



Futures in Biotech, 33: Dr. Milner's Explorations into the Human Mind

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[Music]

Marc Pelletier

Welcome to Futures in Biotech, I am Marc Pelletier. Today's guest, we are very fortunate to have Dr. Brenda Milner from the Montreal Neurological Institute and McGill University. She is an outstanding scientist. She has a career that has spanned 60 years and she's won numerous awards, including 19 honorary degrees.

She is a fellow – she has won the fellowships of the Royal Society of Canada, and of London; Foreign Associate title of the National Academy of Sciences, USA; Officers of the Order of Canada and Quebec; first recipient of the Wilder Penfield Prize for Biomedical Research; member of the Canadian Medical Hall of Fame; Golden Jubilee Medal of Her Majesty Queen Elizabeth II; and the National Academy of Sciences Award in Neurosciences in 2004; and even more recently, Companion of the Order of Canada, a position that is only held by four people.

I don't know, is that – was that okay? I can edit that.

Dr. David Brodbeck

That's great. No, I like it, I like it.

Marc Pelletier

Well, that voice you hear is Dr. Dave Brodbeck, Canadian Psychologist and Chair of the Department of Psychology at Algoma University, Sault Ste. Marie. I invited him to help me with the introduction, because I really wanted to give Dr. Milner the introduction that she deserves and to really tap into how her career has changed or moved forward what we know about the human mind.

Dr. David Brodbeck

Right. Well, Marc, I mean it's funny, coincidentally yesterday I was marking final exams in a course called Brain and Behavior that I teach, and that course would not be possible without the work of Brenda Milner.

I actually got a chance to meet her – one of those honorary degrees was given to her by the Memorial University of Newfoundland when I was there. I got a chance to hang out with her a bit and I will tell you something, I have not met anybody that's this dynamic, of any age, and what she's done is she's taken psychology, and she was a psychologist by training, and neuroscience – well, then neurology, and sort of blended them together into what we today call cognitive neuroscience.

There would not be, like I said my course, there wouldn't be a field called cognitive neuroscience without Brenda Milner and without especially, she will probably talk today about her work with

HM, and that changed everything. That changed psychology, that turned us into a science that, maybe some of my older colleagues may not like this, but one that was a little bit too concerned with looking at rats pressing at bars and pigeons pecking at keys and, believe me I have done some of that myself, but it took us from that into something looking at internal mental events, and looking at them from a scientific perspective, and looking at the corresponding neuroanatomy and physiology.

When I got to meet her in 2002, it was like I had met a combination of Bono, and like Bono and then if Bono was a scientist, except, you know, I mean it was incredible and it was like that, I was star struck, except that she was just so nice and warm and wonderful, and we talked about – a little bit about science and a lot about hockey.

Marc Pelletier

And so she was born in 1918 and has really influenced generations of psychologists.

Dr. David Brodbeck

Yes. Yes, I look back, she is – one of awards she won that you didn't have in your list was the Hebb Award, Donald Hebb was her Ph.D. supervisor and probably one of the greatest experimental psychologists ever along with her, in – from the Canadian Society of Brain, Behavior, and Cognitive Science in 2001. And other past recipients of the award are people like Gus Craik, Endel Tulving, there wouldn't be Gus Craik and Endel Tulving without Brenda Milner. There wouldn't be Kandel's work, you had Kandel on the show, and he has credited her.

She not only influenced psychology and neurology, because she also worked with Penfield, but she's influenced this and helped invent a brand new field, cognitive neuroscience, which is something that not a lot of people, you don't get to meet a lot of people that have invented a whole discipline.

Marc Pelletier

Well, you were mentioning as well that, in our conversations that, how we were going to talk about her past work, and this is of course a show called Futures in Biotech, we're looking at the future, but how has her work influenced the various fields that are moving forward in the area of psychology?

Dr. David Brodbeck

Well, there's a few ways, and some of them are very specific and obvious. There's things like, if we are going to look for cures for things like let's say autism, let's say schizophrenia, let's say people with amnesia perhaps, let's think of attention-deficit disorder, whatever, if we are going to find cures for these kind of things we have to know how the brain works, and we have to be – somebody has to understand the physiology and the anatomy, but somebody has to design the clever behavioral experiments that fit in with the anatomy and physiology, with the MRIs, et cetera. And we wouldn't know how to do that without – that's what cognitive neuroscience does. So, that's on one very tangible level.

On another more, I guess tangential level in some respects, one of the big things that she did with the case of HM, is she gave, I guess call it anatomical and physiological proof that there are multiple memory systems in the brain, and that we could actually study these things scientifically. And of course, nowadays, we look at artificial intelligence, they use neural networks, things like this, so, in that respect too, looking at stuff that you might not always think of every day as what's psychology and say cognitive neuroscience has done. That's doing things like running the traffic signals in cities, it's being done with artificial intelligence neural networks. And I mean, without her work, her pioneering work, really none of this stuff could happen, so we would all be stuck in traffic.

Marc Pelletier

Well, she won the Gairdner prize in 2005, right, so that gives her about a one in four chance for the Nobel Laureate, to become a Nobel Laureate. I don't want to jinx her.

Dr. David Brodbeck

Neither would I.

Marc Pelletier

Okay, well thank you very much for helping me with the introduction.

Dr. David Brodbeck

Not a problem, Marc.

Marc Pelletier

It was very important to get this right. And so, I will move on to the interview.

Dr. David Brodbeck

Thanks.

Marc Pelletier

[7:25] When did you move to Canada, you're at the Montreal Neurological Institute, but how was that – how did you make it to where you are now in terms of when you started?

Dr. Brenda Milner

I came to Montreal in 1944 when I thought that I was coming for a year I believed, I started my life in mathematics, actually. And I was working on a radar research establishment. I turned over to psychology at Cambridge and I was working on a radar research establishment in Malvern in England during World War II and that's where I met Peter Milner, I married, who was an electrical engineer and he was designing the equipment that I was actually testing out. We were testing out the proper methods of display and control for the radar operators, as you know radar played a big role in the Battle of Britain and in World War II. And then when we knew that the war was coming to an end in England, the war in Europe, not the war all over, I was making plans to return to Cambridge, my university.

But suddenly, Peter Milner with whom I'd become very close friends was "invited", I mean you don't refuse these invitations to go with a group of scientists led by Sir John Cockcroft from Cambridge to Canada to set up the beginnings of Canadian atomic energy research. It was a very sudden thing that had to happen within a week or two. So on the spur of the moment, we got married and we came over here supposedly for a year. That, actually, began the – this atomic energy research in one wing of the Université de Montréal, the French University here before it moved to Chalk River which you probably heard of.

During that period I got a job in French University at the Université de Montréal, because I'd always liked French and I never had a chance to use it. But for the first time I was, I was teaching in French about animal behavior and about psychology. It was a great challenge, but it was a wonderful experience. And it was in the middle of that that McGill University, Psychology Department, which had been really rather in the doldrums during the war because people had gone off to do other things, began to pull itself together and they recruited Donald Hebb, who became very famous for his work on his book *The Organization of Behavior*. People talk about the Hebb synapse and so on.

But Hebb came to McGill and he had previously – he was a Canadian – and he had previously spent a year or so here at the Neurological Institute with Wilder Penfield at the beginning. The Neurological Institute here was founded in 1934 and it was really devoted at that time, the goal of it was pioneering the neurosurgical treatment of epilepsy. It was really very novel.

And so Dr. Hebb in those days had the opportunity to study one or two of Dr. Penfield's patients. And really believed that it was important to – that you could get important information from – about the normal healthy brain by studying essentially the brain – a person that had some brain lesion or brain damage. I had been brought up in that belief in England too, so I certainly agreed with that and still do.

So, when Hebb came back to head up the Psychology Department at McGill, he got a promise from Dr. Penfield that he could send one graduate student to study the patients at the Neuro.

In the meantime I of course, was teaching – a professor at the Université de Montréal. But I attended the first Hebb seminar at McGill where there were a lot of – a number of quite well known people like Mishkin and so on were in that first group, when we went through Hebb's chapter by chapter, this book that was to become so famous. It was just in manuscript and we read it chapter by chapter and all the background reading, and I became very excited by this and decided that I – and I realized that I needed a Ph.D. In England people did not in those days or before the war, even if university professors did not go on to the Ph.D., it didn't wasn't considered sort of necessary; the first earlier degrees were the really competitive and important ones.

But I realized that in North America it was important and I was really – I think we were all inspired by Hebb – his ideas and so I decided I wanted to do a Ph.D. at McGill and I wanted to do it with Hebb. I had some work to persuade him because you always had to persuade him, he always said no to people at first just to prove how serious – test how serious they were.

Once I had agreed that he had accepted me, I started doing some research on perception in the congenitally blind; I had some experiments going in tactile concept formation in the congenitally blind. I had just got this going when Hebb asked me if would like to go and study Penfield's patients. That was June 1950, and as soon as I got up here, I say here because I am talking to you of course from the Neuro, I realized that I just found this so fascinating and this is what I wanted to do.

And then after I got my Ph.D., Hebb thought I would go back to him – I had a tenured teaching position. In the '50s it was hard to come by good jobs and it was – I didn't have any money, and Hebb assumed that I would just continue with my work, once I got the Ph.D., and I certainly enjoy the Université de Montréal and I enjoyed working in French. But the temptation to stay at the Neuro was too great.

So, I stayed – he said, very grudgingly he told me I was a fool. He said no psychologist – no he really said that, he said no psychologist can survive for long at the Montreal Neurological Institute.

Marc Pelletier

Wow.

Dr. Brenda Milner

[13:38] So you are a fool, essentially. He was a very outspoken, straightforward guy, and he told me I was very silly.

Marc Pelletier

Was he wrong!

Dr. Brenda Milner

And I said – I said I'd like to try. So he said well, I'll support you out of my research funding, he had some money from Ottawa, for one year, and you can have a little office in the Psychology Department and not at the Neuro but down in Psychology on the lower campus at McGill and that's it, you know, and you really are very foolish.

So, I gave up my job at UoM and before the end of the year, and this was really quite amazing, Dr. Penfield suddenly said to me, we need you, you have to come up to the Neuro, we will find you some little office space and so on. We need you. And that the great Dr. Penfield, would ever be saying, "we need you", I had never thought, and of course the reason he said this was because by that time, we had run into the problem of patients with memory disturbance, two patients with memory disturbance after an elective surgery for epilepsy. Up to that time I think Dr. Penfield thought he could – he liked having people come from different disciplines studying his patients. He encouraged visitors from all over.

But he – I think he felt himself that psychology was really commonsense and that he had lots of commonsense which was true, that he could probably get along fine. It was nice to have a psychologist as a sort of luxury but not essential to his life. But then when he ran into these memory impairments, he really was very, very concerned and wanted to understand as much about them as possible, and that was when unfortunately for the patients, but luckily for me, my luck turned and I was invited to come here and I am still here, after 58 years, I have been here now. So, that is quite a long time.

Marc Pelletier

58 years.

Dr. Brenda Milner

That's my long answer to your short question.

Marc Pelletier

Well that's an excellent answer. So, from what I understand, with your background in psychology going to a clinical environment or a research clinical environment that really works on the anatomy and the function of the human brain was a really great – was an insightful move and obviously risky, especially if you are leading a good teaching position at Université de Montréal, which is...

Dr. Brenda Milner

Yes, it was risky I think. I mean Hebb certainly thought it was. And it's very funny. There is a lot of other people thought so because the correct thing to do for a psychologist then was to work either with rats or with healthy undergraduates, right? I mean I wasn't a clinician. I wasn't a clinical psychologist. I was an experimental psychologist so I should be working either with rats or with undergraduates where you could do well-designed experiments and that was the way to go. People did think I was very foolish. But the amusing thing is that years later, years and years later people said to me, "Oh, Brenda, you were so lucky having that opportunity". Because now of course everybody thinks this is an interesting and important thing to have done, but at that time it was not viewed that way and as I say Hebb himself, who was very, very interested, still thought it was incredibly risky as she will have to earn your living, but it was so fascinating.

Marc Pelletier

That's how paradigms change. If you do not take a risk, then there is no chance of paradigm change in science.

Dr. Brenda Milner

Yes, I think that's true. But you realize that I can't say that I was doing this because I had some – get this straight from the beginning, I was not doing this because I had some wonderful theoretical model that I wanted to test out by working with these patients. I am very sort of driven by the phenomena I encounter. I encounter something strange, a memory impairment or what have you, and then I want to investigate, try to understand it better. But it is not that I go in with a great theory that I wanted to study. It is different; I am empirically driven so to speak.

Marc Pelletier

And you don't seem to be, and this is in 1950 that you...

Dr. Brenda Milner

Yes, '50.

Marc Pelletier

So, you were taking on the human brain with the tools of a psychologist and with the data of a neurosurgeon or...

Dr. Brenda Milner

That's right.

Marc Pelletier

So, how did you learn the anatomy? In your training in psychology, did they give you the anatomical functional details or was it through behavior?

Dr. Brenda Milner

[18:26] Well, it was a little bit of both. I was lucky going Cambridge. I mean I went to Cambridge because it was the place to go in mathematics and I was doing mathematics. And so I was very lucky, then I changed over to psychology, that I was in a department that was very biologically oriented because there was the influence – Prof. Bartlett who actually was an expert on memory although I was not particularly interested in memory at that point. But the head of the department is a very famous writer on memory also, not memory in the brain so much but experimental psychology memory, Frederic Bartlett. But the people before him, his seniors were Henry Head and Rivers, these were neurologists with an interest in behavior. And there was a whole tradition that this was the difference in England between – the two big schools in psychology then were Cambridge and London or London and Scotland. These were two different traditions.

The London tradition was very much towards statistics, measurement of intelligence so there was very elaborate developmental statistic method, extremely good statistics. The Cambridge method was very experimental. The degree is a degree in experimental psychology and always thinking of – Bartlett always talked about the organism because he was always influenced by this idea that the brain is responsible for what you do. But we knew very little about – I knew the broad anatomy of the brain but I had not done and do not forget I came through mathematics and physics. I had not done physiology or biology or anything like that as a lab. I've not worked in labs. I came by a different route in my science. But we did know the sort of basic anatomy from our books.

Don't forget also working with these patients, and this is what I always tell the medical students or anybody that I lecture to who is young today, that you have to have really a leap of imagination backwards because in those days we did not even have CT scan. We did not. If we were discussing and trying to assess a patient – because a patient coming in with seizures and – can the surgeon help the seizures with an operation, you are trying to make your interpretation of what is going on on the basis of the clinical pattern of the epilepsy, of the EEG which was extremely primitive. We had Herbert Jasper who was a colleague of Dr. Penfield. He was a brilliant electroencephalographer, a very good neurophysiologist. But it was the very beginnings of the field EEG. Also all we knew about what was inside the skull of this patient, we knew the shape of the ventricles and we knew the plain film of the skull but we knew nothing, I mean it's not that we didn't have beautiful structural MR. We didn't have, as I say, CT scan, we didn't really know much until actually – and Dr. Penfield turned a big bone flap, which was unusual in those days and started the electrical stimulation of the awake patient – brain of the awake patient to map out areas and to gradually elicit the beginnings of the seizure.

So we knew extremely little. When you ask me what I knew of the anatomy, I learned sort of hands-on, I learned to know a lot more about the human brain obviously because we were working with patients with brain lesions, we were in the operating room, we were getting in the gallery actually where the EEG, electrocorticography was going on and seeing the electrical

activity. We were studying all these things and at the time I was sort of learning these things on the job I suppose. Yes, that would be a fair thing to say.

Marc Pelletier

Literally looking into someone's head. That's amazing.

Dr. Brenda Milner

Yes, it was one of that – actually one of the great – in those days in Montreal I remember when we had the International Congress of Psychology, I remember that in Montreal. And that was because it was during in McCarthy era, and so many of the foreign scientists couldn't get visas to go to the United States so they could come to Canada and so we had this big meeting in Montreal. And one of the things, the delegations were always coming up when Dr. Penfield was operating, to come and look in the gallery and see this brain stimulation in the awake patient. It was very innovative in those days I think.

I think Dr. Penfield studied with Surgeon Foerster in Germany briefly in order to get an idea of how this could be done and then came here and really pioneered this work in Montreal.

Marc Pelletier

How did the patients react to the idea of this going on? Were they – I mean obviously they were willing patients. This is very, very experimental and what's going through – well no, well going what's going through the mind of the patient that he is going to have 30, 40 people watching him or more while his – I guess he's – these are severe patients, severely epileptic and in need of...

Dr. Brenda Milner

Well, not so much – I don't know, not severe in the sense of having dreadful seizures – most of these patients had temporal lobe epilepsy, and temporal lobe epilepsy seizures, actually they are usually a sort of change in your ongoing behavior, what Hughlings Jackson in England called a "dreamy state". People suddenly behave in a slightly odd way, they may just start fumbling if you are testing them or humming a tune or they may go and put something inappropriate in the icebox, or do – and during this period when they are behaving in a slightly strange way, and they're not responding to you when you talk to them they have no memory afterwards of this period of the epileptic attack. And then afterwards there may be a period of confusion as they – or not as the case may be, as they return to just to their normal state. They may not even know they've had an attack.

[24:28] So these are not so – when you say severe, they are not, it's not, but it's very – it's something that is really very – intolerable is too strong a word – it's very hard to take for patients, first of all they are taking medication and most patients don't really like taking a lot of medication, they feel it slows them down in some way. There have been study – now of course this whole thing has become much more refined and it is done all over, this temporal lobe surgery particularly. And here you'll find that there has been really extensive studies showing that the quality of life in the patients whose seizures are controlled by the surgery is really significantly better. But there are all kinds of things they can't do when they are having seizures – they can't drive, they can't – it's things like this. It's the nuisance value in their daily life and their feeling that they are slowed down by – whether it's true or not, they certainly feel slowed down sometimes by the medications they're taking.

So they are very motivated, they are highly motivated to help to control those seizures. So, and they are very – they tend to be very grateful to the surgeon if it does help, you know. I don't know if that answers the question.

Marc Pelletier

Sure, absolutely. How do you – so in your work on piecing together the function of memory or the processes of memory...

Dr. Brenda Milner

We haven't got, we haven't pieced it together yet. Fortunately there's lots of questions.

Marc Pelletier

Well it goes down to the atomic level I suppose with Dr. Kandel's work as well.

Dr. Brenda Milner

Yes.

Marc Pelletier

But it has to be approached from every facet?

Dr. Brenda Milner

Right. His work is wonderful – yes, that's right, looking at the molecular side of it and looking at the system's level, right.

Marc Pelletier

So in these first patients that were undergoing epilepsy, surgery for epilepsy, how did you piece together your framework for questions? I know that you are very curious, did you have to go through exhaustive night after night of thinking how can I get an understanding or sort of a global to context, because the brain – did you approach it reductionist with the principle of reductionism?

Dr. Brenda Milner

I wasn't trying – well, don't forget that I'm an experimental psychologist. So I go there and when I went to the Neuro I was not interested particularly in memory. I was interested in perception and I was very – I've always been inspired a great deal by the experimental work with monkeys and with rats. And a colleague of mine, Mort Mishkin who would have been a student at McGill was – who is now – still at NIH – carrying out important work on the temporal lobes of monkeys and I was getting hypotheses from what we knew in the monkey for what one might look for in people. And so I was looking for visual deficits because it's been shown in monkeys with bilateral damage that the damage to the inferior surface of the temporal lobe in the monkey, it was associated with difficulties in learning based on visual cues and learning that a square meant you are going to get piece of banana or something like that, whereas if you choose a diamond, you are not going to get anything. This is a pattern discrimination learning,

We were finding that – I wasn't, the people working with monkeys were finding that they – back in those days, far away days, early '50s that the inferior part of the temporal lobe – temporal cortex was important for this kind of visually guided learning. And later others showed that another part of the temporal lobe was important for auditory discrimination and so on.

Now, I went to – I was – my challenge was to see patients who were having unilateral – and don't forget that of course this elective surgery is unilateral, it's taking out part of one temporal lobe in the assumption that in the other hemisphere the temporal lobe is working normally, so it is a unilateral procedure. And whereas, in the monkeys, in order to see the function of the temporal lobes you have to have a bilateral lesion, in unilateral you would not see anything. And so, I knew that I would be looking for very some subtle changes if it was just in one hemisphere and avoiding of course areas critical for language in the left hemisphere and so on. Whatever I was looking for, it was going to be very subtle. Fortunately, for the patients, because whatever they have in a way of subtle deficit is what they exchange for that, they get the control of their seizures and it's a good bargain. That means I am looking for small things, that didn't bother me as long as they're quantitatively, orderly – I have a group of patients having a left temporal removal in the dominant hemisphere for speech. And I have another group having a right, and I can compare and contrast statistically then I am happy with these small things.

[29:44] But I wasn't thinking about memory. I was thinking about these higher level visual functions and I remember Dr. Penfield was rather surprised at that because he said the temporal lobe is quite a long way from the visual cortex, why are you interested in vision? But of course he didn't know the monkey work. And it was because of the monkey work I was interested in vision. So I did in fact for my thesis do – produce evidence of some minor complex visual deficits in patients with unilateral temporal lobe lesions. And I got interested in something that became quite a passion with me, and stayed with me, was teasing out the special functions of the right hemisphere, the non-speaking hemisphere. The sort of underprivileged – I got rather annoyed with hearing neurologists talking about the dominant hemisphere when they should have been saying the dominant hemisphere for speech because speech isn't everything.

So I became a champion, I think, for the right hemisphere and interested in trying to find out the things that were going on in the right hemisphere. But in the middle of all this, I am talking, of course, to my patients. I go and get the patients and we chat. And the patients have their own complaints and when they have complaints, particularly the patients with left temporal epileptic foci and so on start saying, "Oh, doctor" – well I wasn't doctor then, but, "oh, you know, I have this trouble with my memory".

And if a patient starts complaining about memory you can't say, "Well, I am not interested in memory. Don't you understand that I am working on visual perception?" You work on what your patient is telling you about himself or herself. And when they say, I have trouble with my memory, you think, aha, I should look into this.

And then, the patient – so you ask the patient what they mean because obviously these patients are not amnesic, they are going from day-to-day about their businesses and not to forget they know who I am and so on. What do you mean by you have trouble with your memory? And then the patients with left temporal lesions gave their examples that are all from the field of language.

And remember, these are young patients. The average age of my patients at that time was in the mid 20s, just a bit older now that we see, I think. But in those days they were young patients and so you should have a good memory in your 20s. Most people have pretty good memories in their 20s. And they were complaining that they didn't remember people's names. They would go to a lecture and they wouldn't remember what they heard, but also when they were reading and studying they did not remember either.

In other words, it wasn't specific to one sensory modality, such as vision through reading or audition through listening. It was the material, the fact that it was verbal and the same – so, I began to study these, these same people that were complaining of memory because people value language so much. So they say, I have a terrible memory. And in fact, they just have a terrible verbal memory, and not a terrible – a poor.

And so I start measuring this and show that they do indeed have verbal memory deficits. When I look at – but they don't have any difficulty in remembering unfamiliar – tasks where they have to remember faces or nonsense patterns or nonsense designs or music, they have no problem. It's specifically verbal although they call it a memory deficit; it's a material specific one.

And then when I look at the patients with right temporal lesions, I find that these right temporal patients, the ones who have a removal from the right, non-dominant minor hemisphere – there you go, bad words – have no trouble with verbal memory. But they have trouble with memory for faces and for places and so on. And so, I became interested in these subtle deficits, which were very orderly.

And this was really what I was working on and what I was doing when I begged Hebb to let me – when I gave up my job at the UoM, I was very intrigued by these small differential effects depending on the side. This was before all the split brain patients whom I was able to study at Roger Sperry's later. But this was before the corpus callosum patients were studied. This was – it

was very small but very orderly changes. And it was in the middle of all this that one of Dr. Penfield's patients developed a severe generalized memory impairment and this – it was this case and another case and I would like to say something about them. But, this was what stimulated Penfield to say to me, we need you.

Marc Pelletier

I would like to take a short minute to thank audible.com for sponsoring Futures in Biotech. They have over 50,000 titles now, I think. Just an amazing library of audible books, speeches, interviews, shows, kids' books, fiction, non-fiction. They have almost anything you can think of.

My pick of the week is a science fiction book by Jerry Pournelle and that is indeed the Jerry Pournelle that wrote the column in BYTE Magazine for twenty years and is often a host on this WEEK in TECH on the same network with Leo.

His book is entitled Starswarm. It's about a child living on a research outpost on a distant planet. The child has heard a voice in his head for as long as he can remember. One day finally daring to ask the voice some really tough questions discovers that his computer scientist parents had implanted a chip with artificial intelligence, which interfaced with his mind. He also learns that his parents died under suspicious circumstances and his very existence is a well kept secret. And when the secret is revealed, his life and the whole outpost at Starswarm are in danger.

So if you would like to download Starswarm head over to audible.com/biotech and sign up for a 14-day free trial. If you like the service, you can stay with it. If you don't, well you get to keep the free book. Now back to the interview.

Dr. Brenda Milner

[35:17] Now, I should go back to the temporal lobes. Up till now I have been talking to you, first of all, about the monkey data and then about people, emphasizing really the temporal neocortex what you see on the surface of the brain, but of course the temporal lobe has these structures deep to it, the medial temporal structures, particularly the hippocampus is a beautiful orderly structure and surrounding it entorhinal and perirhinal cortex, medial – structures on the medial surface of the temporal lobe.

And when Dr. Penfield first began to work on temporal lobe epilepsy before I came to the Neuro in those early days, in the early 1940s, he was very conservative. He was a very prudent surgeon and he decided to remove – he was really always trying to remove as little as possible to control the epilepsy. He was searching for a focus for where the epilepsy originated and hoping he could get away with a small, small removal, you know, and help the epilepsy but he found out in the course of those first few years that he very rarely – sometimes but very rarely succeeded in controlling the patients' seizures unless he extended his removal to include structures on the medial aspect of the temporal lobe, the amygdaloid nucleus and part of the hippocampus.

And so by the time that I started working with Penfield in the early '50s, we would almost call this a routine, every patient, the removal was always tailored to the individual patient's problem. It was done under local anesthesia, we tried to elicit the beginnings of the seizure and so on and so forth, but practically all of the removals were involving the medial structures as well as the lateral surface of the temporal lobe in one hemisphere.

And also during this period, some of the earlier patients, the ones who had been there in the early '40s and had the more restricted removals were still having seizures and so Penfield took them back to have – to complete the temporal lobectomy. Penfield realized by now that his removal had not been extensive enough, that he should have invaded the hippocampus and so on and so the patients came back and had a second surgery.

And one such patient that I saw, first such patient that I saw we'll call PB, who was an engineer from New Jersey, I think. A very bright man, ran his own engineering office, was married and had

a grown-up daughter, I think, and was – and a life, a social life, quite an active social life and he had had this, a left dominant hemisphere temporal removal with Dr. Penfield some years earlier. He came back in 1951 still having seizures.

I tested him extensively as I did all these patients. I tested them with a variety of tests, intelligence tests, memory tests, all sorts of things with as much time as I could have before the operations and then I would test them again afterwards in order to see what the effects had been and then if I was lucky would test them in follow-up and so on. And so I saw the patient and then he had this operation, which was just removal really of the medial hippocampus on the medial surface, just really to complete what had by then become a standard removal.

And after that PB, this patient said, what have you done to my memory and he was quite – and of course he knew Dr. Penfield because he had surgery a few years earlier. He knew Dr. Penfield and he knew the Neuro and so on. I had worked with him for hours and hours but he didn't know me at all and he didn't know any of the newer residents or staff that had worked with him. He had some retrograde amnesia. He didn't remember when they had installed a new furnace in his house and so on but the serious thing was the what we call an anterograde amnesia, the continuous forgetting of the experience of his life as he lived and in this patient it was – we got a little bit of a glimmering as the day went on. He would say in the morning, he woke up and it was buzzing, booming confusion and then he got a little clarity but he forgot everything from day to day and of course it changed his whole life from then on.

Now this was really disconcerting now, it was this patient that enabled me to show that first of all the IQ, the general intelligence, is not changed by this. What had happened to this patient his overall intelligence was not changed, it was high, he was a highly educated, highly intelligent man. His immediate memory, his ability to repeat a series of digits after hearing them, capacity of immediate memory, which was again superior in this guy to begin with was not changed, and was not affected, so you know that primary memory, what William James called this immediate memory, primary memory is a good term, was unchanged but it was the inability to build up his life from then on, which was so shocking.

And we wondered, Dr. Penfield, Dr. Jasper and I, we really wondered and worried what is going on and I remember Dr. Jasper trying to reassure Dr. Penfield and saying, there must be something peculiar about this patient, maybe something down in his brainstem we don't know about and here I would remind you again, I can't emphasize it enough, that we had no way of really seeing what was going on in his brain except that bit of the temporal lobe that was exposed at the surgery in the left hemisphere. So any speculation was possible.

Now this was a situation when about a month later we saw another case of this. We saw a young man, a glove-cutter by profession actually from a family of glove-cutters who came, he was 28 years old and he had a left temporal lobectomy again. This time a one-stage one of removing the lateral surface and the medial structures including a good deal of the hippocampus and he showed this effect.

It was interesting that he was able to go on doing his glove-cutting and learning, which is a motor skill, it was an interesting thing. So, he wasn't as incapacitated actually as being able to work as the other patient but the same thing, forgetting from moment to moment and at that point we really had to sit down and think what could this mean. It was unacceptable. You cannot in elective surgery have this risk of this devastating memory impairment is so much worse than having epilepsy that you know you can't in good conscience go on like that and of course we also had to report these cases.

[41:53] So, Dr. Penfield and I – and I cannot remember really the course of this conversation, but we hypothesized between us that perhaps in these patients there was, unknown to the surgeon, unknown to any of us before the surgery, some atrophy, some damage in the mediotemporal region in the hippocampal region of the opposite hemisphere, the un-operated hemisphere,

because remember we couldn't see that. And these epilepsies, these temporal lobe epilepsies typically, not invariably, but typically are attributable to something that happens very near birth, either before birth or some febrile illness in the very first months of life and can easily affect both temporal lobes, both medial structures. And we know now of course, in these days with our enlightened possibilities because of very good MR, structural MR and magnetic resonance imaging.

So, we can see now actual atrophy, sclerosis in the hippocampus in many of these patients that probably goes back to the first either pre-birth or early years of their life, although the epilepsy itself may only manifest itself at around adolescence or even later.

So it is quite possible, quite reasonable that there could be damage in both hemispheres, but we couldn't see this. We just speculated that why we are getting this huge effect when we have this long – by that time a long series of patients with unilateral lesions who never showed anything like this at all, just showed these rather specific little memory deficits that I had been studying and which were really not too serious for the patient compared with the epilepsy. Instead you are seeing this huge change in their whole life because they are not remembering from moment-to-moment.

I don't know if any of your readers, sorry listeners have seen the film Memento, but this is a wonderful picture of the state of mind in which you really know that you are going to forget from moment-to-moment, anything you want to retain, you have to write down because you are not going to keep it. These patients have very good insight that they have this memory impairment and they cannot, of course, compensate for it.

So, we speculated, Dr. Penfield and I and this was in 1953 that in these two patients unbeknown to the surgeon there must be some damage in the hippocampal region of the opposite hemisphere. Now why hippocampus? Why hippocampal? Well because PB, if you remember, had the lateral surface of the temporal lobe removed in a previous operation and this had not left him with this memory impairment. It was only when Dr. Penfield extended that removal on to the medial surface. And we didn't know – he had always been respectful of the hippocampus, because it's such a beautiful structure, and it is a very big structure and a very ancient structure phylogenetically, but we didn't know what it did. But it must do something important and we believed so.

So, when we said, and as I later said with the surgeon Scoville, the hippocampal syndrome, we did not mean that the hippocampus was the only important structure involved in this big memory impairment, but that it played a critical role we were very sure we guessed. That was what we thought. And I have to say that 12 years later, PB died 12 years later from something quite different, from a pulmonary embolism, nothing to do with the brain, and Dr. Penfield and his neuropathologist, Dr. Matheson were able to study the brain and confirm this hypothesis with clinical pathological verification, because there was indeed more atrophy in the hippocampal region on the un-operated side than there was removal made by Dr. Penfield.

It was again the early days of EEG, he was probably misled by thinking that the seizures were starting on the left when perhaps they were not. But however this may be, at the time, to account for these two cases of severe and generalized memory loss, we speculated that – and it was pure conjecture, that we were seeing the effects of a bilateral lesion. And I reported these findings with Dr. Penfield at the meeting of the American Neurological Association in Chicago in 1953, '54 maybe.

And that was when Dr. William Scoville, a neurosurgeon in Hartford, Connecticut attached to Yale University I think, practicing in Hartford, Connecticut, was also a member of ANA and read our abstract. And he called and he actually came to the meeting and commented on the paper. And he called Dr. Penfield after and said, "You know, I think that I have seen this sort of memory impairment that you have described in patients in whom I have carried out my operation down in

Hartford, Connecticut, and I would like to invite you to come and study, you or Dr. Milner or any of you, whoever, to come down and study patients.”

And so Dr. Penfield said to me, would you like to go, and I said of course. And that was the beginning of – I know you’ve heard of the patient HM. I just wanted the people to realize that my introduction to amnesia and to this kind of patient was not with HM, it was with Dr. Penfield’s patients right here in Montreal, the patient PB particularly, that I had the advantage in these cases of studying them before the surgery. HM, I only met for the first time after the surgery and HM also had had really very little of a life. So I think – I don’t know if you want me to go on talking about HM at this point or if that gives you enough background and you want to ask me something else, I am not sure where we go from here.

Marc Pelletier

[47:55] Well, sure, yeah. Perhaps a little bit about HM. I mean people can cross reference him on Wikipedia. I mean, there’s enough material there for them to also go and look at as well and get a good feel for the story because of his brain. So, if you could tell us a little bit about that patient, HM and what you found.

Dr. Brenda Milner

Yes, certainly. Well, first of all I should explain the background. Because this is – Dr. Scoville’s cases like that and Penfield’s. Penfield said it almost – I mean he didn’t mean it in a sort of cold blooded way, he just meant just by chance, that these two, that Scoville’s studies and Penfield’s, that they almost, they complemented each other almost like a planned experiment, which of course they were not. Because – the background to what Scoville was doing is this.

First of all, HM was – I always used to call him a young man, but HM is 82 now. But he was 29 when I first met him in 1955 and he’d had his surgery in 1927. But HM had had – a grown up young man, an only child with rather elderly parents. And he – we don’t quite know why he developed his epilepsy. He had a minor bicycle accident when he was young – unconscious, I think when he was 7 and he developed some seizures a little after this. But the accident was not enough to produce seizures in itself. It is not clear quite. Also his seizures were not typical of temporal lobe seizures at all; they were much more like what you think of when you talked to me earlier about these severe epilepsies. He was having major convulsions several times a week and many, many little lapses of attention, little, little sort of absence attacks – which again is not typical of temporal lobe epilepsy at all – in between.

And he was on maximum doses of the anti-convulsion medications of the day, whatever that was he had it, he was really, really obtunded with all this medication. And still in spite of that, the seizures were breaking through and he was having – he turned out to be, you know, quite a bright, intelligent young man, but he was – all these drugs were affecting him, all these seizures were affecting him. He did not graduate from high school till he was really quite old. And then he got a job as a motor winder in a factory, but even that was very difficult because you’re working in a factory and you have major epileptic seizures, that doesn’t work either.

And so he had consulted Dr. Scoville more as you would consult a neurologist, you know, what can be done about this epilepsy and they had – and there had been some EEGs done on him at the time. And again, it didn’t look like temporal lobe epilepsy. He had widespread generalized abnormality in both sides of the brain, but nothing that looked like a focal lesion.

But in the meantime, Dr. Scoville had been – but again, you have to get a sense of history here. I didn’t know Scoville then; I met Scoville only when I – in the context of HM. But Scoville was a very good surgeon; he was a very skilled surgeon. He had – this was a bad period, the heyday of frontal lobotomies for schizophrenic patients. It was before they developed any medications really for – or any other treatment for severe mental illness. And so there had been all these frontal lobotomies done. And they gave very – they were very worrying in the sense that the patients became what Scoville described as – I haven’t worked with these patients – but what Scoville

described as a blunting of the personality or something. And Scoville did not want to go on doing frontal lobotomies for schizophrenia.

And so he wondered about whether if he did some medial temporal operations, that this – because the temporal lobe – part of the temporal lobe was connected to parts of the frontal lobe, that maybe could have some help with schizophrenia rather than – without some of the bad effects. And so he had developed a technique of doing a bilateral – in Montreal, we would never be doing bilateral operations, right, you'd do it on one side of the brain on the assumption or the hope that the corresponding region on the other side is working. You can get along with one kidney or one eye and so on, but you don't lose both. And so this is the philosophy, in general, you don't do bilaterally symmetrical lesions as I told you it's – you need the bilateral lesion in the monkey to show the full effects of the function of an area, for example. So bilateral lesions are not what you are doing, you're doing unilateral lesions for epilepsy.

But in the case of the schizophrenic patients, this was – the approach was different. And so Scoville had developed this operation which was a bilateral procedure. But it was only on the medial structures of the temporal lobe, not the lateral. And this is why Penfield regarded it as sort of complementary. We had – in the case of the surgery, I'm talking of the surgery now – of PB and FC, we had a unilateral temporal lobe lesion, but it included the neocortex as well as the medial structures.

What Scoville was doing was a bilateral procedure but which spared the neocortex, and incidentally, we have had MR studies of HM much more recently and the operation that was done was done exactly as Scoville described it, only somewhat less extensive and indeed spared the temporal neocortex. However, we are not talking about HM now, we are talking about this operation which he had perfected, practiced, for the treatment of very, very ill schizophrenic patients. I was able to study a few of these later. But they were really very, very sick people, and the operation did not change their schizophrenia.

So they were difficult to work with and Scoville had not himself worked with them. He had done the surgery. But he had with that goal in mind perfected the surgical approach, this operation, and that's why he referred to it as his operation.

[54:21] Now you see, Scoville confronted by this young man who was not schizophrenic, very nice, ordinary sort of personality, HM, very nice, well brought up, nice young man. But who has this terrible epilepsy. And he consults Scoville over and over, and finally Scoville suggests the possibility. And this is why HM knows that he has had the surgery, he knows it because it was discussed, it wasn't embarked on impulsively, it was discussed over a long period, that there was this operation. And Scoville had become very impressed from the work of Penfield, he'd become very impressed by the fact that sort of epileptogenicity if you like the term, if you will, of these medial structures of the temporal lobe, the fact that so often this was the villain in the piece of temporal lobe epilepsy. And so, he had the hypothesis that if he removes those structures in HM, it might benefit him, although he did not have focal temporal lobe seizures, it might benefit his epilepsy. And so, this was why the operation was carried out in HM.

And the amazing thing is that Dr. Scoville was in fact right, that although the boy did not have temporal lobe seizures it didn't seem, yet this operation had an extremely beneficial effect on his epilepsy. That he's able to – he has maybe one big seizure a year, he still has these little lapses of attention now and again, he's on so much reduced dose of medication. I mean, it was – and so Scoville's hunch that he might help this patient's epilepsy turned out to be thoroughly justified. And then I always add, but at a totally – the tradeoff was obviously unacceptable.

But whereas my colleague, Dr. Suzanne Corkin who was my graduate student then, now at MIT who has followed HM all these years, would even debate that because HM was really destined to go really downhill with the drugs and the epilepsy and so on. He had a very dismal future either way. Nevertheless, to me it seems it was an unacceptable price to pay, but of course Scoville did

not know, what was going to happen. So this was HM, and I was invited then to go down and see him. And so I went and I was very naïve, I always say this, this was 1950 and I think in 1955 when I met HM and I really by hindsight now I would say I was extremely naïve. But I suppose everybody was about amnesia in those days. Because there had been a lot of clinical descriptions of amnesia in elderly people. But the actual trying to break down and analyze what they could and couldn't do, was new.

However I went down and I met HM and first of all I went with a pretty open mind about what I was going to find. He was very pleasant and courteous and I would give him numbers to repeat and remember. And I remember – perhaps this gives you the feel of this. I gave him the number 584, went out for 20 minutes and came back. He said 5, 8 and 4 add up to 17. Divide by 2. You have 8 and 9, remember 8. And then he said very solemnly, remember 8. Then 9 it gives you, divided by 2, you have 5 and 4. So there you have 584 and then he said it's simple.

Marc Pelletier

That's not a simple way to remember.

Dr. Brenda Milner

He had been doing this, he had been playing around with these numbers for 20 minutes. And he said, explaining the mnemonic for me, and he said it's simple. And so I said, do you remember my name, do you remember? I have introduced myself lots of times. "No I'm sorry, the trouble is my memory." And then I laughed and then I said to him and what was the number? And then he looked at me and he said number, was there a number?

So you see the whole essence of this is that he had kept these numbers – this 584 going by constant rehearsal, remembering the 8 and so on, and talking to himself really through this period. But as soon as he was distracted, he had absolutely no access to this anymore, it had gone. And this was really the heart of this. And in fact these patients can only keep something going really by verbal rehearsal. If you give them – if they have to remember the shape of an ellipse for example, and then pick it out later as Murray Sidman was able to show in Boston, pick it out from a group of other ellipses, do a delayed matching task. A few seconds later, after about 30 seconds, they seemed to retain no representation of the item they were shown before the interval in order to match it later. It's only if they can actually verbalize and keep talking to themselves. And you see that actually, you see them, during memory tests you see the lips moving and HM as he talks to himself really and keeping something going with very high motivation, very high motivation, but with total failure once they're distracted.

[59:36] So this was the situation. Well then, as a psychologist, I mean let's not forget that, that's what I am. I said it's not satisfactory just to say that patients with these lesions cannot remember anything. If you don't try to train them with repeated practice, can they learn anything? You can't just say they – you can't prove the null hypothesis. You just can't say these patients can't do anything.

So I go back and see if I can do some learning tasks with the patient, to bring them with multiple trials, can I train the patient to do something? And in those days, I would go over to the Psychology Department at McGill because by now I was based at the Neuro, I would trot down to the Psychology Department and look in the elementary psychology, experimental psychology lab and pick up a couple of tasks that I could take. I took the night train to Hartford in those days from Montreal arriving somewhere early in the morning in Hartford. And with whatever I'd been able to carry with me, and spending the next two or three days working with HM and then taking my data and my equipment back to Montreal and pondering over it.

And that was when I had my first real breakthrough. Well, I still find this perhaps one of the most exciting things. And this is back again in '57 something like that. I go down and I took – first of all I took some mazes, I took learning tasks that he failed really. Predictably, I thought he would fail but I had to give him a chance on some maze learning tasks and so on, we would do a lot of

practice one day and we would continue over the three days I was there and with no progress. That was more or less what you were expecting.

But where I had the breakthrough was in a sensory motor task. A mirror-drawing task that I had picked up from the psychology lab here. In this little task, you see a five-pointed star with a double outline, a double contour, a five-pointed star drawn on a sheet of paper. And you're given a pencil and you're – have to start on the top of the star there, and try to trace the line keeping within the narrow confines of this star until you've been right round it and come to where you started.

Now that sounds awfully easy. The trouble is that you only see your hand and the star as reflected in the mirror. And that means that if you try it, you will find this – whenever you come to a – it's very difficult doing these drawings test in the mirror when you haven't done them before. And when you find yourself at the point of the star, your hand goes back and forth as you try to correct and you make bigger movements and – but the wonderful thing of course is that we learn. We learn rapidly over with practice. We learn with practice. You can't tell somebody how to do it, you just learn with practice. You learn by doing. It's a motor skill.

And the wonderful thing was that HM learned completely normally. I did ten trials with him on the day one and his errors were diminishing, beautiful learning curve, and then the next day of course he didn't know me at all, let alone the fact that he had done it. But he started again, he started more or less where he had left off and then day 3 at the end, after he'd done these 30 trials, he had the most beautiful performance, absolutely perfect and he looked at this trajectory and said, "I thought that would be hard." And he had absolutely no memory, no memory at all of every having done this task before so he was really impressed with himself that he had – you know, he thought doing this in a mirror would be difficult and instead he'd done it so perfectly.

So one part of his brain had been learning, acquiring this skill, and the other part – whereas the rest of him, HM, was not even retaining the memory of the experience, an amazing dissociation. That was a very – this is banal now, everybody knows this, but it was so exciting the first time to see it. Some early evidence of multiple memory systems in the brain, because obviously this kind of motor learning was going on independently of what I'm going to call loosely the hippocampal, the medial temporal system.

I speculated then that motor skills would be learnt with a different kind of learning. And there was already, of course in experimental psychology – experimental psychologists would be perfectly happy with this – even those who were not interested in the brain often thought of motor learning as following somewhat different rules. These are the kinds of things, sports that you learn best when you're young, that survive from season to season. You know how to swim, then you don't swim till the next summer but you still know how to swim. But most importantly they're things that you can't describe what you've learnt. If your stroke in tennis or at golf improves with practice or with lessons you cannot after the practice say – you're doing better now, what is it you've learnt? You can't possibly say. And even the attempt to analyze in what way you've improved or changed what you're doing destroys the performance, because you learn by doing and it's a different system in your brain.

[64:40] Now we know that a lot of these motor skills are mediated through parts of the basal ganglia, a part of the motor system and have nothing whatever to do with this medial temporal region. And then shortly thereafter some colleagues of mine in England, Elizabeth Warrington. Prof. Warrington at Queen Square, London, and Prof. Weiskrantz in Oxford, working together with some amnesic patients, people who – everybody wanted their amnesic patient at this point. It became interesting and they were working with patients who'd had herpes encephalitis, which can sort of sneak in through your nose and attack the medial structures of the temporal lobe and sometimes leaves people with this kind of memory impairment. And they had worked with such patients.

And they were finding some sort of perceptual learning I call it, which is now called priming, a kind of priming, where if you look at a puzzle picture long enough you may not see – if somebody shows you a puzzle picture, something that's meant to be a bit confusing to identify, you won't see it – you may take quite a while to see it, but once you've seen it you can be shown that picture months later and you will see it much faster, much quicker, so you've learnt something.

And they tested this with fragmented drawings of common objects and you just see a little bit of impoverished circumference, a few clues to the outline of this object, which could be an aeroplane or a telephone or a chair, and say what could this be. And you need – and you can gradually add contour until you see it. Then the next time you're shown this set of pictures you see it with less information, you require less filling in of the contour to recognize what the object is. And that I would call a perceptual learning, priming – you've been primed by your previous experience.

And this kind of learning we know is dependent on the visual cortex, is different again from the motor skills and different from the sort of memory that I'm studying with the medial temporal lobe. And this was a discovery of Warrington and Weiskrantz, but I replicated it in HM, who showed again normal priming also, although again not being aware that he'd ever seen these pictures before. So that was another example.

And gradually of course psychologists have studied other kinds of learning. The simple conditioning, in which parts of the cerebellum are very much involved. So this whole idea of multiple and different kinds of memory in the brain is very well established. But I would say some of the very early and critical evidence for this came from this mirror drawing study in HM.

Marc Pelletier

Wow! That's amazing. So that's one experiment that sort of shifted the area of neuroscience. It's a very pivotal point. It must have been pretty exciting to see.

Dr. Brenda Milner

It was very exciting. Of course, you have to sell these things. You're very much aware of this I'm sure talking to different scientists that this sort of history of ideas and so on, that it goes through this phase, at first you have to convince people that this part of the brain really is this important. It's such a circumscribed lesion and such a very devastating effect on a critical part of every human being's existence really, this memory of one's autobiography, so to speak. And so there's always a little skepticism and so you get an animal model. It's very hard at first because it is a difficult thing just intuitively to know what is going to be the equivalent to ask from a monkey that has to learn something over many trials maybe, and what you ask of a person. It took a long time to get a good model, which came out with Mishkin's work in 1976, but that was 20 years later, to show that such lesions in a monkey really did produce a monkey that couldn't do a delayed match, that couldn't bridge an interval in memory after a single trial.

But it took a lot of false starts, a lot of false approaches before we reached that. In the meantime people were saying, well maybe humans are not like monkeys, which is a very distressing thought because I rely a lot on what we know about monkeys. Or maybe HM is not amnesic, which is a silly thought, anybody who'd worked with HM knew that he was amnesic. But people were just trying to make sense of all this.

Then, once it got really accepted, and these different kinds of memory became evident, that they were separate, then it somehow acquired an enormous impetus. I mean memory is such a hot area of research these days. It wasn't back then. It wasn't particularly fashionable back then. So what I was saying is that you must realize from all the people you've talked to I'm sure this strange trajectory whereby at the beginning people question something and then it gets established and they say, well maybe, yeah, they're not so interested. Then suddenly it takes off.

Marc Pelletier

Oh absolutely.

Dr. Brenda Milner

It's a strange thing to live.

Marc Pelletier

[69:52] I would call it, first they think you're crazy, then they think, well maybe it's true, then the next level is it – if you're working on fundamental processes of biology or any science, I think that's where it goes. First they think you're crazy, then they think, well maybe it's true, and then, this is how it works. And this is what gets into the – our understanding of ourselves or the universe itself.

I think this is a tremendous story. We do have a lot of scientists that listen. From your early work and your determination to get accepted to the program, Ph.D. program, that showed a level of tenacity and a level of curiosity that you took the risk of doing the risky science, being a psychologist going into an area of clinical neuroscience and taking that risk. So you were, one, tenacious and, two, curious, so curious that you took a major risk. I hope people can take some inspiration as to, one, be tenacious and, two, take risks because that's how we're going to advance our understanding of ourselves.

I really appreciate you coming on. It's a great honor for me to have you on the show.

Dr. Brenda Milner

Yes, I don't think you think about the risk you know, when you're just driven by the curiosity. And then once you're embarked on it of course, that's where the tenacity comes in.

Marc Pelletier

I'd like to thank Dr. Milner for her time today and for sharing her fantastic scientific work with us. I'd like to also thank Dr. Dave Brodbeck for helping with the introduction. You can hear more from Dave in his series of podcasts at thunderbirdsix.org.

Thanks to Will Hall for the opening and closing themes and to the listeners for helping support this podcast. Thank you for your donations. Just before going I'd like to mention that the transcripts for today's show have been made available by the kind folks at Pods in Print. You can find a link to these transcripts in our show notes. For Futures in Biotech, I am Marc Pelletier.