AN INTERVIEW WITH DR. RICHARD MCLAUGHLIN

From left to right, top to bottom: Dr. Richard McLaughlin, Professor of Mathematics at the University of North Carolina at Chapel Hill; Dr. Jonathan Bennett, BSS Faculty Advisor; Teresa Fang, 2024 BSS Essay Contest Winner; Jane Shin, BSS Editor-In-Chief; Keyan Miao, BSS Editor-In-Chief; Phoebe Chen, BSS Publication Editor-In-Chief.

Thank you so much for joining us today. Before we get started, could you briefly introduce yourself?

My name is Rich McLaughlin. I'm a professor of mathematics here at UNC-Chapel Hill. I run, with my colleague Roberto Camassa, the Fluids laboratory, and I was the chairman of the Math department for ten and a half years.

What would you say sparked your interest in fluid dynamics and applied mathematics?

When I was in high school, I was really interested in science and math. In graduate school, I focused on applied analysis, which is mathematical analysis techniques in applications, and the applications I was working on were primarily fluid dynamics. Then I moved to Utah for my first job, and two things happened there. One was that I was working and interacting with a lot of the mechanical engineers who had fluid lab facilities. And then the second thing was that I was seeing the impacts of pollution on the air. There's a thing that happens in Salt Lake City called a thermal inversion. where the temperature in the bowl in Salt Lake City is very cold compared to the mountains. So you get this really cold, dense air mass. It sits in the bottom of the bowl, nothing really mixes, and you get a lot of smog. Smog was quite interesting, to drive up to the mountains and see different layers. So I began to migrate from working in more pencil-paper, computational mathematics to adding an experimental component to my work. And I always worked on cars and stuff when I was younger and that helped make that transition. I can tinker with stuff. I'm not a really good engineer, but I get a lot of help from a lot of people to get things to work.

Could you explain the significance of studying fluid dynamics?

Fluid dynamics is really all about the atmospheres and the oceans of our planet and other planets, even suns and solar things. It's a very general topic. The equations of motion are extremely difficult, but the range of phenomena that it encompasses includes everything from large-scale, atmosphere and ocean circulations, to small-scale water waves, to tornadoes and hurricanes. All of these things are under the umbrella of fluid dynamics. So it's a very broad subject with important implications. All of life is built around fluids. We are the water planet, so to speak, so water is an incredible, incredible fluid. But so is the air that is in the atmosphere, which has slightly different properties from water but is also considered a fluid.

What is your favorite research project?

We made an interesting discovery years ago. It was motivated by the observation of these pollution layers in Salt Lake City. When I moved here, I tried pouring these density-stratified fluids and began to probe their properties. We discovered a phenomenon where you drop a sphere into water. As it falls, it moves through a constant density fluid, but the density suddenly becomes more dense, like in the thermocline. If you've ever been swimming in a quarry, you'll have something called a thermocline, where suddenly the temperature gets colder. Generally speaking, when you get colder, you get denser for water, except down near the freezing point. We found that if you have things just right, this sphere could fall and momentarily bounce and rise off this internal layer. We were the first to observe this, and so we published this some 20 years ago now. And we've been working on this problem ever since. This problem has all kinds of applications to the ocean and how the ocean absorbs carbon. The ocean is a great sequesterer of carbon. Trees like carbon dioxide and perform photosynthesis to convert it to solid carbon. The ocean does the same thing through phytoplankton that use photosynthesis to convert dissolved CO_2 to solid carbon, forming marine snow, a continual movement of solid carbon. It's sinking through the water column, but it's been observed to collect on these layers in the ocean. It gets stuck there, slowing down its ability to get sequestered to the bottom of the ocean. But the bacteria can also eat it and turn it back into dissolved carbon dioxide gas. And so this stratification and this phenomenon of how these particles get hung up on layers is a rate limiter for the ocean's ability to absorb carbon. A big mystery is how much carbon the oceans can absorb. There have been geoengineering suggestions such as putting nutrients in the ocean to try to enhance the bio-activity of phytoplankton to accelerate the conversion. But the problem that is interesting is that as the atmosphere warms up, the top layer of the ocean becomes warmer and the stratification is enhanced. So it's a continuing sort of feedback loop for how strongly the ocean can be slowed in its ability to suck up carbon. So we've been looking at all kinds of problems along these lines. One really interesting discovery was that if you have particles floating in stratification, there are forces that are generated by the way the ball talks to the salt that give rise to a self-assembly phenomenon. The evolution of these particles happens on much longer timescales, like hours. These flows are like five microns a second — very, very slow. It's a totally unexpected behavior.

We were looking at your website and read about the Himalayan Gokyo Lake field campaign. What do you think is the value of on-site research compared to the fluids lab, which is a more controlled environment?

I would say that any kind of laboratory work is great. But we like to push it to the scale of the environment. One of the things we can do in the labs is start with little experiments in fish tanks. Then we can push those experiments to the scale of our wave tank, which is maybe an order of magnitude bigger. But the ultimate test is to go to the field and see if the stuff you're seeing in the lab happens in the real system. We decided we wanted to do an experimental campaign on this series of lakes that are near Mount Everest. We did three separate campaigns, each about a month long. The trip total is 3-4 weeks, the hike up is 6 days from Lukla, then we spend a week working at 16,000 ft, and roughly 2-3 days hike back down. Getting to Lukla is also a challenge, either by airplane or helicopter. Weather leads to frequent delays both in and out. So it's very intense and like nothing I'd ever done before, but it was interesting because that system is experiencing rapid climate change, probably more rapid than anywhere else on the planet. So it's a good place to study things. There are a lot of potentially bad things that could happen with these glacial outburst floods from the glaciers melting and building bigger and bigger lakes that ultimately break the earthen dams, which causes all kinds of problems for people down below them. We were looking — and still are — for self-assembly in nature. A good stratified lake is a good place to see it, though the best place would be the bottom of the Gulf of Mexico because of the brine pools at the bottom. They are very interesting, but it's very hard to get down there — you have to have a robotic submarine.

You briefly mentioned obstacles during on-site research or unexpectedness in the research. What are some challenges you've faced while researching and how were you able to overcome them?

We've been really fortunate to have been lucky — we bumbled around and found stuff, which is really cool. And we have been really fortunate to have lots of really strong students from all levels, from high school to post-doc, that have helped us move things along. Funding is always a challenge. We spend a ton of time writing proposals and the funding rates are not great. A lot of times, you're writing something that's probably not going to get funded, but you don't have a choice. And then there's infrastructure. We have a fantastic lab engineer, but we don't have the resources to keep this person working for us all the time. Not having strong technical support is tricky, but we get through it and have a good time, and it's been really productive and enjoyable. We're very fortunate at UNC to have the space that we've got — that's been a really wonderful thing. I know, for a lot of people, finding space is a challenge.

How does your background in mathematics shape or influence your scientific thinking, For example, all the math on the chalkboard behind you — how does that translate into a paper?

Our philosophy is that we would like to make predictions about what we're observing. If we're so lucky as to observe something interesting that has not been studied a lot, then the challenge is always how do you explain what's happening? The language for making those quantitative predictions is mathematics. It's lurking within the subject of partial differential equations, which are basically Newton's laws but for fields. You need to have a velocity field that talks, somehow, to solid bodies. The challenge is that, even though we know the equations, we can't solve them. They're really nasty, nonlinear equations, and in general, they're just very difficult to solve. There are very few analytical mathematical solutions that you can write down with a pen and paper. Then you could say, "Let me just go put these on a computer and try to integrate these equations computationally." Great idea. Awesome, but we can't do that either, because it turns out that the problem of turbulence gives rise to very small scales that you can't resolve. So if you want to do the airflow in this room, it's already, from first principles, beyond the largest supercomputer on the planet. So you can go say, "Oh, we're going to develop all these filtering methods for computation to try to get around this problem. I can maybe replace those small scales that I can't resolve with something else." Or maybe what you can do is use different analytical techniques — we call them asymptotic methods — that take advantage of certain small parameters in the system. A good example would be slenderness: if you have a slender body, the aspect-ratio parameter can be used to help do analytical calculations to simplify the equations so that you can actually make a forecast. Or maybe you can simplify them so that you can run a computational code to solve them and make a forecast. The same thing is true for the subgrid phenomena problems. If you move a ball through the fluid, you generate a lot of small scales, and to resolve those small scales, you have to have a really fine mesh or some kind of adaptive mesh. But another thing you could do is try to parameterize the effects of those small scales, and sometimes we use mathematical methods to do that replacement. One of the things I think is really exciting is that there's a woman named Laure Zanna at NYU who has a big campaign to try to use machine learning algorithms to do subgrid-scale parameterization by learning from big data sets, and she's applying it to the climate system. That's really exciting. I don't think data science is going to replace physics, but I think that there may be applications where you have enough data and you might as well use it to learn something, and the stuff that she's doing looks really interesting. A lot of times, you spend weeks trying to come up with some approximate technique to overcome the challenge of not being able to solve these equations.

What do you enjoy beyond teaching and research?

I'm a musician, and I've been playing rock music for a long time. I have been in bands for many years, and I am currently a piano player. I'm in the final stages of completing an original classical music record, and just this morning, I was in the studio working on it. I'm also working with my close collaborator, Daniel Snyder, on a rock record which we just finished tracking. In my spare time, I do a lot of music. Chapel Hill, along with the whole Triangle area, is great for music. I've been really fortunate to be able to play and collaborate with a lot of really strong musicians. For instance, earlier this morning, I was recording with Matt Douglas, who's a member of The Mountain Goats—a band you might recognize. I've been really fortunate to have met friends through playing local music who have gone on to become incredible musicians. Have you heard of a band called Sylvan Esso? They're kind of electronica and I was fortunate to record my Travel Horse Interlude record at their studio. There's another band called Hiss Golden Messenger. They're kind of big right now and out of Durham. I'm pretty close with a lot of those guys that are in that band. So that's my kind of hobby.

Do you have any goals for 2024?

We have a lot of exciting research we are working on. The self-assembly behavior that I showed is one of them. We're trying to better understand it, from the mathematics to the prediction to the experimental observation. In music, I've got a couple of new albums coming out that we're about to start mixing. If you know music, there's a big process behind it. You have to write your songs, you need to learn how to perform them, and then you have to record them, and the recording process is often you doing multiple layers of stuff. When you get to the level of mixing where you're trying to blend in the things, put them in the right reverbs, have the left and right panning all done in a way that doesn't sound crazy. That's where we are right now. So we're 90% done — the hard parts are the writing, the recording, and the tracking. But those are big goals for me for this year. Trying to finish those things and advance what we can about the research on these self-assembly problems in stratified fluids.

What advice would you give to high school students seeking deep interests or careers in STEM?

Take lots of mathematics — that's clearly going to be helpful. Lots of computer science classes and lots of physics. You can't go wrong with those three topics. There are so many different exciting things that are happening in science right now. The future is really bright. It's all over the place, from new, exciting methods for scientific probing to new data science approaches to things. There are a lot of things that are being developed that are potentially quite game-changing. The climate is a real concern. There is always going to be work in climate science. Just look at the frequency of what we call a 100-year flood. We were calling a 100-year flood a few years ago something that happens once every hundred years, but now it's happening much more frequently than that, so the system's clearly changing. There is going to be a need for young people in STEM to get ahead of those problems and try to stave off disasters that we're probably going to be experiencing in our lifetimes. If the Thwaites glacier collapses in Antarctica, we'll be looking at massive sea-level rise in a much shorter timescale than we might have anticipated, so there are a lot of important problems to look forward to working on. My advice is to go work on these problems. The planet needs you. Learn as much of the technique as possible to get yourselves ready to advance the needle in understanding these complicated problems. But go find something you love. That's another important thing — make sure you go and do something your heart's behind.