Inspiring Change through Curiosity and Innovation

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Dr. Mark Freeman is a Professor of Physics at the University of Alberta and a former Canada Research Chair in Condensed Matter Physics. Beyond his innovative research in nanotechnology and magnetism, he is actively involved in The Shack, a makerspace at the university that empowers students to explore hands-on projects in engineering, design, and technology.

Gopesh Gopinath: Thank you very much for joining me today, Dr. Freeman! We're honoured to have you as our feature researcher for this issue. To begin, could you tell us a bit about yourself, your path to academia, and your connections to the University of Alberta (U of A)?

Mark Freeman: My connection to the U of A is literally lifelong. I was born on campus in the old University Hospital. One of my earliest memories is of my dad, who was a chemistry professor, descending an outside staircase to enter the old physical sciences library – now the site of the undergraduate chemistry labs in the Centennial Centre for Interdisciplinary Science (CCIS). I was about two years old then.

I went on to study physics as an undergraduate at the U of A and attended Cornell University for graduate school. Then, I had an opportunity to stay in New York and work at the IBM Thomas J. Watson Research Center in Yorktown Heights, about 40 minutes north of New York City. At the time, when I went there, it was about as close to an academic environment as you could find outside of a university. I felt like, "This place is amazing. It could be on the dark side of the moon, and I would still want to go there." But things started changing around 1991. After five years at IBM, I started looking for a university post. It wasn't a great time - maybe it never is a great time to look for faculty jobs. But in Canada, big provincial budget cuts were starting in Ontario and Alberta. Somehow, I was extremely lucky to get a job back here and join the faculty.

Was physics always the field that inspired you, or did your interests evolve over time? How did those early experiences shape your commitment to research?

The Apollo moon landing happened when I was nine. I remember sitting on the floor on the veranda at my grandmother's cottage, mesmerized, watching this incredible event unfold. That made a big impression on me and fostered an early interest in astronomy and related fields. After high school, physics seemed to be the science most closely connected to those interests. So I went on to study Honors Physics at the undergraduate level. I even convinced myself that I could pursue physics until I was 40 and then transition to something entirely different – a reflection of youthful optimism.

What kept me in physics, though, was discovering experimentalists – scientists who spent much of their time working in small labs with apparatus they had often built themselves, controlling every aspect of their experiments. The more I learned about that, the more it appealed to me. To this day, it still feels like having a private conversation with nature. Every now and then, nature tells you something new – hopefully something worth sharing with the rest of the world. I also have to give credit to the upper-level experimental physics courses here at the U of A, as well as a summer job I had at the National Research Council in Ottawa after my second year. Those experiences played a huge role in solidifying my decision to continue with physics after undergrad.

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That's fascinating! It's incredible how these seemingly simple experiments can reveal so much about such complex phenomena. Seeing the creativity and precision involved in that process is truly inspiring.

Absolutely! One thing I've found over the years is that, as an experimental physicist, I feel like I've developed a deeper appreciation for some of the amazing things happening in this field. For example, the successful detection of gravitational radiation in 2015 – that was incredible. I'd known about that project in the background for decades, and it always seemed like one of those things that probably wouldn't succeed in your lifetime. It was just so ambitious. I remember feeling such a profound appreciation for what they had accomplished when it happened. In a way, just being able to truly understand and admire that achievement felt like it made all the years of being a physicist worthwhile.

At Eureka, we aim to support undergraduates as they seek out opportunities outside the classroom and grow as researchers. The Shack, another resource here at the U of A, provides hands-on experience that complements classroom learning. Could you tell us about your role with The Shack? What motivated you to help lead this unique resource and how do you see its impact on student innovation and learning?

The traditional physics curriculum is very theory-heavy. It doesn't give the full flavour of what the field is like. When I was a student, I felt pretty lucky to learn more about what physicists did day to day and the variety of activities that encompassed different subfields.

It wasn't until grad school that I fully understood how hands-on physics could be. One of the expectations for experimentalists was to take a shop course, so we could manufacture some of our own custom apparatus for experiments and better design other parts that might require professional machinists to create. I didn't know this was coming, but I discovered I absolutely loved that aspect of experimental physics. It opened up creative outlets for me – you could dream up a part, design it, and then make it to serve a specific purpose.

In doing background reading to draft some of the first proposals for The Shack, I came across a long, fascinating, but not very well-known history of this kind of work. There's an essay called *The Craft of Experimental Physics* by P.M.S. Blackett. He did amazing things during World War II, won the Nobel Prize in 1948, and this essay is part of a 1933 volume called Cambridge University Studies. He described, "The experimental physicist is a Jack-of-All-Trades, a versatile but amateur craftsman. He must blow glass and turn metal, though he could not earn his living as a glass blower, nor ever be classed as a skilled mechanic…The experimental physicist must be enough of a theorist to know what experiments are worth doing and enough of a craftsman to be able to do them." It really resonated with me and captured what it means to be an experimental physicist.

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Now, with the emergence of consumer-oriented 3D printers, it's possible to put the design and manufacturing of custom apparatus into the hands of undergrads. We have a great student shop in our department, and there's a shop course taught by professional machinists, but access for undergrads is limited, and the turnaround times are often impractical for most one-semester courses. With 3D printing, students can dream up a part and have it in their hands the same afternoon. This has made our second and third-year labs much more adaptable. At the same time, The Shack offers tools to others on campus who want to build their own do-it-yourself (DIY) science-related hardware. Over the past 10 years, the U of A has developed a larger ecosystem for innovation, including the Digital Scholarship Centre in the

Cameron Library and the Student Innovation Centre. The Shack is a part of this, and it's been exciting to see how it supports student creativity and learning.

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There were a few key developments in late 2013 that helped set the stage. I remember Geoff Steeves from the University of Victoria sent me an email just before Christmas in 2013. It had a picture of a circuit board hanging from a monitor on his desk, running a technical computing platform called Mathematica. That circuit board was one of the first Raspberry Pi® – a $50 board capable of running sophisticated software. Coupled with advances in 3D printing, technologies like this have made it easier and more affordable to introduce programming and computer-interfaced instrumentation into the labs.

A big part of building The Shack has been responding to ideas and enthusiasm from students. It's been incredible to collaborate with so many of them. Ross Lockwood, for example, was one of the first contributors when he was a senior PhD student with Al Meldrum. He was an extraordinary individual with diverse interests – he even competed in a contest to become an astronaut. His office was right across the hall from mine at the time, and I enjoyed exchanging ideas with him. Since then, many others have contributed to the success of The Shack, including Jasmine Mehdwan, Sam Harris, Summer Scott, Robin Robinson, Danielle Jenson, Kayte Mori, Clayton Coutu, Tristan Stark, Logan Fairgrieve-Park, Brian Qi, Adam Cunningham, Grace MacDonald, and Sophie Gans. It's exciting to see undergraduates taking charge and steering The Shack toward new ideas and opportunities.

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What advice would you give to students looking to take on ambitious, self-directed projects within their undergraduate program, and how do you approach mentorship to support students with diverse goals and interests? What do you think is essential for fostering a strong mentor-mentee relationship in this context?

I think it's important to try and find out if there's something specific students want to get out of a project. Often, it's a general experience, but sometimes there's something more targeted. If that's the case, you can steer things to help them achieve what they're looking for. That said, it shouldn't be about micromanaging the project on their behalf. It's essential to give students enough leeway to make mistakes because, unfortunately, learning from your own mistakes is almost always so much more effective than trying to learn from someone else's. As much as people try to help you avoid repeating their mistakes, it's not the same. It's also important to ensure students don't get lost for too long in blind alleys. High-bandwidth communication is key. The mentor needs to be accessible, and the mentee should keep good project records and regularly share updates.

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For students aiming to pursue ambitious projects, my advice is to seek mentorship early – someone who can give constructive feedback on your proposal and help identify resources to make the project feasible. A common pitfall, even for experienced researchers, is underestimating time. It's easy to misjudge by a factor of ten or more. But once it's approved, we can help arrange access to additional resources, whether that's equipment in The Shack, materials from research labs, or other specialized tools. This collaborative approach fosters creativity while keeping projects manageable.

From what you've observed, it sounds like the most successful students are those who are proactive, open to collaboration, and willing to learn from both their successes and failures. Do you think there's a specific mindset or attitude that helps them stand out in such a dynamic environment?

Curiosity and enthusiasm are the big ones. They naturally lead to motivation to work on a project. Some students might not be as naturally curious or enthusiastic about some of the things happening in courses, but they might find opportunities to engage more in research projects. And, of course, organization and time management are also crucial. Enthusiasm needs to be controlled, and there's some truth in the old saying: if you want to get something done, ask someone who's already busy. Typically, that's someone good at managing their time.

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I'm going to switch gears a little bit. In the current landscape of open-access research and online learning, students have more avenues for engagement than ever. What opportunities do you think are most valuable for students to explore today, and how can they make the most of the resources available to them?

Absolutely, there's so much out there! I think we're at a point where there's always going to be more and more out there. So, it's crucial to develop a strategy for curating all the available information and honing in on what truly matters. It's often better to focus on a smaller number of things in more depth rather than spreading yourself too thin. In teaching and learning, we talk about this as uncovering a little instead of covering a lot.

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For me, one influential resource was *Scientific American*. The "Amateur Scientist" column provided interesting do-it-yourself projects. Looking back, I didn't realize at the time how impactful it was, but just reading that column every month was helping to build an interest in me that would eventually find this outlet in experimental physics. Now, of course, there's an overwhelming amount of information available online, but the lesson remains the same: narrowing things down to a smaller selection is key. One approach for filtering through all this is to recognize the difference between knowing about something and actually knowing it. To really understand something, you have to do it. You might see some incredible demos on YouTube, and it only lasts two minutes. But if you're interested in that thing, it might be worth trying to recreate it yourself. When you do, you'll undoubtedly discover there are so many more layers to it that didn't come through in the video. This is a crucial step in curating and winnowing down the vast amount of knowledge out there, and it's a strategy that can guide students in their research and learning.

The path of scientific research often comes with challenges, and resilience is key. Could you share a time in your career when you faced a setback or challenge? How did you overcome it, and what did it teach you about persistence in research?

One thing that has always stuck with me is a saying of one of my professors. He said, "The second one is always better." The idea is that when things go wrong, you should take it in stride and try again. During my PhD work, I needed to vacuum anneal a copper piece that had to remain vertical during the process because copper softens at annealing temperatures, and it would collapse if positioned sideways. Unfortunately, the furnaces in the department were all horizontal tube furnaces, so I had to design and build a vertical tube furnace myself. I found a stainless steel tube in the shop that seemed perfect for the vacuum chamber. What I didn't realize was that when the steel got hot under a vacuum, it became soft and collapsed during the annealing process. I later learned this collapse pattern is a well-documented phenomenon, forming a distinctive threefold pattern around the circumference of the tube. If I had done more research beforehand, I might have anticipated this issue – but that's part of the trade-off in research. You can't read everything before you start, or you'd never get anything done. Sometimes, you just have to forge ahead. Ultimately, I managed to cut my part free from the collapsed structure, procure a quartz tube, and upgrade the furnace to continue my work. That experience reinforced an important lesson: every mistake seems avoidable in hindsight, but perfection isn't realistic in research.

On the other hand, could you share a memorable breakthrough or a 'eureka' moment that stands out in your career?

I've always really enjoyed building new experiments – almost as much as actually running them. I find it so rewarding to dream up a new way of studying something, design the apparatus, and then see it all come together. For me, the emphasis has been more on the journey than the destination.

One example that stands out is from my time at IBM. We were developing a new way to study dynamics in magnetic microstructures. Essentially, we figured out how to make stroboscopic movies of these dynamics, combining optical microscopy with short-pulse lasers as the light source. By analyzing the polarization of the reflected light, we could extract magnetic information in what's called "time domain measurements." This allowed us to capture snapshots of dynamics happening on the scale of picoseconds. Before this, most studies of magnetization dynamics were done in the frequency domain using radio or microwaves, which lacked the spatial resolution you can get with optical microscopy. While the frequency and time domain approach are mathematically linked through Fourier transforms, the addition of spatial resolution made a huge difference. Some specialists at the time initially doubted that we could do what we claimed. But having both spatial and time information together made it much easier to compare experimental results with theoretical models of this physics, which naturally work across both domains. It was a lot of fun, and it felt like we were pushing the boundaries of what was possible.

"Really get to know yourself! Be sure that the goals you're pursuing are genuinely your own, and not what others think you should be chasing."

Looking back, is there any advice you would give to your undergraduate self, knowing what you do now about the journey through academia? Is there anything you wish you'd known or done differently?

I'm sure you've heard this: "Always do your best, and anything worth doing is worth doing well." I heard that a lot and I tried to live by it. But there's a caveat to this advice. Your best depends on the context. In most cases, you're doing your best within the time available. You can't always do your absolute best for everything because time is often limited. So, in those situations, your best is whatever you can do within the time constraints. The moments that truly require your absolute best are few and far between, and when those come up, you need to make the time and space to give it everything you've got. But most of the time, that's not possible. This is something I wish I'd known sooner as it would have alleviated a lot of stress in many situations.

Also, when you dive deep into research, you often think you've discovered something totally new, only to find out that someone, decades ago, had the same idea – or something similar. Maybe they didn't have the same technology at the time, but it just reinforces the idea that there's nothing new under the sun. It's all about perspective. Things may seem to change fast at a micro level – like the new equipment in the lab, the shift from analog to digital technology, or even the new administrative procedures we have to follow. But on a broader, longer timescale, a lot of these changes are just refinements of what came before. For example, even though lasers today can do things unimaginable back in the '80s, they still existed before. It's the details that change over time, and it's important to keep that perspective in mind.

Looking ahead, with all the uncertainty around AI, climate change, and other global issues, I feel that 50 or 100 years from now, people will still look back and think, there's nothing new under the sun. All of these massive upheavals, as they seem in the moment, will eventually be seen as part of a much larger continuum.

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That's such an important point you made about balancing the drive to give your absolute best with being kind to yourself. Lastly, for undergraduates who might be uncertain about their direction in science, what advice would you give? How can they balance the need for exploration with the pressures

of career planning, and are there paths that are often overlooked but worth considering?

Firstly, really get to know yourself! be sure that the goals you're pursuing are genuinely your own, and not what others think you should be chasing. University students, especially, can often feel the weight of expectations from others, but those shouldn't be the foundation of your career choices. Focus on identifying what truly excites you – whether it's solving problems, creating things, or learning new concepts. Research problems, as we know, tend to be hyper-specific, but the satisfaction from solving them is more universal. I love puzzles, so research is a great fit because it's all about tackling puzzles. But the specific puzzle doesn't matter as much as the process of diving into it and figuring it out.

It's also helpful to adopt a broad perspective. In any job, especially in science, satisfaction often comes from what you bring to the table, not just what the job demands from you. That's why it's important not to be too rigid or overly specific in your career goals. So, my advice is not to feel pressured into finding a super specific path right away. Explore broadly and let the satisfaction of the work guide you, rather than feeling locked into one particular direction.