CERAMIC TECH CHAT

Episode 13

Title – "Thermodynamics in the classroom and lab: Scott McCormack (E13)"

INTRO

De Guire: "I'm Eileen De Guire, and this is Ceramic Tech Chat.

When traveling to a new place for studies or a job, people often remark on the cultural differences that they experience. But the differences in geography can be just as shocking."

McCormack: "When we got there, we knew it was like in the center of the country, but we also didn't like fully appreciate how far away it was from water because with us growing up where we did, we were constantly on the ocean. So going to Urbana-Champaign was a bit of a shock to the system, where it snowed and did stuff like that."

De Guire: "That's Scotty McCormack, assistant professor of materials science and engineering at the University of California, Davis. Scotty is originally from the far south coast of Australia, where he studied metallurgy as an undergraduate. However, a series of events led to a move to the United States to pursue a Ph.D. in ceramics at the University of Illinois at Urbana-Champaign.

What is it like to change your materials focus and also move to a new country halfway through your education journey? What is it like for a young professor to set up a research program of your own? And, we'll also find out the secret to teaching thermodynamics—a subject that strikes fear into the hearts of many undergraduates."

(music)

SECTION 1

McCormack: "So as you mentioned, I grew up in a small town called Eden on the far south coast of Australia. And it's traditionally a fishing town that's currently going through a transformation to be more of a tourist town.

When I was growing up, I was pretty inspired to do something NASA-related, sort of like space sciency sort of theme of things. But as you can imagine, coming from a small town, that wasn't the sort of the job path that everyone had, right? The population there was only around 3,000 people and the closest city was about two hours away. So, we're pretty secluded down there.

So, going from this small town to wanting to get a career in ceramic science I think was most influenced by actually a lot of the people around me. I'd say even when I was growing up, I always had my parents' support. They were always telling me that I would go to university ever since I was a small kid, even though a lot of the people in my town didn't necessarily go to the university.

To be honest, when I was little, funny thing with me was that I didn't actually learn to read until I was in what they call Stage Three, and what Stage Three translates to is grades five and six."

De Guire: "Oh, my."

McCormack: "So I was actually, yeah, I was actually pretty behind the curveball on the whole learning how to read part of things. And that actually led to some interesting and funny conversations. I remember my mom contacting like the primary school being like, 'My son doesn't know how to read. How do we do things to him get him to read better?' and they were kind of like, 'Oh, you have to introduce him to more books.' And my mom said, 'I'm a librarian. He comes to the library after school at least once a week, sometimes more times than once a week. He puts the books away at school, I cannot surround him with more books,' right?"

De Guire: "Right, that's not the issue."

McCormack: "Yeah. Anyway, so back with me. My high school, I think it was my chemistry and physics teachers, they really excited me about STEM. So I can't stress enough how important it is with young people to get good STEM teachers because I really think they ignite and excite the sort of imagination. It was those two that really excited me to want to do something related to NASA, related to this sort of STEM engineering sort of stuff."

De Guire: "So you were inspired by NASA and the work they were doing, but was it the materials that excited you? Or, because there's a lot of aerospace and rocket science and other pathways."

McCormack: "Yeah, so at this point, I would say actually it was just the excitement of exploring what's unknown. Just the excitement of the sort of work that NASA was doing was trying to get to other worlds and exploring their environments. I would say that's what excited me the most. And this is actually where it is kind of funny too, that when I actually first went and did my undergrad at the University of Wollongong, which was five hours north of Eden, what I actually signed up to do was a degree in mechatronics. Mechatronics is like a combination of mechanical and electrical, and it's really focused on robotics. I was only in that program for a week and then I transferred to materials science. And really when I did that transfer over to materials science, the main reason why I did that is because I realized that the mechatronic stuff was a lot more like mechanical physics than like fundamental physics, and I think it was the fundamental physics and the fundamental chemistry that excited me the most in high school. And that's why I did that shift over to materials science and engineering because everyone there told me, the messages I was getting even from some of the professors there that I talked to in that first week, was that materials science had that focus on the fundamentals—fundamental physics, fundamental chemistry—as well as that engineering application. So I kind of liked being further down in that fundamental space."

De Guire: "That sounds like you were attracted to the fundamental space but with an application endpoint in view."

McCormack: "As well, yes."

De Guire: "So, you weren't one to study solid hydrogen, for example."

McCormack: "No yeah, yeah a little bit too fundamental."

De Guire: "Right, okay. So, when you went to Wollongong, did you anticipate a graduate degree? Or did that evolve over time?"

McCormack: "Yeah, so, when I was actually at Wollongong, I got what they call an integrated learning scholarship with an iron and steel making company called Bradken. I said iron and steel making company, they're actually more of a casting company, say like arc furnaces and they melt metals and then cast them into different shapes for the mining industry. So I got to work with them for every summer for three years. Really at that early stage, it was kind of no, but towards the end of that I did have a discussion with them about doing a Ph.D. in Australia with some steels working for them. That obviously did not end up happening, as you're aware, because I ended up in the U.S.

So the thing that changed there was me and a really good friend, who also went to Eden high school and also came to Wollongong, we decided to do study abroad, and we did study abroad in Urbana-Champaign. And when we selected Urbana-Champaign, we didn't, it's kind of funny, we didn't realize how prestigious Urbana-Champaign was for materials science. We solely selected it because we could get all of our course credits required to graduate and not have to extend our degree by going over and doing six months abroad. So that was that was our criteria, and Urbana-Champaign met that, which was fantastic.

It was a very exciting experience. It was actually in Urbana-Champaign where I did all of my classes related to ceramics engineering."

De Guire: "Okay, so Illinois introduced you to ceramic materials."

McCormack: "Yes. So Wollongong was definitely metals focus, and it was Urbana-Champaign that was ceramics. And that's also where I met there another Australian, professor Waltraud Kriven.

De Guire: "Yes. I know Trudy."

McCormack: "Yeah, good old Trudy. And so she was the professor for all my ceramics classes. So that's how I started to get to know her. And then just before I left, towards the end of the fall quarter of 2012, I was having lunch in the bottom part of the Union, and Trudy was also having lunch there and somehow we started chatting. And then she started telling me of a Ph.D. project that she was applying to the NSF for and asked me if I'd be interested in it. And so the project, what she told me about it was, 'I'm building phase diagrams, the hafnium tantalum titanium phase diagram.' And that's actually what my Ph.D. project ended up being.

So, after that meeting, I obviously went back to Australia because I still had 12 months to finish my undergraduate degree, and this is also when I was still having that discussion with the iron and steel making company Bradken about whether or not I would do a Ph.D. with them in Australia. And they kind of said yes, and we were working on the paperwork, and then I got the official offer from UIUC. And I was kind of like, 'Unless you can like give me the agreement that this is all going to be happening, like in the next few weeks, I'm going to have to pick UIUC because they've given me the offer now and I have to say yes, like now.' And so the company wasn't able to work that fast and get things there sorted in that time frame, and that's how I ended up coming to the U.S. to do my Ph.D."

(music)

SECTION 2

De Guire: "So you spent a fair amount of time working on the metallurgy side of materials science, but you ended up making a career on the ceramic side of materials science. So can you do a little bit of compare and contrast about the materials and what attracted you to really commit to a career studying ceramics? Why are they so interesting?"

McCormack: "So I think there is actually two points why I ended up settling on ceramics. First is actually by this stage in my career, I decided that I really enjoyed thermodynamics. I think that I found out that I enjoyed thermodynamics so much was when I took my undergraduate thermodynamic course with the professor in Australia, professor Brian Monaghan. He was a brilliant teacher and he explained things very well.

I just found thermo to be extremely logical and it just made a lot of sense to me, which I, you know, saying that, and then contrasting to the fact that I didn't learn how to read to such an old age is kind of funny, right? It's like, the reading just seemed completely illogical to me and the word structures just didn't make sense to me, where like something like thermodynamics for a lot of people find extremely confusing was just something that made so much sense to me."

De Guire: "Yeah."

McCormack: "I think the reason why thermo made so much sense to me is because I think of it like, almost like it's accounting. I feel like a thermodynamicist is merely someone who, they're the energy accountants of science, they just account for energy. What my undergraduate professor always relayed, and even what I now relay to my students, is that really what you're doing in thermodynamics is you're identifying key states. You're identifying state one and state two and then you're playing spot the difference. You're trying to figure out what is the difference between those states and then you're trying to quantify the energy difference from those states. And as long as you remember that fundamental principle, of how you're comparing those states and comparing what the differences are between those states, if you're careful with that, you can clearly set up your thermodynamic studies to define those situations clearly. And the reason why these differences in states is so important is because thermodynamics is based a lot on state functions. So you only care about the start and the end.

Okay, so you're probably wondering, 'Okay, how does that kind of relate to why I like ceramics?' Well, thermodynamics was one of the key reasons. I really liked thermodynamics. The project that I was going to do in metallurgy was not a thermodynamic project, it was a different sort of project. It was going to be focusing on looking at TRIP steels, transformation induced plasticity steels, so it's gonna be a little bit of mechanical stuff. Where the project that I got offered with Trudy was this phase diagram project. So thermodynamics I think was one influential factor that made me go to the ceramics route over the metal route.

The second factor is that we understand metals thermodynamically a lot, lot more than we do ceramics. And that's, what I mean by that is that we understand, we have far more thermal chemical data on mixing different elemental metallic components than we do mixing different oxide components. So, the research there is kind of already done in that sort of frame of things, whereas in the ceramic side of things, as Trudy would always tell me, it's like the Wild West. It's like everything's so new. So that was I think the second core factor that kind of drew me over to being in the ceramics.

And, I guess you could say a third factor is then going back on to my dream of like doing stuff with NASA is that the ceramics also have this high-temperature component, where they will operate up to, you know, the oxides that I was studying could go up to around, you know, 3,000 degrees C before they would melt, and then if you start transitioning to other sort of ceramic materials, they can go even higher. So there's also this high-temperature realm that also really excited me and the thought of like using them for reentry vehicles and stuff like that I just found really exciting."

De Guire: "So in a way you're kind of exploring both ends. In the applications, with the high-temperature materials, it's that outward looking view, but really exploring the unknown, diving inside to crystal structures and the thermodynamic behaviors of these materials because you want to take them into extreme environments. Kind of, you're a holistic explorer in that sense."

McCormack: "Yeah, I think that's a good way of summing it up, yes."

De Guire: "So you are unusual because you like thermodynamics and understand thermodynamics. Why do you think it is that it strikes fear into the hearts of so many undergrads?"

McCormack: “Yes, I think there’s a couple of reasons why it’s so scary. The first one I think is because thermodynamics is fundamental to so many different fields. Physicists, chemists, materials science all teach their own flavor of thermodynamics where they kind of have their equations. You know, they all stem from the same fundamentals, but they can all be slightly different based on what they’re trying to describe and explain, and I think this gets reflected in all the books that are available. It makes it very difficult to find a book that like covers things in a really good way or a way that someone wants to think about it. So I think that’s point number one.

The second point why I think it’s so difficult is that when you’re learning thermodynamics, all of the concepts, like the concept of internal energy, the concept of entropy, the concept of entropy, they’re all like interconnected. And when you learn them, typically how it’s taught, you learn them individually. And so when you’re learning them individually, you’re kind of like, ‘Oh, that’s a fun fact about enthalpy,’ or ‘That’s a fun fact about entropy.’ But it doesn’t all make sense until the end when you put it all in terms of Gibbs and you start building phase diagrams. So I feel like students are kind of like waiting through this ‘Why am I learning this? This doesn’t make sense’ for the first half of the class, and then at the end it’s like, ‘Oh my God, it makes sense now. Now I have the pieces to put everything together, and now I can do something useful with it.’ I think there’s no really good way to convince people that I’m teaching you this part for a reason. It’s going to become important soon, you just have to bear with me. And it’s going to be relevant soon, just keep going with the story and eventually it’ll make sense. And I feel like that makes it very difficult for students to be able to latch on to the concept because the question they were always asking me is, ‘Where am I going to use this? And how is this going to help me?’ So that’s what I think those are two reasons why thermodynamics is such a scary and challenging topic for new people coming into it.”

De Guire: “Yeah. So, you’ve started a career as a professor, you’re an assistant professor, so you’re teaching and you’re researching. Can you tell us a little bit about your research program and maybe how it relates to thermodynamics and extreme environments?”

McCormack: “Yeah, so the research program that I’m setting up at UC Davis is to study oxides, carbides, nitrides, and borides in extreme environments to characterize both their thermochemical and thermophysical properties. And when I say thermochemical properties, I’m referring to like their stability, so it’s like thermodynamic quantities, like enthalpies of formation, heat capacities, and stuff like that. And when I say thermophysical, I’m referring to their volumes and also like their crystal structure. So, that’s the two key spaces that I’m looking into.

And when we’re adding the extreme environment dimension, the main part that I’m focusing on there is ultrahigh temperatures. And when we say ultrahigh temperatures, we’re talking above 3,000 degrees C. So we’ve built a really fun system, it’s a levitator laser system, and we built it in collaboration with Materials Development Incorporated, they’re a group in Chicago. Essentially what it allows us to do is levitate these small beads that are around 2.5 to 3 millimeters in diameter. We can levitate them in a gas stream and then we shoot them with high-powered lasers to melt their surfaces. And the system that we have currently designed is, it's set up to reach temperatures of 4000 Kelvin. We only just got it set up in the lab, and the highest temperature material that was successfully melted is at 3000 Kelvin. So we're still working to get it to its max capacity, but I'm hoping in the next few months I will have everything sorted. So basically the game plan is to go through different oxides, metals, some diborides, carbines, and nitrides, just to verify that we can get them all to melt, and then we'll start using the system in conjunction with in situ X-ray diffraction at Argonne National Lab to start characterizing their structures and also start to build phase diagrams of multicomponent systems."

De Guire: "Oh that's great, sounds very exciting. And part of what I find interesting about what you're doing is there's so much computational science right now. For example, CALPHAD phase diagrams, or other computational methods. But you're really an experimentalist."

McCormack: "Yes."

De Guire: "So how do you see computational methods integrating or supporting the kind of work you do?"

McCormack: "So funny that you asked that. The early career award that we just won through the NSF is actually doing a combination of some new CALPHAD calculations that were developed at Penn State in conjunction with our high-temperature measurements. And so the essential idea with this is they've developed some techniques that allow for error quantification of a calculated phase diagram. So the idea is in this NSF, the early career proposal, is that we've identified a five-component carbide. It's the titanium zirconium niobium hafnium tantalum monocarbide.

So the idea is that we'll first do CALPHAD on the currently existing data to map out what the phase diagram would look like. Now, one has to understand that when doing this, this isn't going to be super accurate. It's going to be basically extrapolations into areas that we don't have data. The idea then is to use this error quantification to get an understanding of what regions of this phase diagram do we think there is the highest error. So usually this error quantification will identify compositions that have the highest error in describing their thermodynamic functions, then we'll go to that composition, make it in the lab, then go collect the thermochemical and thermophysical data on it at ultrahigh temperatures using our levitated system and some of the calorimeters in our lab, update the CALPHAD model, then get it to redo the error quantification to then identify what next set of compositions have the highest error. And we kind of want to do this process, and kind of iterate, to try and build a phase diagram a little bit faster.

And the reason why we want to try and do that is because, if you want to imagine, if I have a two components system and I want accuracy in my phase diagram of, you know, point one mole fraction, I'll need 11 sample. If I go to three components, I'll need around 80 odd. When I go to four, I'll need around 300, right? And when I go to five, the number explodes, the number that I need to get that sort of resolution. And, you know, when you're in these five components system and you also have to do all these advanced experiments that all take a ton of time as well, it just starts to become encumbering if we even want to get into these multicomponent spaces if we have to do that many experiments. So we're hoping this technique will reduce the number of experiments that we have to do, but that's yet to be determined, how many less and what sort of accuracies we can achieve."

De Guire: "I think that sounds really exciting, and I look forward to reading the papers on that one."

(music)

BREAK

De Guire: "ACerS' eighteen U.S.-based Sections offer a way for our members to develop a network of colleagues in their local geographic area. Learn more about ACerS Sections at ceramics.org/sections."

SECTION 3

De Guire: "Let's switch gears just a little bit and talk about The American Ceramic Society, your involvement, when you got started, some of the activities you've been a part of."

McCormack: "Yeah, so I've been a part of ACerS now for, oh, when did I join? Was it maybe 2016, I think? I can't remember exactly, but I think it was 2016. I first got involved with the President's Council of Student Advisors, which is a student organization in ACerS, which I can only say good things about and recommend to any new budding scientists. It's tons of fun, you get to meet tons of interesting people in your field, and on top of that it really does help you set up your network to meet other people. One great thing that I found was that you'd make friends in the field. You would then, when you're at a conference, you'd be going around with your new friends that you met in this group, and then they would see their professors, so they'd go say hello to them, and then you'd get introduced to their professors because, you know, you're their friends, and it's just a great way to meet as many different people as possible.

So when I was a part of the PCSA, I was a part of the Outreach Team, and then I also got to spend a year being the chair of the PCSA, which was also amazing. Got to work with the group as a whole, as well as that enabled me to interface with other ACerS committees a lot better, so I really enjoyed that and I, to be honest, I really think that the PCSA really made me able to make the connections that enabled me to get the professorship job that I did."

De Guire: "Yeah. Of course, Davis has a very strong ceramics faculty, so it's great that you're able to be part of that too. So, that's really interesting to hear you say that that was such a formative part of your entering the Society. So, now that you're out of the student life and into the nonstudent side of careers, what roles are you taking on in the Society and what role do you see the Society playing in your career?"

McCormack: "Yeah, so as of now I'm on two committees. And I guess when I say committees, one of them is the Member Services Committee, which is a lot of fun. And then the other one is I'm the chair of the Northern California Section. I helped reinvigorate, I guess is the word I want to use, re-set up, reestablish the Northern California Section, which has been a lot of fun. Sylvia Johnson has definitely helped a lot with that and she was the one that identified the need to reestablish the Northern California Section, and she was the one that asked me if I'd be interested in helping set that up. And I honestly think too that sort of, me getting into that role also stemmed from PCSA, because when I first met and got to chat with Silvia about that sort of stuff, that was when I was the chair of the PCSA."

De Guire: "And Sylvia was president at the time, right?"

McCormack: "Correct, yeah. It was two Australians, president of two separate things in ACerS."

De Guire: "And we've been benefiting ever since. Kind of circling back to the beginning, there are plenty of young people out there who struggle in their early days of education. Whether it's with reading or maybe attention issues, they're not getting a lot of encouragement from the educational system. So, what kind of advice would you have for somebody who maybe is starting off a little slow on the learning scale but obviously a lot of potential there. How would you encourage them to just stay engaged?"

McCormack: "Yeah, I think that's a really good question, and I guess I can speak from what my experience was with the difficulties that I had learning how to read. I think one of the key things there is you have to set up a situation in which the student or individual doesn't give up. I think words like 'dumb' or sayings like 'That's a bad question' or 'That's a stupid question' I think things like that are very damaging and just shouldn't be said. And the reason why I say that is because if an individual has the want to learn something, wants to get something out of something, and they also have the environment to achieve that, I think they can achieve that. I don't think there's anything that can stop them. I think those are the two key things: their desire to do it and their environment. And I think we have to cultivate both of those things to enable them to be successful. So I think if a student is struggling to learn how to read or they're struggling with math, I think the secret there is you have to find out, is it an environmental factor or is it an individual factor, where they're not motivated to do it.

So obviously if it's the environmental factor, that could mean like they don't have the books, they don't have the resources, that can be easily corrected, or should be easily corrected, I should say. It's something that governments or people have the power to go give them a book or give them the environment they need to survive. But when I say individual, if it's like desire, if they've like lost the desire or they're starting to give up, I think the trick there is that we have to find ways to motivate them, to engage them, and to excite them.

And so, for example, the way that I learned how to read, which I thought was great is, that I got taken out of class with Mrs. Elliot. She was the person who took me out of class to teach me how to read, and we would play 'Guess Who?' with words. And she pulled on the fact that she realized that I was competitive and I was visual. And so we would use 'Guess Who?' with different words to make me learn how different words were spelt and make me identify the similarities and patterns with the words, which really, really helped because I feel like I spent probably like three months with her and then after that I just knew how to read all of a sudden. I was like once that pattern clicked, it wasn't a problem anymore."

De Guire: "Right, once it was unlocked. So it sounds like she helped you find a different way in."

McCormack: "Exactly right, yeah. She was able to identify what excited me, which I think was the competitive aspect, and also realized that I was a visual person and that's what was messing up with my words and then she found a way to excite me about learning how to read, so then I wouldn't just be I don't want to do it because I can't do it."

De Guire: "Right, yeah."

McCormack: "Those are the two secrets, environment and desire."

De Guire: "Yeah."

(music)

CONCLUSION

De Guire: "Everyone learns in their own way and at their own pace. Finding the rhythm that works best for you is a key to achieving goals that may once have seemed out of reach."

I'm Eileen De Guire, and this is Ceramic Tech Chat."

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"Visit our website at ceramics.org for this episode's show notes and to learn more about Scotty and his research. Ceramic Tech Chat is produced by Lisa McDonald and copyrighted by The American Ceramic Society.

Until next time, I'm Eileen De Guire, and thank you for joining us."