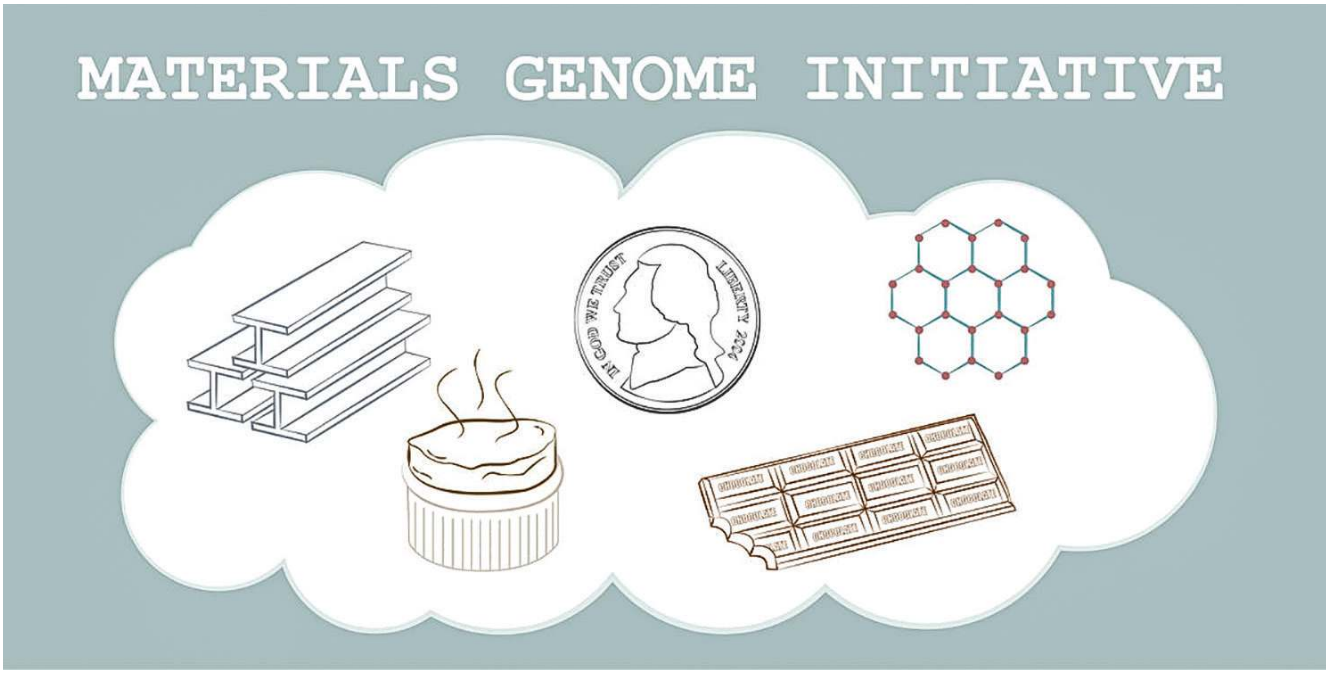


Credit: N. Hanacek/NIST

Materials Genome Initiative 10 years later:

An interview with James Warren

By Eileen De Guire

In June 2011, President Barack Obama's Office of Science and Technology Policy released a white paper called "Materials Genome Initiative for Global Competitiveness" that got the attention of the materials science community.[1]

The goal of the MGI was to reduce the time for materials development-to-deployment by 50%, or about 10 years—and for less cost. The MGI was motivated by a vision to accelerate the pace of new materials development to address urgent national challenges in clean energy, national security, and human welfare. Those developing the MGI concept to catalyze quicker lab-to-market products using new materials understood that success would require building an infrastructure of computational tools, experimental tools, collaborative networks, and digital data.

The white paper was prepared by an ad hoc group of the United States National Science and Technology Council (NSTC) with representation from most federal agencies that fund significant materials research, including several offices each from Department of Energy, Department of Defense, National Science Foundation, and Department of Commerce. A four-part strategic plan drove the first decade of MGI:

- Equip the next-generation materials workforce;
- Enable a paradigm shift in materials development;
- Integrate experiments, computation, and theory; and
- Facilitate access to materials data.

NSTC established the Subcommittee of the Materials Genome Initiative, which maintains a website of interagency activities and resources pertaining to the MGI (https://www.mgi.gov). Since 2011, the MGI grew to include more federal agencies and broader participation from the original agencies. The subcommittee is working on a new strategic plan to guide the MGI into its second decade and leverage the significant advances of the first decade.

As the MGI stands on the threshold of a new decade, ACerS marks this milestone with an interview with James Warren, director of the NIST Materials Genome Program. Warren was part of the 2010 ad hoc interagency committee that produced the original MGI whitepaper. Since then, he has tirelessly advocated for the MGI, working with government, academic, and industry stakeholders to build the infrastructure to realize the vision set 10 years ago. Warren talks about the genesis of the MGI, the journey of the first 10 years, and what the future holds.

This interview is condensed from a longer conversation, which will be published as an ACerS Ceramic Tech Chat podcast on June 9, 2021. Find it at https://ceramics.org/ceramic-tech-chat.

Q. *The Materials Genome Initiative is 10 years old. What drove the idea behind the MGI and how did the materials community react to the white paper?*

A. The MGI, when it was rolled out, was a collection of ideas that were not terribly new. There had been a large number of reports over the last few decades that preceded the rollout looking at how one could accelerate the design, discovery, and deployment of new materials faster by tightly integrating modeling with experiment and better data management.

These ideas were starting to bear enormous fruit. The early- to mid-2000s started to see reports coming out calling for integrated computational materials engineering. A lot of the database efforts in the computational regime, mostly around density functional theory, were yielding true payoffs. And so the idea for the initiative had been sort of bubbling in the firmament of materials science and related disciplines like chemistry.

When the Obama Administration approached the National Science Technology Council saying, "Hey, we think something like a materials genome initiative would be a good idea," there were a lot of people in government who thought, "Yes, we can make that work."

And, I am laughing now because, of course, the one thing that we did not love was the name!

I think there was a great deal of delight over a major initiative in materials coming out of the government. The only other one really at that point was a nanotechnology initiative, which was very substantial. The notion that there would be something that went beyond nano and also had an emphasis on computation was very exciting.

Q. *One of the goals of the MGI right from the start was to build an infrastructure that would support its goals. What progress has been made on building some of these computational tools, the experimental tools, the collaborative networks, the digital databases, and data access that was part of the vision?*

James Warren

A. The MGI is a bit sneaky compared to a lot of these other initiatives because the focus is really on the evolution of this infrastructure. In that sense it is a "meta" initiative. That is, we are trying to build the things that allow us to make the materials. It is a little bit abstract.

A lot of these tools are about managing data, or how you do a computation. It's not like we want to make the next great battery. We want to make the technologies that allow somebody to make the next great battery.

In terms of specific infrastructure, they are all over the place. One of the marquis examples is the DOE's Materials Project. There are a lot more resources, like the Materials Data Facility and Materials Commons, which NIST and the DOE fund, respectively, which are more sort of generic data hosting efforts that have made a great deal of progress.

There are a lot of efforts at NIST and at other places trying to think about better ways of curating and managing data so that other people can find that data and reuse that data in ways that are more efficient and robust.

How do you merge data sets? How do you gain extra value from that information? There is a tremendous amount of effort. You mentioned software tools and computational tools. We fund a lot of these sustainable software efforts, which the MGI is happy to build upon for computational research in predictive materials research.

And then there is also this whole community building activity. And that is almost a whole separate conversation about how we engage. (See sidebar: Materials Research Data Alliance)

Q. *You talked about the MGI predating or anticipating some of the big advances in artificial intelligence, machine learning, and deep learning. Do you think those changes were coming anyhow or did the MGI help push them forward?*

A. I don't want to take too much credit! In other words, I think they would have happened. And I think that the MGI is a framework for understanding how to accelerate materials discovery, design deployment, etc. Essentially all AI is a system to use data to develop a model. Well, the MGI is largely about taking advantage of modeling and integrating with experiment to accelerate materials discovery. So, AI as a paradigm is just another suite of tools to allow us to do that acceleration.

Plus, the MGI is to a large extent about data management. AI needs data. The MGI also is poised to provide the raw materials for an AI effort and you have to make the MGI data "AI ready." And the AI itself can be integral to an MGI effort. It is that two-fold aspect that I think is the overlap. I think the MGI provides an incredibly useful template for articulating what can be done and can also be integrated with the broader efforts.

Q. *What kind of impact has the MGI had on data-to-data driven discovery of ceramic and glass materials?*

A. Can I point to some broad-base answers to that question? Probably not. Can I find superb articles of recent provenance that do precisely what you are talking about? Yeah, sure. One of my colleagues Jason Hattrick-Simpers and collaborators have a very nice paper that came out a couple of years ago. It was about a glassy metal they discovered using a combination of high-throughput experiment and machine learning to find and then to fabricate.

That is just one example. The number of people now who are trying to use these techniques is large because it is clear that for materials discovery, anything that can increase your efficiency is something worth exploring. Adding robotics and intelligent systems to help you decide which experiments to do next is where a lot of the action is on this front.

I do not want to sell theory short because I am a theorist. One of the fun challenges, and where you will see a lot of the intellectual energy going right now, is how do you fuse classical theory and predictive models using AI techniques, which are purely data driven. How do you merge those two efforts? There are a lot of smart people thinking about it, but it is not like there is a canonical known answer. And whether there will be eventually, I do not think we know the answer to that.

Materials Research Data Alliance—MaRDA

A grassroots community grows in response to MGI

MaRDA—the Materials Research Data Alliance—coalesced from discussions and working sessions at the 2019 NSF-funded Summit on Big Data and Materials Cyberinfrastructure, which brought together 80 leaders from across the materials data landscape. That event revealed a community with similar values and goals interested in building a culture of data sharing and the kind of work it enables.

MaRDA aims to connect and develop the community needed for sharing materials research data to foster a materials data infrastructure combining software, hardware, and community-wide standards for access, interoperation, and use of materials data.

"That's a big goal, but that's why it takes a community effort. In fact, a central outcome of the 2019 Summit was agreement that there are shared incentives that span academia, industry, national labs, beamlines, publishers, funders, and anyone interested in materials research and associated data," says David Elbert, research scientist at Johns Hopkins University and chief data officer of PARADIM (Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials), an NSF Materials Information Platform.

MaRDA held its first Annual Meeting in February 2021 via WebEx. Co-organizer Cate Brinson says, "Over 130 people attended the three day meeting, covering the significant topics of FAIR materials data, connecting materials data infrastructure, and integration into education. The strong participation in a virtual event is evidence of the urgent need and passion for a grassroots approach to solving materials science data challenges." Brinson is Sharon C. and Harold L. Yoh, III Distinguished Professor in the Department of Mechanical Engineering and Materials Science at Duke University and co-founder of MaterialsMine.

The work to advance specific aspects of these goals will be done through Working Groups. Any MaRDA member may propose or join a Working Group. Membership in MaRDA is open and free to anyone interested in a community approach to accelerating data-driven materials research. To date, five MaRDA Working Groups (below) have been established.

1. MDI Provider Integration and Interoperability
2. Documenting Interoperable Data and Modeling Resources
3. Workflow Interoperability
4. Materials Data Repository Priorities
5. Data Dictionaries Working Group

For information about MaRDA and Working Groups, visit https://www.marda-alliance.org.

Q. *Do you think we will ever be able to design a material for an application from first principles?*

A. If you are talking to somebody who is trying to make a semiconductor material for application in a nanoscale electronics, we are already doing that. We are already using quantum mechanics and designing materials and manufacturing.

In those cases, you are effectively using modern technology to build materials atom by atom. And there you can immediately see the connection between some of these tremendously fundamental computations and the material itself. The materials are existing at the nanoscale or smaller even. The wires and the vias in microelectronics, these are now down to three nanometers. The process is just mind boggling. I can guarantee that semiconductor companies are modeling these things all the way down. In other words, they are using MGI techniques. They have to be, right? The effects of the sizes are quantum. You know the leakage issues that they are suffering have got to be all there.

As for structural materials? If I told you that you needed to design a plane wing or build the alloy for a plane wing using molecular beam epitaxy, you would say "I can't afford that. It is not a good idea." So instead you take the material, melt it in a bucket, and pour it in a mold. You are trying to make mass quantities and you have to make compromises. This processing technique is going to end up with a mess inside that system, a mess that you probably would rather not have in there. But you are going to have to live with it. [Integrated computational materials engineering] is about managing the costs by being able to predict these internal structures.

Am I ever going to be able to do a first principles computation of a turbine blade? The answer is no, never. You are going to have to make all sorts of compromises and intermediate calculations now.

I've dreamt for 30 years that computation would eventually be good at internal pattern recognition and can do its own coarse graining. You could imagine doing a calculation at a level, then it [AI] finds a pattern and does the next order calculation at the next pattern level up.

If you look at what AI is doing right now, it is kind of like that. It is finding patterns in systems and effectively trying to coarse grain. That is how you can get these predictions out. So I may have to eat my words where I said "never." It could be again in my lifetime that we see computations that can start with Schrödinger's equation, and some few other things, and really make macroscale calculations or predictions.

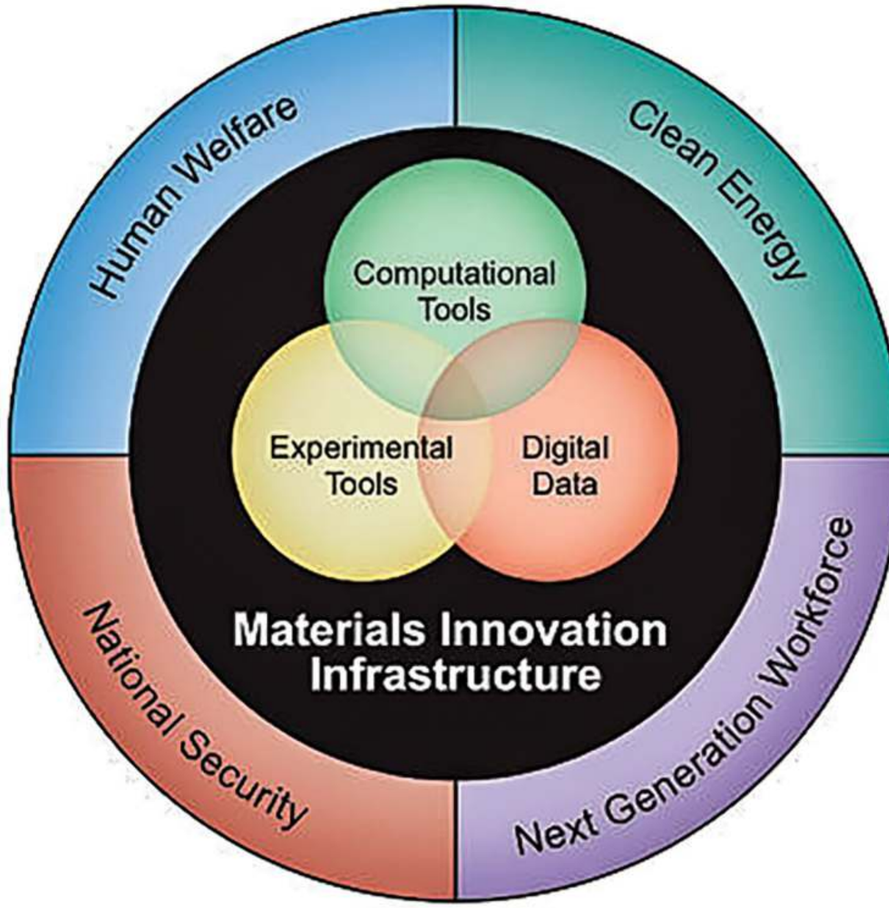
Q. *We have mostly talked about basic science and research. How do the MGI principles apply to engineering situations? For example, QuantumScape [San Jose, Calif.] recently announced development of new ceramic electrolyte materials for high-density, solid-state lithium-ion batteries. While the company did not reveal their R&D methodology, how could some of the ideas we have discussed have been used?*

A. It turns out that the company [QuantumScape] has an explicitly MGI approach. That is, they are doing computation to predict the materials and then down selecting and doing real experiments on a much-reduced number of potential compounds. And if they are not already, they are going to be using AI. I can guarantee it.

Companies are trying to use these techniques because they can actually make money and make new materials for their designs. A major aerospace company I am aware of is now doing simultaneous design of new materials and the rocket engines that they are building. I think they got the materials development insertion time down to 18 months from what used to be about 30 years. It is completely, unbelievably mind boggling.

This is the goal of the MGI. We are really trying to make it easier for people, companies, researchers, whomever, to use these ideas and tools. The government is funding this initiative to lower the barrier to entry for these ideas so that more manufacturers can do it with lower resources [initial upfront costs] so they can see the return on the investment quicker. This will help the billion-dollar revenue companies, and it also will allow more players in the field.

So you asked me about engineering impact; that is what this is about. It is already demonstrable.



Credit: NIST

Q. *What are some of the barriers to realizing the MGI's full potential, including workforce development needs?*

A. Workforce development is a big piece of this. You have to have the people that can use the infrastructure to reap the benefits of these developments. To make that happen, there have been a number of efforts, and there are more and more all the time. Another wonderful benefit of the AI revolution is more interest in that field. Because of that, there are programs that are springing up in materials design and the application of AI to materials design at a number of universities.

I think you are going to see materials departments, chemistry departments, lots of different kinds of engineering, any place there are materials looking at these things and trying to figure out ways to de-silo the AI efforts, which mostly have been taught by electrical engineering or computer science. It is just going to become another tool.

Computational work is part of most undergraduate and graduate training, including some undergraduate programs in materials. The same thing is going to be true for the MGI-style design. It would be crazy not to.

Q. *What does the future of the MGI look like, as it turns that corner of 10 years and looks to the future?*

A. At least two ideas are in the front of my mind. One is this deeper integration with manufacturers. We need to figure out the engagement models and the discussions needed to get them these tools. We must figure out what the barriers are to adoption, what are their incentive problems. It's complicated, and it's very company dependent. A big focus of the MGI going forward is getting us all the way out on the TRL [technology readiness level] scale.

Beyond that, I want to see a lot more focus on the integration piece. It always has been at the heart, but there are a lot of gaps. The distance between the gaps is now starting to become small enough that we can really start to knit this thing together. And as we start to see more interoperation of various resources and scales, I think this is going to start to accelerate the MGI.

In the Human Genome Project, there were some very nonlinear moments in how the cost of sequencing changed. It started at nearly a billion dollars for the first one, and now you do your cat for 100 bucks or something like that.

And I would imagine that we are going to see similar kinds of changes, where suddenly something that is going to drive the cost of certain pieces way down and then you start to attack some other element in the structure. As people start to see the value proposition in these kinds of approaches, it becomes obvious to people and we start to see real disruptive rapid change in the way that things get done. There is no question in my mind that materials science is likely one of the most lucrative aspects of the application of AI because you are going to make stuff that people want. It is really that simple.

The economic potential is so enormous that I do not think most companies have been able to really grapple with it yet, although you're starting to see it. The capacity to make things more cheaply and easily, which is what the MGI is about, has got to be at the center.

Q. *What role do you see the federal agencies having for the future of MGI?*

A. We are trying to be very careful to figure out what is the government's role. Certainly, the government's role is not to say that this kind of research is important, without understanding what the community thinks is important. All the agencies have missions, and how do we fund the research that will meet our missions? We will think about the technologies there and also understand what the industry needs so that we are there for them. And if that means understanding AI and how everyone can use it more easily and more intelligently, then that's where we'll go.

So then the question might be when does the government step back? And usually, the answer is when the private sector stepped in and solved the problem so it's not a precompetitive situation any longer. That's great. That's called winning, right?

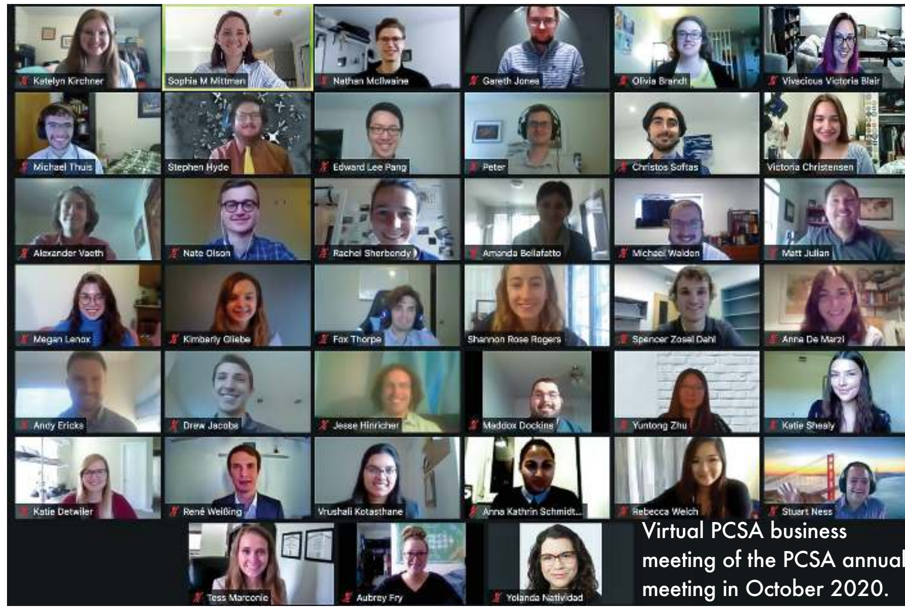
In a certain sense, you could say the MGI would be done when everyone says "yeah, that is the way we do things" and "we have all these tools at our disposal."

References

[1]"Materials Genome Initiative for Global Competitiveness," White House Office of Science and Technology Policy, June 2011. https://www.mgi.gov/sites/default/files/documents/materials_genome_initiative-final.pdf (Accessed April 27, 2021)

Chair's update on PCSA activities and welcome to the student *ACerS Bulletin* issue

By Michael Walden,
PCSA Chair



Virtual PCSA business meeting of the PCSA annual meeting in October 2020.

The June/July issue of the *ACerS Bulletin* offers students a chance to document their experiences entering the field of ceramic and glass materials.

These students, who began or continued their scholarship during the COVID-19 lockdowns, faced uncertainty in navigating remote-learning college classes and the challenge of conducting in-lab research during a global pandemic. While these reasons for feeling uncertain may be rather new, the common thread of uncertainty which persists even in more "normal" times serves to connect the students of today to students who have gone before.

The articles in this year's student issue of the *Bulletin* explore the many ways students face uncertainty while undertaking a college degree program, whether moving to a new country, changing one's major, or dealing with stalled experiments, among other challenges. In many cases, students have paved their own roads: not the road more traveled or even the road less traveled, but new roads that were not even on the map before.

One of the main difficulties that students face when transitioning from undergraduate studies to professional occupations or graduate research is the absence of an "answer key." Success is not a quantitative measure of performance (a "grade") that adheres to some universal standard. Rather, success is like using a pottery wheel—it is formed by one's own hand, rather than through the use of a mold. The students who have written the following articles, like many of their peers, are forming their careers by their own hands. Their careers may be international or multidisciplinary; through a diversity of experience, the future of the ceramics field is made stronger and all the brighter.

This outlook on the future has been a unique focus of the ACerS President's Council of Student Advisors (PCSA) during the 2020–21 term, ever since the quarantines led to our welcoming the new class of delegates with a virtual rather than in-person annual business meeting last October. The PCSA currently comprises 41 delegates, representing 25 universities and four countries. Despite never meeting in-person, these delegates successfully maintained the status quo set by the Council in previous years and also extended and strengthened the operations of the Council in virtually all facets. For example,

- **The Programming Committee** supported new opportunities for networking and professional development at virtual conferences, substituting for in-person analogues of activities which could not take place this year.
- **The External Partnerships Committee** expanded the size of its mentorship program by over 60% since 2019–20.
- **The Outreach Committee** presented technical demonstrations and information about access to STEM and ceramics studies in more classrooms than ever before. The new trial liaison program with the Colorado Section of ACerS is exploring a range of opportunities for implementing the existing national programs of the Council at a more focused, local level.

We hope that the following articles remind you of the types of uncertainty you may have faced at the beginning of your career in ceramic and glass materials. For current students, the following articles may serve as lampposts, illuminating newly-paved boulevards as well as well-trodden paths walked by students of all backgrounds and in all corners of the world. The PCSA is and shall long be an organization focused on connecting current and future leaders of The American Ceramic Society.

Michael Walden is a Ph.D. candidate at Colorado School of Mines, located in the city of Golden, Colo. As the 2020–21 chair of the PCSA, he strives to encourage the creative ambitions of its delegates. His vision of the best version of the PCSA is one that continuously looks toward the future, anticipating all the roads it may travel next. 100

Congressional Visits Day 2021 recap

By Yolanda Natividad
ACerS liaison to the Material Advantage Student Program

The Material Advantage Student Program's Virtual Congressional Visits Day (CVD) was held this year from April 20–22, 2021. The CVD is an annual event that gives students an opportunity to visit Washington, D.C., to educate congressional decision makers about the importance of funding for basic science, engineering, and technology. While we were not able to physically be in D.C. this year, we did offer a virtual CVD program for Material Advantage students.

The CVD experience began with a virtual welcome event on April 20, featuring talks by

- Alex Martin, 2019–2020 TMS/MRS Congressional Science & Engineering Fellow
- Matthew Hourihan, American Association for the Advancement of Science
- Megan Malara, 2020–2021 TMS/MRS Congressional Science & Engineering Fellow

After the talks concluded, the students were provided with a chance to go into break-out rooms to further organize their teams and to do some role-play in advance of their appointments in the following days.

This year's student attendees worked hard to schedule congressional visits with legislators and staffers for April 21 and 22. Despite their hard work, it proved to be a difficult task to schedule congressional visits due to a variety of factors outside of attendees' control.

On the evening of April 22, the Washington, D.C. Chapter of ASM International and the Washington, D.C./Maryland/Northern Virginia Section of The American Ceramic Society cohosted an event, which gave the students an opportunity to network with local professionals in the D.C. area. Additionally, the Washington, D.C. Chapter of ASM arranged for a speaker from the Defense Advanced Research Projects Agency, who presented a talk on Advances in Personal Protection (PPE) Strategies and Technologies.

The Material Advantage CVD event was attended virtually this year with a total of 27 students and faculty from the following universities:

Boise State University
California State Polytechnic University, Pomona
Iowa State University
Michigan Technological University
Missouri University of Science and Technology
Purdue University
San Jose State University
University of Tennessee, Knoxville
University of Maryland, College Park
University of Michigan
University of Minnesota, Twin Cities

Credit: Pexels (left, Lea Bonzer; right, Andrew Neel)

Continued thanks to David Bahr, head and professor of materials engineering at Purdue University, and Iver Anderson, senior metallurgist at Ames Laboratory and adjunct professor in the materials science and engineering department at Iowa State University, for conducting the training on how to visit with legislators and for their assistance over the years in helping to coordinate CVD. Bahr and Anderson both serve on the Material Advantage Committee, the advisory committee that provides recommendations and feedback about the program to the four partnering organization's leadership.

An additional thank you to Stephen Kampe, chair and professor of materials science and engineering at Michigan Technological University, for helping to cohost the virtual CVD welcome event this year.

We hope to be back in-person in D.C. again for the 2022 CVD event. If you are a student and did not get a chance to participate this year, make sure that you plan to register EARLY for the 2022 CVD event. Or if you are a professor/faculty advisor, make sure to plan on gathering a group together from your university.

For future updates, visit the Material Advantage website at www.materialadvantage.org. It is an opportunity that you will not want to miss! 100

MATERIAL™ ADVANTAGE
The Student Program for Materials Science and Engineering

Embracing growth when experiments stall

By Kimberly Gliebe

Gliebe

As a Ph.D. student studying thin film deposition, I feel fortunate that the internships I had during my undergraduate studies enabled me to experience research early, which confirmed that research is the career path I want to pursue. The internships also introduced me to the uncertainty that is inherent to research when things do not go as planned.

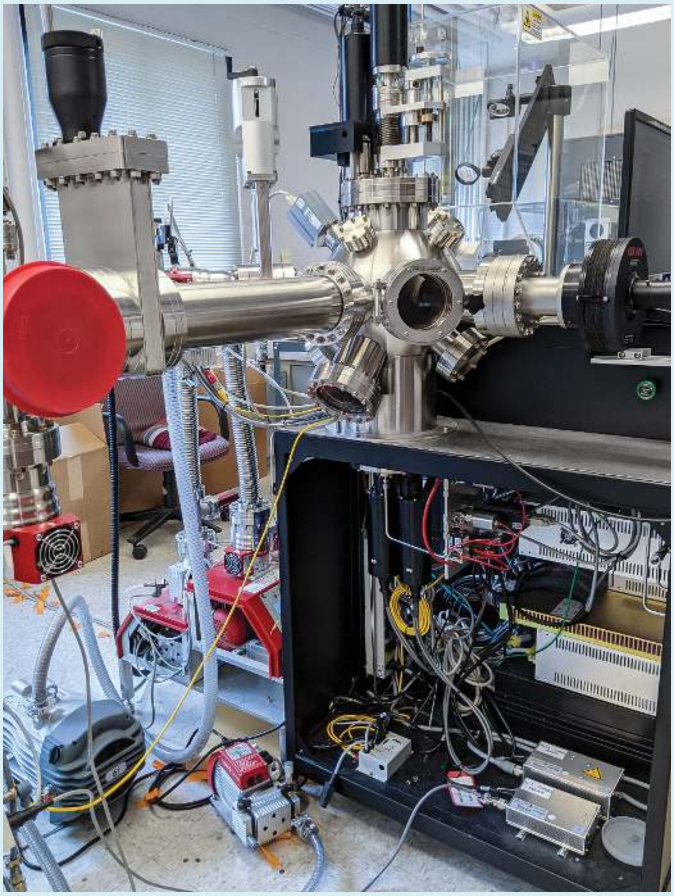
My first big experience with uncertainty was during a project at the Wright Patterson Air Force Base in Ohio, which took place during and after the senior year of my undergraduate degree. The Air Force project involved laser annealing a premade film to change its electronic properties for use in an integrated circuit. Several months after the project started, the laser that was central to my experiments began experiencing problems—it was unable able to reach its maximum level of power. I had no knowledge of the technology behind lasers and could not fix the problem myself. After weeks of discussions with the company that manufactured the laser and thousands of dollars, a company representative came to inspect and fix the laser.

This problem was unavoidable on my part, and yet it set my work back several weeks. I had to learn to be patient with this process and find other ways to use my time, such as reading literature about laser annealing and teaching myself basic Python programming skills. These activities enabled me to better plan experiments once the laser was fixed.

The Air Force experience prepared me for the beginning of my Ph.D., when a pump that was central to the deposition setup for growing my thin films was sent out for repairs (Figure 1). Initially we thought the pump would be repaired in a few weeks to a month, but it ended up taking almost half a year before we got the pump back. Because of my internship, I had learned other ways to fill my time when experiments stall. I enrolled in more classes, took my qualifying exam a year earlier than necessary, and heavily focused on literature searches, which gave me a better foundation of knowledge for writing proposals for fellowships.

Although I kept busy, this period was very difficult for me. Sometimes my successfulness as a Ph.D. student feels tied to how many experiments I am doing and the quality of my lab work. I had to remind myself that even though results from experiments are important, it is not the only aspect of a Ph.D.

The papers that I read about novel oxide structures and the application of machine learning to microscopy helped me to see how crucial data science is becoming for materials work—something I could never have envisioned back when I started my Ph.D. It guided my research from being about doing as many physical experiments as possible to instead spending more time critically analyzing results through machine learning. I have enjoyed this aspect of my work so much that I now am considering a career in data science for materials in the future.



Credit: Kimberly Gliebe

Figure 1. Pulsed laser deposition setup. The spherical chamber (center) is where deposition takes place, and the two red turbo pumps connected to the back of this chamber (lower left) bring it all the way to vacuum. One of the turbo pumps is what needed to be sent for repairs at the beginning of my Ph.D. research.

I am glad that I learned to use times of uncertainty as periods of growth and reflection rather than setbacks. I hope that regardless of the uncertainties I may face in the future, I will push forward and find creative ways to keep working and learning.

Kimberly Gliebe is a third-year Ph.D. student in the materials science and engineering department at Case Western Reserve University. Her research focuses on understanding the growth of thin films by pairing data science with microscopy techniques. When not researching, she likes to run and play board games, as well as host events through her university's Graduate Materials Society.

Building confidence when facing the uncertainty of switching fields

By Nathaniel Olson

Olson

In a career, especially in research, there is little certainty except for the inevitable uncertainty. Uncertain situations can be either sprung on you or jumped into willingly, yet both types can pose a serious challenge to your comfort and confidence. However, your perception of and reaction to this challenge can make uncertain situations an opportunity for growth.

My story is an example of jumping into uncertainty willingly by switching fields for my Ph.D. I majored in chemical engineering as an undergraduate, but during my studies, I saw glimpses of materials science through research at the Ohio State University on catalysts. In 2017, an internship experience at NASA Glenn Research Center on high-temperature aerogels and composite materials helped me realize that I wanted to learn about and work in the field of materials science. To pursue this path, I had to pivot my education and pursue a Ph.D. in materials science.

When starting my Ph.D., I felt woefully unprepared on fundamental knowledge that I believed my peers and mentors would expect me to have, such as not knowing one unit cell from another or what a "grain" is. Now in my third year, I have come to realize how to make the most of uncertainty and how to use it as an opportunity for personal and professional growth.

I will offer three pieces of advice that I find particularly useful in overcoming uncertainty. First, be unafraid to ask questions. This advice is applicable to all parts of life, but it is especially important when you do not know something and are surrounded by people that do. In my experience, conversations with my research group members have proved extremely fruitful in identifying new and interesting routes for my research that I otherwise would not have pursued. Remember, it is important to consider questions on your own first to develop intuition, but do not overthink yourself out of asking.

Second, seek out the right mentors and colleagues, as they can guide you and provide tools to overcome uncertainty. My mentors have been a crucial part of my growth thus far. My undergraduate mentor introduced me to research, showing me how to ask questions and design experiments to answer them. My mentor at NASA allowed me to explore research in materials science and expanded my connections in the field. My Ph.D. mentor advanced my skills in project development and challenged me to think deeper about my work.

Nate at the NASA Glenn Research Center during his 2017 summer internship.

Third, do not forget your own value and what you may be able to teach others based on your own background. We each have a unique story and lessons learned from it. A fresh perspective and enthusiasm can often make up for shortcomings of formal training. My background in chemical engineering allows for a unique systems-level perspective and has equipped me with fundamental knowledge of thermodynamics and transport phenomena that continues to inform my research in materials science.

While I try my best to consistently implement this advice, I often waver in my ability to take on uncertainty. I sometimes doubt myself and will choose to struggle on my own rather than reach out to peers and mentors for help, fearing I will give the impression of ineptness. However, when I do follow my advice and I reach out to mentors, friends, and peers, I am able to make the most of uncertainty by simultaneously learning from others while expressing my own ideas.

Ultimately, while putting yourself in uncertain situations does not make future ones any less uncertain, they build your confidence by letting you know you can succeed in handling them.

Nathaniel Olson is a third-year Ph.D. student in the Department of Materials Science and Engineering at the University of Illinois at Urbana-Champaign. His research focuses on developing porous materials (aerogels) with improved thermal stability for use as insulation in aerospace applications. Outside of research, Nate is a major LEGO enthusiast and amateur race car driver, racing with the National Auto Sport Association and the Illini Motorsports Formula SAE team. 100

Finding jobs and traveling as an international student in the US

By Iva Milisavljevic

Milisavljevic

"You're starting a new chapter in your life! That must be so exciting!" When a friend of mine said this to me right before my move four years ago from Serbia to the United States to start my Ph.D. in ceramic engineering, excitement was certainly one of my top emotions. But though the decision to pursue a doctorate in another country was one of the best decisions I have made, there are a few aspects of it I had not considered that ended up affecting my life very much.

I knew that Ph.D. studies and research would be hard at times and fails would be almost inevitable. However, for an international student, the uncertainties are not bound only to the Ph.D. After earning their degree, international students face uncertainties finding a job so that they can stay in the country. Not so many companies are willing to hire a person who is still on a student visa, which significantly reduces the number of job opportunities an international student can apply for. Fortunately, in the United States, international students that graduate with a degree in one of the STEM fields have the opportunity to stay for an additional three years to gain more experience through an initiative called Optional Practical Training.[1] However, if the student does not secure a job right after graduation, they then are required to leave the country and lose a chance to stay a bit longer. Therefore, preparing for the long process of a job search during the Ph.D. studies is one of the tactics that international students use to make the whole period less stressful.

In light of the current COVID-19 pandemic and dozens of imposed restrictions, especially in terms of traveling, international students faced additional uncertainties when the government started debating whether international students would be able to stay in the U.S. or even enter the country if their university only offered online courses.[2] As explained in the previous paragraph, physically being in the country plays a huge role in securing a job after graduation, so the possibility that international students would have to leave created much confusion and fear for the students. Fortunately, the government ultimately rejected this decision,[3] so international students, including myself, were able to continue with their work and studies.

However, for me and many students, staying in the country was only a partial win—the ability to travel back home to visit family remains a challenge. Specifically, it is returning to the U.S. after traveling that I see as the greatest challenge. In most cases, my one-year visa expires during the time when I would travel back for the holidays. So, my return to the U.S. would require me to apply again for a U.S. visa and go to the embassy for an interview. Although I am sure my name would not raise a red flag during the background check, there is still

Credit: Iva Milisavljevic

Even though traveling to my home country can be challenging, being a graduate student in the United States provides me many opportunities to travel in this country instead, such as to the Kennedy Space Center in Florida.

that small percent of a chance that I might get rejected and not be able to come back to the U.S. This small possibility has always given me a sense of discomfort, but I personally am willing to take the risk to travel home. The current pandemic, though, has only complicated travel even more.

In the end, I want to emphasize that, usually, international students can manage these uncertainties fairly well through forethought and careful planning. By staying informed about current policies and opportunities, you will know how to act and not lose your nerve when the time comes.

References

[1]Optional Practical Training Extension for STEM Students (STEM OPT), *U.S. Citizenship and Immigration Services*. https://www.uscis.gov/working-in-the-united-states/students-and-exchange-visitors/optional-practical-training-extension-for-stem-students-stem-opt

[2]M. Jordan, Z. Kanno-Youngs, and D. Levin, "Trump visa rules seen as way to pressure colleges on reopening," *The New York Times*, 7 July 2020.

[3]N. Anderson and S. Svrluga, "Trump administration backs off plan requiring international students to take face-to-face classes," *The Washington Post*, 14 July 2020.

Iva Milisavljevic is a fourth-year Ph.D. student in ceramic engineering at Alfred University. Her research focus is on novel solid-state single crystal growth technique and transparent ceramics for various optical applications. In her spare time, she enjoys practicing yoga and drawing funny doodles, as well as hiking, camping, and all sorts of outdoor activities.

The two-body problem: Planning a career when married

By Riley Winters

Winters

As an undergraduate student studying materials science and engineering at Boise State University, I faced uncertainty in many ways through my education, from changing majors (from finance to materials science) to research focus (electrical properties to nuclear energy). These choices often are very personal decisions that are decided based on how it will shape your future career plans. However, these choices do not always just affect you—when you are married, you must consider how your decisions align with your spouse's plans as well.

In my case, I originally was certain that I wanted to work in the semiconductor industry, and I set out to learn as much as possible about electrical properties of materials. However, in my second semester of undergrad, I joined the Advanced Materials Laboratory (AML) as an oxide nuclear fuels student researcher, which led me to intern at Oak Ridge National Laboratory (ORNL) as an expansion on my research in the AML. I spoke with many researchers and other students while interning at ORNL, and I toured the University of Tennessee Nuclear Engineering graduate program. These experiences ignited my passion for nuclear energy research given that the motivation for such research is to develop an emission-free, consistent, and reliable energy source. So, I decided that getting a Ph.D. was the best option for pursuing a career in nuclear energy.

However, while my personal feelings about the decision were set, I needed to consider how pursuing a Ph.D. would affect my husband. He graduated in 2018 with a bachelor's in materials science and engineering and already had a job in the semiconductor industry in Boise, Idaho, which is 4+ hours from any nuclear-related industries. If I went the nuclear route, we would have to move, and most likely he would have to switch industries.

After a lot of discussion, it was clear that we were both supportive of each other's career goals and were willing to make compromises for each other. We each made of a list of what was important to us in a career choice, including things like location, industry, materials type, and education level. The most important factors to us were location and industry. We wanted a location that we could enjoy outside of work and be near our families, as well as one that supported our desired industries. To supplement both factors, we also considered material type. If I were to compromise on the industry, I would still like to work with ceramic materials.

Part of the decision was made easy when I received an email from my university's advising department letting me know about a ceramics engineering R&D internship at a company that manufactures thermistors, located in Boise. I was excited when I realized that many of the skills and experiences I gained when working with oxide nuclear materials would transfer seamlessly to working on thermistors, so I applied.

Credit: Riley Winters

Riley with her husband and Australian Shepherd dog at their home in Boise, Idaho.

I started the internship this past August and felt like it cleared up all my career path uncertainty. I feel fulfilled in this position, as I can conduct research and experimentation in addition to process improvements. While I am no longer connected with the nuclear industry, thermistors do have a significant impact in many areas, including military, medical, and countless everyday appliances. Additionally, this industry is one that I can be successful in with just a bachelor's degree, but I can remain open to getting a postgraduate degree in the future. Between these aspects and the fact that my husband can stay at his job, which he has been at now for two years, my choice was made. I will be graduating in May 2021 and my internship will become a full-time position as ceramics process engineer right here in Boise.

Riley Winters is ceramics process engineer at QTI Sensing Solutions. Her research focus is process development for thermistor manufacturing, including tape casting, rheology, and sintering. Outside of work, she enjoys gardening and does agility with her Australian Shepherd dog.

Harnessing the potential energy of uncertainty

By Elisa Zanchi

Zanchi

Uncertainty can be defined quite literally as the absence of certainty. In other words, someone experiencing uncertainty is unsure and/or ignorant of future developments or consequences following from a current situation, which leads to a state of doubt, insecurity, and anxiety.

While uncertainty can be experienced to varying degrees, it generally can be traced to either external or internal factors. External factors, such as when you are waiting for an answer from someone or the results of an experiment, often trigger uncertainty due to featuring an outcome beyond your control. But for uncertainty coming from internal reasons, such as when you find yourself at a crucial crossroads that requires major decisions on your personal or professional life, you can experience uncertainty because the outcome is entirely in your hands.

Two events of my academic life brought me face-to-face with these two types of uncertainty—first, the choice of my master's thesis; and second, the decision to do a Ph.D. The degree of doubt that I experienced on these two occasions differed noticeably and reflected the new strategies that I have matured over time to react to uncertainty.

Being born and raised in stable family conditions, neither external nor internal uncertainty played a significant role in my early life. Many of the choices I made both in personal life and career path were chosen in a light-hearted manner. However, when the time came to decide on my MSc thesis, for the first time I realized that a choice could have consequences on my future career.

On the one hand, I had the option to focus on an easy topic, allowing me to graduate quickly and find a job close to my family and friends. On the other hand, I could take the chance to go abroad and be part of an innovative project, involving a huge personal and financial investment. I found myself trapped in uncertainty, making lists of pros and cons that were influenced by an aura of insecurities: the fear of not being able to overcome possible obstacles (e.g., language, being independent, getting along with new people) and of meeting others' expectations.

After pouring over the pros and cons, I finally had a paradigm shift. I wanted to challenge myself and realized that embracing uncertainty was an opportunity to discover who I could become outside of my comfort zone. Thus, in the end, I decided for the second thesis option.

From that experience I learned that while a high level of uncertainty can cause high amounts of stress, it also entails a huge number of possibilities. Uncertainty and action are similar to how potential and kinetic energy are strongly dependent on each other: an uncertain situation holds a lot of potential to be transformed into the kinetic energy of our action.

Picture of the DTU Risoe Campus in Denmark, where I conducted research for my master's thesis and began to appreciate the opportunities to which uncertainty can open your eyes.

Credit: Elisa Zanchi

Following my master's, I was caught again in a moment of indecision when deciding whether to pursue more education or to find a job. Compared to my MSc thesis, which involved a lot of internal uncertainty, a Ph.D. project would introduce a lot of external uncertainties because, as a Ph.D. student, it is not only required to plan my own work but also that of collaborators, students, and technicians, which is a complex task with probabilities of failure that would have long-term consequences. Fortunately, the lessons I learned about handling my internal uncertainty when choosing a MSc thesis allowed me to accept this feeling as an alarm bell informing me that I was at a relevant crossroads and it was time to ponder over the next steps.

Now, at the beginning of my professional life, I see how uncertainty gives me the chance to make decisions based on my aspirations instead of going by default for the safest and most convenient option.

Elisa Zanchi is a second-year Ph.D. student in materials science and technology at Politecnico di Torino, Italy, under the supervision of Prof. F. Smeacetto. She works on the synthesis of innovative glass-ceramic sealants and ceramic coatings for steel interconnects and their integration in solid oxide cell stacks. In her spare time, she enjoys hiking, playing tennis, and crafting handmade jewelry. 100

Using themes to find comfort in uncertainty

By Collin Holgate

Holgate

There are few questions I find more frustrating than "What do you see yourself doing in five years?" Blessed-be those capable of constructing grand life visions—I am not one of them. I do not know what I want to do with my Ph.D. in materials science once I receive it.

Life transitions—especially those that are uncertain—are scary. But we can build some comfort with this uncertainty by changing the question. Rather than focusing on *what* you plan on doing later in life, you should explore what you want life to *feel* like. In other words, instead of choosing a specific goal or aiming for a particular job, you can develop a general theme for your life that helps to guide decisions when they come up.

Finding a theme can take quite a bit of self-exploration. Evaluating how you prioritize things like money, independence, time off, mentoring opportunities, location, and possibility for impact can help you identify the factors necessary for attaining long-term fulfillment. You will not have it all early in your career, so it is important to know which aspects you are willing to sacrifice for others. For example, one of the big themes in my live is helping people. I'm willing to sacrifice money to satisfy that desire. Priorities evolve over the years, but themes are flexible and can be reworked when the time feels right.

Once you have an idea of your priorities, explore career paths that offer some overlap. The point is not to find the perfect path but rather to discover your priorities in lots of different paths. For example, my desire to help people can be satisfied through mentoring others. Career paths as a professor, an industrial research scientist (at the right company), or as a teacher all offer opportunities to be a mentor, and I believe any of these roles would fulfill me. Be creative in your search and keep an open mind! Search within and beyond the scope of your technical expertise.

Credit: Mohammad Bagher Adib Behrooz, Unsplash

Your career is a labyrinth of different paths—but developing themes for your life rather than specific goals can help you navigate the many options.

However, be aware of education sunk-cost fallacies, or the belief that you must continue on a certain path because you've already invested a lot of time, effort, or money in it. This type of thinking—that your education is only good for one type of job—entirely discounts the personal growth and transferrable skills you have gained. Your education, no matter what you do after, is never wasted. As a starting point for exploring possible careers, I highly suggest visiting your university career center—such centers can be a repository of information and tools. (If you're not currently affiliated with a university, the career website through the University of California, Santa Barbara offers diverse and well-organized information, much of which is publicly available.[1])

Perhaps a couple of career paths have really piqued your interest. If so, pay attention to what skills and experiences would make you a competitive candidate; work to build these skills, especially those you are currently missing. Remember, our themes can guide us even if no particular path hit home. For example, I tried to maximize mentoring and leadership opportunities throughout graduate school, experiences which will help me in my future, regardless of the exact path I choose. Even if you are years away from graduating, start thinking about your themes now. Early introspection will allow you to catch more opportunities.

Developing a theme will not completely erase feelings of uncertainty, but hopefully those feelings will be more comfortable, especially for those unable to laser focus on a specific goal. Work on exploring yourself. Your career is a labyrinth of different paths. Even if the route ahead is foggy, when you arrive at a fork, your theme can illuminate the way.

References

[1]UC Santa Barbara Career Services, https://career.ucsb.edu

Collin Holgate is a Ph.D. candidate at the University of California, Santa Barbara, working under the direction of Professor Carlos Levi. His research investigates the thermodynamics and kinetics of how molten sand and ash degrade the protective coatings used in jet engines. Outside of research, he has been involved with organizing and running UCSB's annual Beyond Academia career exploration conference. He also enjoys spending time in nature by exploring the mountains and coast of California.

Student perspectives

The difference in thinking between Chinese and German scientific research scholars when facing unknown challenges

By Bo Chen

Chen

My name is Bo Chen, a Ph.D. student in chemical engineering at the Karlsruhe Institute of Technology in Germany. I am originally from China, and I completed my bachelor's and master's degrees there before moving to Germany for my Ph.D.

I chose to pursue my Ph.D. in another country because I believe getting out of your comfort zone exposes you to new opportunities that broaden your academic horizons and comprehension of different cultures. I chose to study in Germany because Germans are known for their scrupulousness, which is a good characteristic to have when performing research.

In Germany, I have experienced a completely different scientific research atmosphere and way of thinking compared to China. In my opinion, both the Chinese and German approaches to research have their pros and cons, which means we can learn a lot from each other. I believe that this exchange of information is a necessity of international academic collaborations.

From what I have experienced, Chinese scholars spend far more time than German researchers in aggressively pursuing a solution to challenges—it is normal for some Chinese research scholars to work more than 12 hours a day, six or seven days a week. This diligence is due to cultural and national conditions that emphasize efficiency. In experiments, Chinese scholars usually pay more attention to the results because they like to pursue a high impact factor for the subsequent paper. In terms of social interactions with colleagues, there is an obvious hierarchy between superiors and subordinates in Chinese laboratories, both at universities and research institutions. I believe this hierarchy can greatly limit the enthusiasm and motivation of researchers, and it also can limit the communication between colleagues, which inhibits a lot of interesting ideas.

Credit: Bo Chen

Me traveling in the Czech Republic. I believe the process of actively interacting with various cultures exposes you to new opportunities that broaden your academic horizons.

After several years of study and exchange in Germany, I have identified several significant differences in the academic environment here compared to China. The most impressive thing about German scholars is their passion and enthusiasm for research. While scrupulously approaching unknown challenges step-by-step, they spend time looking to understand the reasons for their results rather than just focusing on the results themselves; they discuss intensely with their colleagues. I am excited to witness this kind of love for one's job. It is this kind of love that makes them full of passion for unknown challenges and also makes them full of possibilities in scientific research—professor and student alike can speak freely and humbly like friends and discover new possibilities through comparing their different viewpoints. However, because German scholars attach great importance to family and personal time, they typically spend less time in the lab than Chinese scholars, which often leads to slower progress.

These differences are just a few of the ones that I have observed in how the scientific research process is conducted in China and Germany. In the process of actively interacting and colliding with various cultures, I developed my own approach to research that I will likely take with me after graduation. I hope that more international young scholars will give up their prejudices and communicate with each other seriously and profoundly. When we face unknown challenges, we can walk hand-in-hand to overcome difficulties. I firmly believe that the future will be full of possibilities.

Bo Chen is a Ph.D. student at the Karlsruhe Institute of Technology, Germany. His research focuses on solid electrolytes for batteries. He likes traveling and reading. 100

Facing uncertainty in new types of jobs

By Aubrey L. Fry

Fry

I am a first-generation college student. I cannot remember having a conversation about college with anyone—not a parent, teacher, or friend—before my junior year of high school. I grew up in farm country, and a four-year college was not the default expectation for high school graduates in my town. Like many of my peers, I grew up working physically demanding jobs—gardening, mowing, throwing hay, tending to animals. Though I am extremely grateful for these jobs, I knew I didn't want to do such work forever. However, I didn't know what I *did* want to do either.

When I started research for my master's in materials science and engineering, the work was unlike my previous job experiences. This type of exercise was unfamiliar to me, and I felt much more uncertain of my aptitude to succeed. Unlike manual labor, the fruits of performing scientific research did not culminate at the end of each day—I could work 50+ hours a week and feel that I had accomplished nothing. But accomplishments did come over time, and they were marked with great satisfaction and pride.

When I neared the end of my master's program, my advisor offered me to stay in his group for a Ph.D. I declined his offer because I wanted to explore other materials and other places before choosing a Ph.D. program. While I enjoyed research, I felt that I needed more experience to know if I wanted to dedicate my life to such a career. So I interviewed for a research position at a government lab after just one year in materials science.

The position involved fundamental research in glass and ceramics, and it was my first "real world" interview. The interview process was intense. The day's agenda was set to last only a few hours, but it ended up going all day.

My visit to the USS Midway Museum during the International Conference on Sintering 2017 in San Diego, Calif.

I met with branch heads and senior scientists, gave a presentation on my research, and toured the labs. That was the first time I presented my research (or any research, in any capacity), and to my pleasant surprise it was the most enjoyable part of the interview process. "Wow, maybe I could really be good at this," I thought to myself.

That glimmer of confidence was quickly snuffed out during my one-on-one interviews, which felt like one long oral exam—I was bombarded with hours' worth of questions. I gave my best responses and hypothesized about things I did not know the answers to. The most stressful interview was when one scientist pointed out every materials-related word I misused or mispronounced; I felt so over my head, and my inferiority complex grew. Later that afternoon, hours after the designated end time, I left the building and walked to my car in a nearly empty parking lot. I felt so unprepared and like a fraud, and I was sure everyone there thought the same.

After what felt like three months—which was only three weeks—I got a call from the government lab, offering me the position. Even though I felt so behind during the interview, what mattered is that I demonstrated my potential and willingness to learn—key qualities for growing in any job.

That was the best first job I could have asked for. Research became more familiar to me and I became more comfortable knowing that the delayed reward of fundamental research was truly satisfying. I learned so much in my two years at that job, and at the end of the experience, I earned a Department of Defense SMART scholarship, which allowed me to return to graduate school for my Ph.D.

I am immensely grateful for those in my life that have seen potential in me even when I do not see it myself. I must constantly remind myself to face uncertainty as an opportunity. And when I do, I count it as a success.

Aubrey Fry is a Ph.D. candidate in the Department of Materials Science and Engineering at The Pennsylvania State University. She researches silicate glass composition–structure–mechanical property relations with a focus on exploiting topological adaptability under stress. Aside from glass science, she is passionate about music and painting, and enjoys camping and water sports. 100