click this button to win. That's kind of a boring game. But there are some games like that. But I think at least for a lot of people, like us scientists, we really like games with a bit of a challenge and you really have to think a little bit to figure out how to-- or perfect the action to get there.

It becomes more of a skill. And so for me, it's really fun because it lets you take these things which everyone loves and enjoys and bring them into a mathematical context. And so in particular, you can illustrate to people hey, here's a reason why you might care about mathematics or computer science. You can actually analyze these games and puzzles. And hey, that's fun. So I usually give these examples to high school students who are trying to figure out what they might be interested in.

It's also just the actual process of analyzing these games is really enjoyable. Because essentially to prove that these games are hard, you have to design levels. So you design a collection of little pieces of levels. We call them gadgets. So there's a little level where you have to make a binary choice. Either I fall this way or I fall that way. And there's another piece of a level where there may be several entrances, and if I come into any one of them, then I destroy an enemy, which later lets me traverse through it.

So if you have just those two units, you can prove NP-completeness, for example, if you can combine them in the right way. And so it's, I would call it, a metapuzzle where instead of solving a specific level, you're designing levels that have certain properties. And if you can design these levels and then basically with just these two diagrams, two pictures, you can prove that this game is really hard.

And so that process is really fun. And I think it also gets students excited about research, because it's relatively accessible. They may not understand the big theory. But I can explain, look, you just need to design a level with this property and a level with this property, and show that you can connect them together. And boom, you have a level generator that can simulate computers.

And you can do all sorts of cool things in your video games. That's why I taught this class last fall, because I have a lot of experience with this. But I think there's a lot of techniques that more people should know. And I don't think there are any classes like this one where it's sort of a practical guide to how to prove problems are hard. Lots of people do it, but there are very few experts in the area.

And so the goal of this class is to make lots of experts so we could all solve these problems together. And we've proved lots of different problems are-- lots of games and puzzles and things are hard in this context.

**INTERVIEWER:** So a lot of what you do clearly has commercial or other types of applications. And you've mentioned a few of those along the way. And you actually had a early venture in your puzzle company with your dad--

**DEMAINE:** That's true. Yes.

**INTERVIEWER:** --into that realm. But do you go in that direction? Do you see yourself ever going in that direction? Is that of interest?

**DEMAINE:** Not personally really. The academic world is so free to explore all the things that I want to explore. And I feel like for me, I've taken that freedom more literally than a lot of people do and just explore what is fun and interesting. And it's hard to get that in other settings. Even the grant model has a fair amount of flexibility where you don't have to get all of your research funded.

As long as you have some research that's considered important enough to get a grant, you can use that to fund your other more recreational things partly as outreach. Like NSF cares about reaching the public and getting students excited about research and all that and that sort of thing. And the more recreational side can support that while the more serious side supports the more serious science things.

And it's hard to do that if you care about a commercial bottom line. There are definitely things that-- like we invent something and I think, oh, it would be really cool if this existed, like if you could go to a store and buy it. But I know how much effort it would take to reach that point. So I'm definitely open to collaborating with people who want to push things in that direction. Because there are a lot of things that I would like to exist that don't currently exist.

But it's not as attractive to me to go jump through all the things required to actually make that happen. I think to a lot of people, that is exciting. And that's cool. And there are a couple instances where I would really like it if there were an arcade in Cambridge for people to play video games together instead of just in their separate worlds. So that's one example where I might push a little harder to make it happen. But yeah. I'm more the academic type.

**INTERVIEWER:** So one of the last things I wanted to ask you is, well, clearly so much of what you do is fun and recreational to you. Are there other things-- do you have free time in which you do yet other things that are fun and recreational too that are outside of this?

**DEMAINE:** Yeah. In general, I always try to lead an integrated life as much as possible, where my hobbies are also my research and vice versa. I also like juggling, for example. But there's a mathematics of juggling. I haven't done any mathematical things there yet. But another form of artistic expression that my dad and I explore a lot are making fonts where we try to express some mathematical idea or open problem or something through the font itself.

So each letter of the font can be a puzzle where you have to solve this math problem in order to figure out what letter it is. So for example, we have an origami font where one way to write it is you just have the crease pattern and then if you folded that crease pattern, it would become the letters. But another one we did is a juggling font, where each letter of the alphabet is represented by a juggling pattern, which you can represent mathematically.

And so we just designed that font earlier this year. And I performed it at a birthday party for a mathematician named Ron Graham, who's famous as a mathematician and also famous as a juggler. And so we performed his letter, R-O-N G-R-A-H-A-M, where each juggler was performing one letter. Because at this conference, of course, there were many jugglers. So it's always a lot of back and forth between things that start out as hobbies. Like improv started as a hobby, but then it started impacting my teaching. So it's fun to do it all together as much as possible.

**INTERVIEWER:** Yeah. The integrated life.

**DEMAINE:** Right.

**INTERVIEWER:** So if I gave you a piece of paper-- and can I-- and what would you--

**DEMAINE:** Sure.

**INTERVIEWER:** --do with it?

**DEMAINE:** It might take a little while, but we could make one relatively simple model. But it's going to take like 10 minutes to fold it. All right. So I'm going to fold a model called a hyperbolic paraboloid. And it goes back to the Bauhaus in the late '20s. It's a very simple geometric model, but also very, very cool. And to start out, I'm going to make a square. There's this really famous origamist called Yoshizawa.

He started the artistic origami revolution, designed some really beautiful models from Japan. I met him at my first or second origami convention in '97 or '98. And one of the things he believed in is always folding in the air. Most origamists do not fold in the air, including myself. But I took his class. And if you ever tried to fold on the desk that was in front of you, he would slap the desk and say no, no, no, you have to fold in the air.

I don't know the exact philosophy behind it. It's a little more challenging to fold in the air. It's a good challenge. All right. Pro paper cutting. Tongue method. All right. So now we have a square. And I'm going to fold the two diagonals of the square. Let's just figure out where the center is. And what we're going to do is fold concentric squares in the square.

So I'm going to fold a quarter of the way up, folding to the center four times. OK. Now I'm going to fold an eighth of the way up, folding to the previous line. So three eighths four times. We'll make our concentric squares.

So Josef Albers was at the Bauhaus, and he experimented a lot with paper as a way to explore design relatively easily, not having to acquire fancy materials. You can just pick up a piece of paper and start folding, see what you get. And so I think he viewed it is a kind of way to experiment with form. But we, of course, view it as the final product also.

But either he or one of his students came up with this model around 1928, I think. OK. We're halfway done. I'm going to fold all the squares in between those squares, but this time the other way around. So these are going to be valleys where the others are mountains. And then we'll be done. So it's a funny model, because it looks almost boring. You're just folding squares.

The surprising thing is what you get as a result of these squares. I like this model for a bunch of reasons, but partly because it kind of folds itself. You give the paper these very simple instructions, which are fold squares please. But those turn out to be, in some ways, difficult constraints for the paper to satisfy. And so it kind of becomes this self-folding structure.

And that has lots of applications, of course. You can imagine how it's going to work is that if you can just get the material to become creased at these places, then the overall 3-D form will happen automatically. So that's why we're interested in it from a scientific perspective. From an art perspective, it's also a really fun way to interact with material where you have some say in the process, like these kind of square instructions I'm giving the paper.

But a lot of it also comes from the material itself. So like in glass blowing, you see a lot of form that happens naturally from gravity and things like that that's particularly appealing. This is kind of the paper folding analog. And we used to fold a lot of these, my dad and I. We even made some sculpture based on them. But these days, we work mostly with curved creases, but in a very similar style.

So here, we're folding concentric squares. But with curved creases, we fold a lot of concentric circles. And it has a very similar kind of self-folding aspect where we give some instructions to the paper, but a lot of it is done by the material itself. And there's a collaboration between the artist and the medium. OK. Almost done. All right. Perfect. Done. It looks not very exciting yet, but we just need to fold all of these-- now we've made these creases, we're going to fold them all at once.

So just need to go around a few times to make this x shape. That's going to get more and more x shaped as we collapse more.

OK. Almost there. That looks like an x. Still, you're not impressed. But wait, there's more.

**INTERVIEWER:** I'm getting impressed.

**DEMAINE:** OK. All of these folds folded at once. Just putting them in extra hard. And then the magic part is you just open it a little bit. And here you get a 3-D saddle surface. Like whoa, what just happened there? This is what people call a hyperbolic paraboloid. It looks like it has a parabolic cross-section here and a hyperbolic cross-section this way. It's a known mathematical surface.

And so for years, people conjecture that this paper folding leads to that mathematical surface, or an approximation thereof. But it turns out, we proved a few years ago, this doesn't exist. It's impossible out of perfect mathematical paper to fold just this crease pattern. If you want concentric squares plus diagonals, you can't make anything except flat. So that was a bit shocking, and opened up this world of does this origami actually exist, or are we breaking the rules somewhere?

It turns out the paper either has to stretch or it has to have extra creases for this to fold. And you can see along this edge, there's a little kink here. I didn't put that kink in, but the paper wants to break the rule somewhere. Because it has to break the rule somewhere. So we would always fold these and think oh, gee, I guess we're just still not very good folding. You know, it's not quite perfect.

Maybe next time we'll get it. But then it turns out, mathematically, it can't be perfect. You have to make a mistake. But it's definitely fun to make the impossible. So we still fold them.

**INTERVIEWER:** That's great. All right. Well, thanks so much.

**DEMAINE:** Cool. Pleasure.

**INTERVIEWER:** It was great talking with you. Thanks again.

**DEMAINE:** Likewise.