Sue Nelson
Hello, I'm Sue Nelson and welcome to the Create the Future podcast brought to you by the Queen Elizabeth Prize for Engineering.
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The career of today's guest combines engineering, teaching, and writing. Born in New York in the United States, Henry Petroski studied engineering at Manhattan College, and went on to become an assistant professor of Engineering Mechanics at the University of Texas. He worked at the Argonne National Laboratory in Illinois, as a mechanical engineer, failure analyst and group leader between 1975 and 80. And since then, he's been a professor of Civil Engineering and History at Duke University in North Carolina. He's now a distinguished emeritus professor of engineering at the University, and the successful author of 19 books, and over 75 journal articles. He currently writes an engineering column in American Scientist magazine. So, my first question had to be, which he enjoyed more the teaching, the writing, or the engineering.

Henry Petroski
I have to say I enjoy them equally, whatever I happen to be doing at the time I enjoy.

Sue Nelson
Because I do radio, TV and writing. And although it's all related, in terms of subject matter, I do have to have a slightly different hat on for each one. Do you have to do the same?

Henry Petroski
Yes, definitely. Writing deadlines sometimes and classroom has a deadline. 50 minutes is the usual lecture period in our country and doing an engineering job, there are deadlines also to meet. So, there's that in common. And I found different writing assignments I do, I have a different word length to deliver, or I've got a different timeline to satisfy. So, there are similarities. The underlying material of course is the biggest similarity.

Sue Nelson
When you are at university as a student, did you write for a student newspaper? You know, was there a sort of inkling there that you had the potential to wear both these hats?

Henry Petroski
No, I would say not I worked on the engineering magazine, but doing graphics, not words. In my senior year, I took a world literature course that was eye opening, and the assignments they required writing. And I happen to have a kind teacher who praised my writing abilities potential. And I think that was a good boost. So I began as I entered graduate school, to read increasingly and literature and also to write increasingly.

Sue Nelson
Now, you wrote your first book, over 30 years ago now, ‘To engineer is Human: The role of Failure in Successful Design?’ What gave you the idea for that? What made you write it?

Henry Petroski
I was teaching engineering at the time, had been practicing as an engineer and I was officially a professional engineer and I wondered, what exactly was engineering? What exactly was this thing that I was doing? Because many of my neighbours who were not engineers would ask me, what is it that engineers do? And they especially asked this question, when there was something that engineering was responsible for, in their mind, the collapse of a bridge or a nuclear power plant problem. And there were a lot of those back in the 70s and 80s. So, I thought, well, you know, I'm not sure I fully can give a succinct answer to ‘what is engineering?’. But I had learned by that time that I do my best thinking when I'm writing. If I try to write something out, I can see

how it's not clear if one sentence doesn't follow from another or one paragraph or another. And I decided, I would try my hand at a book, writing a book to explain what is engineering. So, the working title of that book was, 'what is engineering?'. I had written magazine articles, I had actually written some poetry. And I had never written a book because I thought that was a Herculean task, but by sitting down and starting and moving from day to day, chapter to chapter, it came out and I did discover in the process of writing it that I think engineering is all related to failure. Successful engineering is when the engineers properly anticipate what could go wrong with their system that they're designing their bridge, or their power plant. That's the core of that book that to engineer is human. And I found that a lot of practicing engineers agree with that. On reflection they say, "yes, that is what we do". All these numbers we calculate all these models we use. The reason we do all that is we want to get a number to compare to another number and that other number is, when will this bridge break? How many cars does it have to have on it to break? Or will it under this hurricane condition or this earthquake? So, engineering calculations are really failure calculations, indirectly. So, I followed that theme in several of my other books, you mentioned that I had other books I've written. And that's a constant theme. That's an ongoing theme in my in my work, I like to think of each of the books as different, looking at it from a different point of view. When I look at them carefully, I see that the concept of failure, success versus failure, and failure and success, the two sides of the same coin, so to speak. That's a constant theme throughout all of my work.

Sue Nelson
There's something about seeing something collapse. A it horrifies you, first of all, shocks you, but then actually, it's intriguing, because you sort of want to know, for instance, with a, you know, the famous bridge, where it almost looked like harmonics swaying from side to side. Was it Tacoma?

Henry Petroski
Tacoma Narrows Bridge. That's right.

Sue Nelson
Yeah, you do, or at least I do, you do start to think, how on earth did that happen? How did they manage to make a bridge, which you think of as something solid that lorries and cars go over, suddenly start to behave like a skipping rope?

Henry Petroski
Failures are relatively scarce in engineering. They're reported upon they make the news, and we all see and think about and do ask, 'how can that happen? why does that happen?'. Well, it happens very infrequently but that doesn't exonerate the engineers who made the mistakes of not thinking about how this could happen, this particular thing that caused the failure. That's why I've advocated, especially with regard to engineering education, that we should be teaching our students about the history of engineering and the history of engineering necessarily includes failures, very dramatic ones, like the Tacoma Narrows Bridge. There are just so many to choose from. The fact of the matter is, we generally in engineering, don't teach about failures in any formal way. They come up incidentally. But I advocate that students should have in their mind, why literature students have a canon of the great works of writing and when there is a debate among engineers about which way to go in designing, say, a bridge, if it's clear to students of engineering history, that that's not the right direction to go in for this reason, that when they went in that direction, with the Tacoma Narrows Bridge, we know what happened, it collapsed. And it can be a very convincing argument, especially for engineers that are hearing, there's plenty of room in the curriculum, to either have a full course on this or to spread it throughout every course. If you're teaching about concrete let's say, you interject now and then, well, this is the kind of thing that can happen to concrete if we don't pay attention fully to how we're designing a concrete structure, let's say.

Sue Nelson
When I'd seen that this first book was then made into a BBC Horizon program, I managed to find a copy, considering it was made in the 80s, I think late 80s.

Henry Petroski
87 I think.

Sue Nelson
Yeah, it really held my attention. I mean, it was informative, it was interesting, and it made me think I'd love to see an engineering series like this now. Because you're right, you learn so much, and I'd never heard of that rather awful case of the hotel in Kansas City, which had a couple of skywalks in the foyer which collapsed. I mean, that was a tragic case because of the number of people, over 100 people killed in that, but that that was due to a very simple failure wasn't a well, relatively simple failure?

Henry Petroski
Yes, simple, very simple. In fact, it's the kind of problem that I would assign to early engineering students in their first or second year to explain why this happened. And it's easy, it's a homework problem. Now, what happened apparently, was that the engineers involved got a little casual, engineers can get struck with hubris, let's say and get overconfident. It's old hat to them. And that seemed like a not a very big or significant structure. They were just very careless. It turned out to be one of the most infamous failures in American engineering history, it was the largest life loss, I believe in any structural failure. And I don't think that record has changed since 87.

Sue Nelson
And what was that failure was to do with a bolt, wasn't it a bolt holding up the walkway, they replaced it?

Henry Petroski
Yes, it had to do with a connection, technically it’s what's called a box beam, the box beam supported the walkway, transversely across it, and it was supported from the ceiling of an atrium, by steel rods. The original design called for a single rod to pass through a walkway and then to continue below it to hold a second walkway. During the construction, there were some problems, so they changed it to using two rods, they thought two rods is better than one. And it was for certain constructional reasons, but not for strength reasons. I'd likened it to if you have a person hanging from a rope with his grip and a second person below him hanging from that same rope, that represents the two walkways and the bolt connection that you alluded to. They can both hang there for a certain amount of time safely. But what happens if the second person, the lower person grabs the feet of the top person? Then what happens, the person on top, his grip has to serve to hold up to people or is originally only needed one. That's the essence of what happened. It exceeded its strength let's say.

Sue Nelson
I wonder what happens to engineers if they design something that fails on a scale like that, where lives are lost? I mean, in some cases, with the space shuttle, for instance, on huge projects, they are a team. But do engineers ever pay the price for something, you know of the scale of that hotel?

Henry Petroski
Yes, that's a very interesting question. And there are a lot of examples throughout history that illuminate it. For example, Robert Stevenson is one of your famous engineers working on railroads, bridges, all sorts of things internationally. One of his first bridges failed, it was the Dee Bridge near Chester, up in England, or Wales border. And he was clearly the engineer responsible for the design of that bridge. But other engineers came to

his defence and tried to explain that. Well, you know, it really wasn't the design it was the train that went off the tracks. In other words, you can make arguments that are apparently convincing, but not necessarily the whole story. But anyway, the reason I bring up Stephenson is he went on to design many, many successful bridges and he's honoured today throughout the world as one of the great engineers of the Victorian era, and of all time, really. Now in the US, we recently had a failure in Florida. It was a pedestrian bridge that was under construction and it suddenly collapsed. It turns out that that engineer, who was the chief engineer, and he was, that's where the buck stops in engineering, as chief engineer, you have somebody who is going to be held responsible. He had such a successful career, but he probably will not work on another bridge. Engineers who, as they gain experience, they gain reputation, they become revered, and they become older, naturally. They become figures of authority to such an extent that the engineers under them are reluctant to challenge that authority to say, “Well, no, you're not quite right here, this this, this looks very, very dangerous. We should look into it much further”. That happens a lot. It's happened with numerous failures throughout history of throughout the world. It's a human factor.

Sue Nelson
Not just engineering either.

Henry Petroski
Well, that's right. Thank you. That's a good point.

Sue Nelson
Engineers now I assume have this, you learn by failure, but actually you want to avoid failure at all costs. But you can't necessarily state that what you've built is failure proof. Despite the mathematics, despite the sort of 3D modelling you can do. Would you say that's the case that you can't failure-proof anything now?

Henry Petroski
I think you've put it quite well. There are many, many factors outside of engineering proper, that affect an engineering structure and an engineering decision. And sometimes we call it politics. It's not necessarily politics in the gross sense, it's local politics, its politics of the office place in some cases, and people get caught up in either championing a chief engineer or being against that engineer, and it becomes a very complex human interrelationship problem.

Sue Nelson
And also, it must be difficult because I know that engineers will test even the simplest thing, you go into a lift and it will say 12 people only, but you know, you assume that lift is probably tested for 18, or something because you know that people will always cram. But there are always going to be things that you just cannot plan for. And that must be very difficult for engineers.

Henry Petroski
It's challenging, but at the same time, very intellectually interesting to be in that situation where you're trying to do something that you have so many unknowns involved, and you have to wrack your brain trying to figure them all out. If you built a bridge or a lift, that would be good example, designed to carry a dozen people, you might squeeze two dozen in. Now that would risk the people. So very often, what would happen in engineering, you wouldn't put people in there you put sandbags, or other load, those are called safety factors. Engineers are conscious of that. And very seldom is any engineering product designed to be so on the verge that even a fly lands on the bridge, it's going to collapse, that is just not done in engineering. But there is a human tendency, and again, engineers are human. When things are working, we're designing elevators or lifts over the course of decades and we're seeing that, well, we haven't had an accident, we know we understand this so let's lower that

factor of safety. We know we're limiting the elevator capacity to 12. Let's make it 14. Well, what's going to happen eventually, it's going to creep up to close to 18 and 18 might be the number that does cause it to fail. That is a common feature in almost every historical failure of any consequence. And it's something that's very difficult to combat because there's so many pressures, economic pressures, for example, you build it stronger than it has to be that means it's more expensive than it has to be.

Sue Nelson
And the thing that you've just reminded me of there, particularly with economic pressures, is I remember reporting on the number of buildings that collapsed in Turkey. This was years ago when there was an earthquake. And a lot of that was due to economics, in terms of it was a bit more expensive to make them earthquake proof. And that was an issue. And also, this materials is quite interesting, isn't it? Because you assume that certain materials, be it steel or concrete or wood, they've all got advantages. They've all got disadvantages, but then you've got weather as well. And that's that impact of extreme heat, or extreme cold as well, would contribute to a failure?

Henry Petroski
That's right. Especially with new materials that we are not familiar with, that we don't have an awful lot of experience with. The people who develop those materials and ultimately selling them would like the person using them or buying them to think that they're as good as concrete or better than concrete. And this has happened a lot, there's always a pressure to improve the materials. But how do you know, some new material is going to last for let's say, 50 years the way you know concrete will? Well, it's only been discovered five years ago, that's quite a leap. So, it takes some ingenuity to come up with ways to test new materials. And basically, this just falls down into the realm of theory, you theorize that this is how it would break down, this is what the sun will do to it, this is what the dry temperature will do to it and so forth. And we see that a lot of times what was promised is not really delivered, in part because the ambition was too great to sell the new material.

Sue Nelson
And I suppose one of the things as well nowadays is with climate change, we are getting those extremes of temperature, which say, 20 years ago, you would not have believed I would not have believed, for instance, that Texas would be having temperatures of minus 20 Celsius or what have you. It's just like, 'Whoa!', which is why I was slightly depressed when I saw that the title of one of your books in 2010, 'The Essential Engineer' was 'Why Science Alone Will Not Solve all Global Problems'. Now, what did you mean by that? Was it a way of saying science may not solve your problems, but engineering will?

Henry Petroski
Exactly.

Sue Nelson
So, it's good news?

Henry Petroski
Yes. Very often engineers are called scientists. And I like to make the distinction. There are scientists and there are engineers. There's a lot of overlap, in what they do, what they know, and how they project their knowledge into the real world. Scientists, in many cases don't have to worry about the real world, because what they're doing is purely theoretical. They can make calculations, they can build computer models, you know, that can predict. There's no real way to test that. And yet we make a lot of decisions based on those kind of projections. This is this is just a fact. Engineers want to be more down to earth. Engineers always have the evidence to refute, let's say, claims that are over the top. Scientists, if they're talking about the, the creation of the universe,

let's say, how can you test that? Well, they come up with clever ways. But one thing you will notice about scientific projections and theories is they're constantly changing. It's hard to check everything all at once. But you know that burden falls on engineers, they have to check everything all at once. If you're building a bridge, you can't say, 'well, here's the most important part, let's forget about everything else', you have to have a very, very rigorous way of excluding the unimportant stuff if you're going to. You can't just look at one part of a bridge and say "this is safe", you have to look at every part, so that you don't miss a detail that might appear to be trivial, on first glance, but on further inspection, could be key. And it's very common for engineers to say that, you know, the details of the design are the most important part. There is a single engineer called the chief engineer or the engineer in charge, or sometimes the engineer of record, who is responsible for the whole team and its conclusions. That's a little different from science, in my opinion. In science, things are compartmentalized to the point where whoever is looking at a particular aspect of a problem, that is reviewed or overseen within that particular entity, let's say or discipline, the big picture. These things just concatenate. That's why in that book, 'The Essential Engineer', has a subtitle, 'Why Science Alone Can't Solve Our Global Problems', we have to integrate it all the way engineers do. Engineers look at systems, they look at the whole picture. Individual engineers may be looking at small parts of it. But it's the engineers who not only integrate everything, but also challenge everything. Basically, engineers want to be shown, show me that this is what you claim it to be.

Sue Nelson
You've taught engineers throughout your career; can you always tell which students are going to make a successful engineer? Is there a quality about them that you think 'ah yes!'.

Henry Petroski
It's easier to answer that in a negative, that there are students that you don't think are gonna make good engineers. And this is a paradox and life is full of paradoxes, engineering is full of paradoxes. I don't think I'll make a lot of friends by saying what I'm going to say, but the students that are less likely, in my opinion, to be successful engineers, in the big picture of things are the straight A students, let's say, the students who get perfect grades, it suggests that they conform too much to what they think is expected of them. They will regurgitate what the professor is saying, rather than look for the correct answer. And I've seen this happen time and time and time again. So, thinking that a great transcript with all top grades is the best. I disagree with that. On the other end, they were barely passing but they were they thought about engineering and engineering problems in a way that the, well we would say straight A students in this country. And they're non-conformists, they think about each problem as if it's a new problem. I won't say that people who drop out of college or engineering school or lower grade, get lower grades, but they certainly, they rebel against going to school, because in many cases, I believe what they hear is not teaching them anything. They realize that, you know, this is really just a very small slice of the big picture. I've had students where they got in trouble with some of their professors, because they would solve a problem in their own way. It was right, but it wasn't the proscribed way, if you will. So, your question about how do you know which students are good. It's not easy. There are plenty of counter examples to 'Oh, the best grades are the best going to be the best engineers', in my experience, and I think the world's experience that is simply not the case.

Sue Nelson
That is so interesting, and my mind was going here, there and everywhere then knowing so many people that fit that ability range where they've got into a bit of trouble, or they haven't done things entirely right. Or they've been told off for exactly that, so that's really interesting. And it sort of goes back to this whole thing of, definition of success and failure, again. I wanted to ask whether you had any advice for engineers who enjoy writing like you, and maybe want to use their degree within the media as well, like you have?

Henry Petroski
Oh, I don't know if I have any advice other than, if you're really attracted to doing this kind of thing, you know, go for it. But writing in my experience is not something you can just do. You have to practice. Practice means, you know, start writing less ambitious things than books. For example. It took me I think, 20 years to work my way up to writing a book. And they were things that I would write late at night. That was my way of closing the day. I've been doing engineering all day and I would go to my study late at night and work on short pieces of writing. I never took a writing course per se, but I read a lot. And I began to read with a critical eye about writing. How did this person write this Kansas study grammar and all these things, the mechanics of it. I don't think it's possible. Nothing's impossible. So, I won't go that far. But if you want to write about engineering, you've got to know two things you've got to know writing, and you've got to know engineering. So, you can't just totally separate yourself from an engineering career. But if you want to know writing, you've got to read, you got to see how it's done. So, my advice, I usually don't give strong advice, practice, practice, practice writing, practice engineering, and bring them together when you feel you've made a connection. And the process of doing that will help you discover what that connection really is.

Sue Nelson
Now, I said in the introduction that you had written 19 books, is that it now, you know, you've retired as a professor, have you retired as a writer or as number 20 on its way?

Henry Petroski
One of the reasons I retired as a professor is so I could do more writing in retirement so to speak. I write constantly. I write regular columns, constantly being asked to write little pieces here and there and I'm always thinking about it another book. So, I’m working full time. But I would say now, as a writer, the more successful you are at something, the more demand there is on your time from outside factors.

Sue Nelson
So, number 20 then is on its way or in the pipeline?

Henry Petroski
Yes, number 20 is in the pipeline.

Sue Nelson
That's great. Well, thank you so much for taking time from your writing to speak to us on the Queen Elizabeth Prize for Engineering Create the Future podcast, Henry Petroski. Thank you.

Henry Petroski
Well thank you very much. It was very enjoyable.

Sue Nelson
Great stuff.