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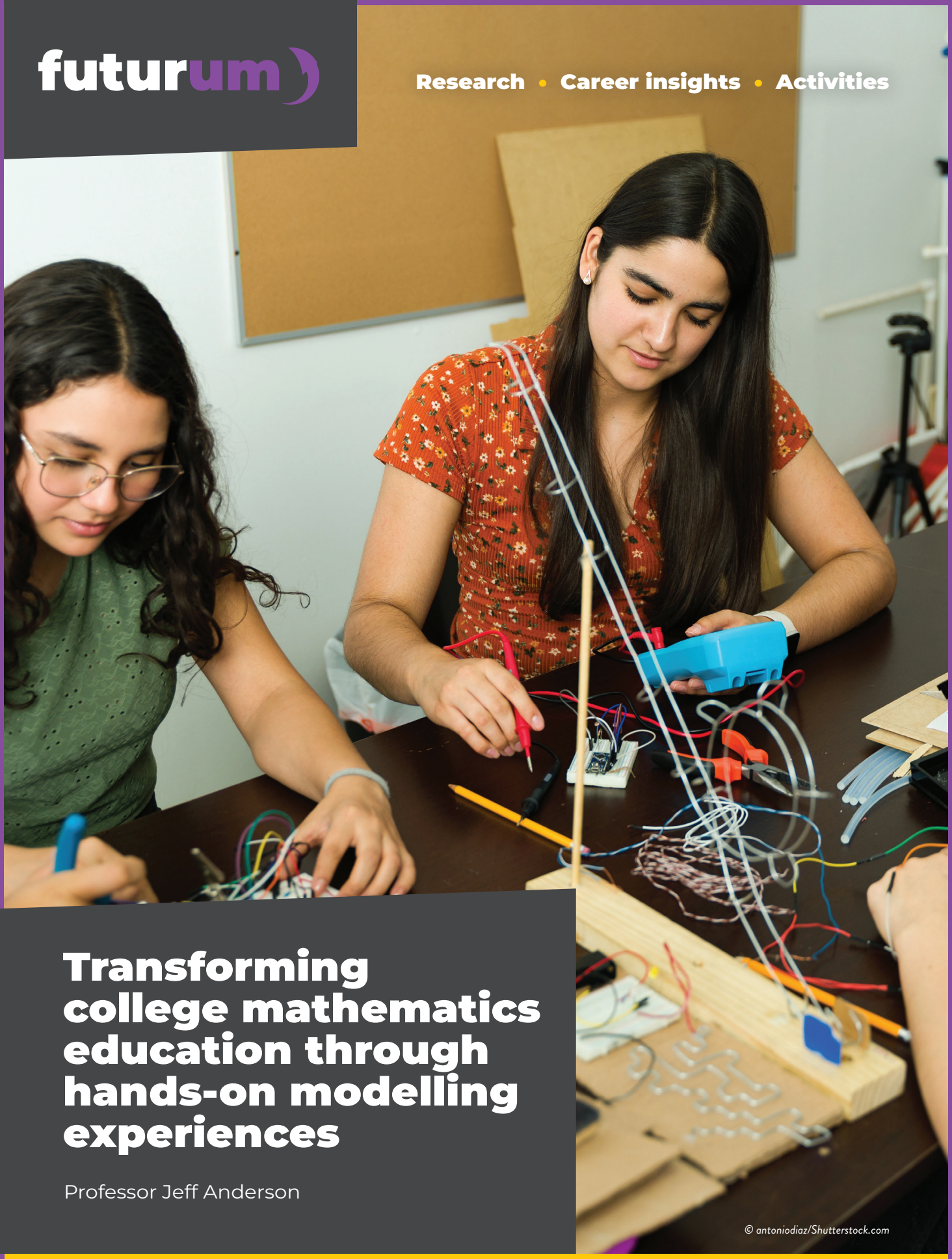

Transforming college mathematics education through hands-on modelling experiences

Professor Jeff Anderson

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STEM students start college hoping to build purpose for their lives and valuable skills for their careers. These students desire to find meaningful answers to questions like, "How does what I learn in school apply to problems I want to solve?" and "How does this relate to the future I want to create?" However, many college STEM courses do not prepare students for a career in their chosen field and focus on content that is far removed from students' lives. This is why, at **Foothill Community College** in California, USA, **Professor Jeff Anderson** is developing an open-access learning curriculum alongside hands-on mathematical activities and laboratory equipment to create rich applied learning experiences for his students.

Professor Jeff Anderson

Department of Mathematics, Foothill Community College, Los Altos Hills, California, USA

Fields of research
Applied mathematics education; numerical linear algebra

Research project
Developing a hands-on, open-access, applied linear algebra curriculum alongside accessible mathematical models and inexpensive laboratory resources to help students build transferable skills while falling in love with applied mathematics

Funders
Patreon community; YouTube revenue; private donors; self-funded

Websites
youtube.com/@JeffAndersonMath
jeffandersonmath.wordpress.com

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PROFILE

Talk like an ... applied mathematician

Applied mathematics — the process of using mathematical methods to solve practical problems in other fields like engineering, science, medicine and finance

Linear algebra — a subfield of mathematics that is commonly used to model, analyse and improve solutions to real-world problems

Mathematical modelling — using mathematics to represent, analyse, make predictions about or otherwise provide insight into authentic problems related to real-world phenomena

STEM — science, technology, engineering and mathematics

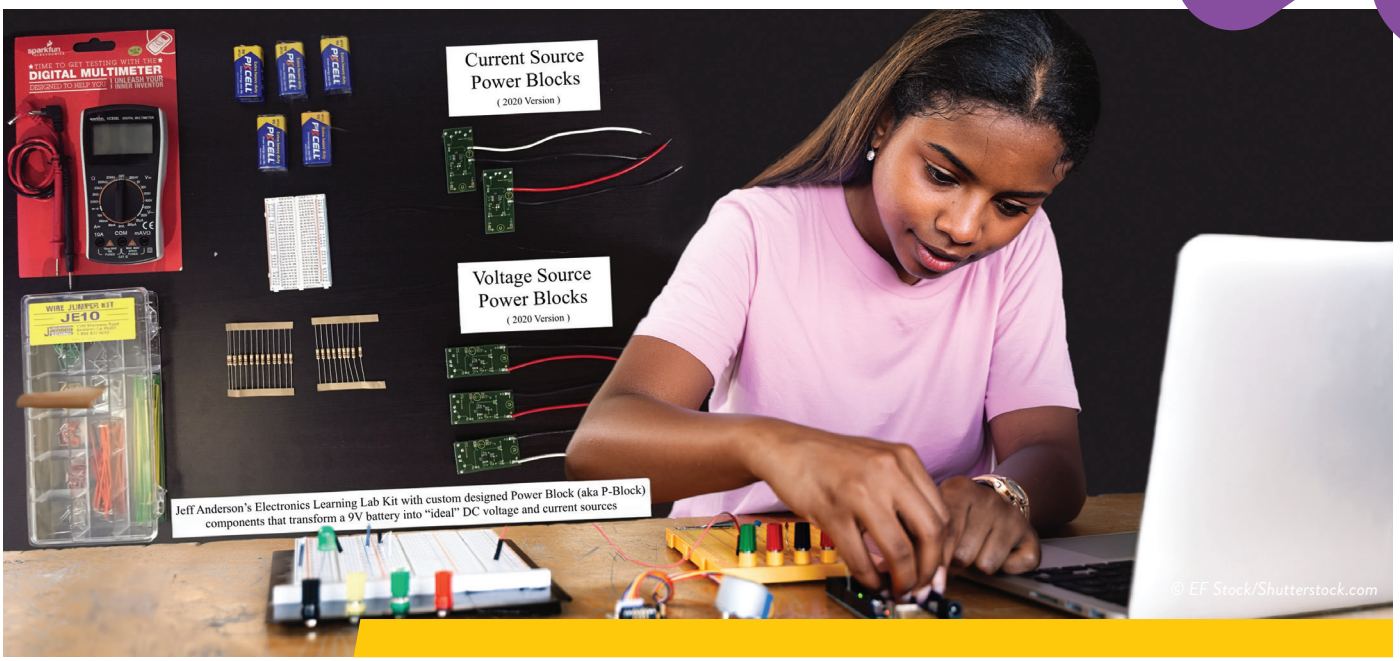
In the US, less than half of college students graduate within the first 4 years of their degree. This staggering statistic raises a difficult question: if airline companies designed planes that killed half of their passengers, would anyone buy a ticket? Yet in higher education, such outcomes are accepted as normal.

Dr Jeff Anderson, a mathematics educator at Foothill Community College, refuses to accept this status quo and has dedicated his career to transforming college STEM education. "I focus on designing engaging classroom experiences that empower students to build transferable skills that they can use to transform their world, build their dreams and ignite their careers," says Jeff. "I believe that the best way to do this is to put students to work using hands-on learning experiences that are directly related to their academic and career interests."

The problem with traditional STEM education

Instead of igniting students' interest and excitement, college STEM classes often leave students feeling disengaged, discouraged and uncertain about how course content is relevant to their lives, career goals and their wider world. "College math textbooks often present a long list of definitions, theorems and examples without demonstrating how that math can be applied in the world to solve meaningful problems," says Jeff. "I believe we can and should do better. When students show up to class, they are looking for purpose, inspiration and hope for the future."

"In addition to these problems with traditional classes, many professors do not explicitly help their students learn how to learn," continues Jeff. "This is a huge mistake. One of the best things I can do for my students is to teach them how to be more sophisticated



learners. While most linear algebra teachers believe our job is to teach linear algebra, I disagree. I believe that I teach students how to learn, and I do this using linear algebra!"

How can linear algebra help?

Most students first encounter linear algebra when using equations such as $y = mx + c$ to plot straight lines on a graph. This relationship is foundational and underlies an important idea: many complex systems can be modelled using linear algebra. Linear algebraic tools are central in applied mathematics for transforming real-world problems into mathematical models that can be used to find meaningful insights and develop possible solutions. Using these methods, a problem that might have taken huge amounts of time and money to prototype can be turned into a simulation.

For example, early aeronautical engineers built physical aeroplane prototypes and pushed them off cliffs, only to watch years of their lives and piles of their money go up in flames. Although this process eventually led to success, it was very costly. Starting in the 1980s, airline companies began using mathematical models to simulate plane designs and improve their engineering methods, saving a lot of time and money.

Unfortunately, college STEM courses often do not teach these types of applied modelling processes. Well-designed, hands-on mathematical modelling experiences allow students to apply their knowledge directly towards solving problems they believe are meaningful. Thankfully, Jeff is pioneering novel, open-access learning resources that put students in the driver's seat.

The LANA project

"When I designed the Linear Algebraic Nodal Analysis (LANA) project, I focused on building learning experiences in which students participate in the entire mathematical modelling process," says Jeff. "I want to give students authentic modelling experiences that mirror what they might do as professionals after they graduate from college." LANA is a hands-on modelling project in which college students gain experience in both electrical engineering and applied mathematics.

Professional electrical engineers design circuits using mathematical models that simulate a circuit's behaviour. "This process saves them time and money because they can improve their design before manufacturing physical prototypes for testing," explains Jeff.

The LANA project simulates this reality by allowing students to create mathematical models of electrical circuits. To verify their models, Jeff expects students to build and test physical prototypes of their circuits. "Unfortunately, testing a circuit traditionally involves using a bench power supply, which can cost up to $500," says Jeff. "So, as part of my effort to develop the LANA project, I worked with an expert engineering team, including two students, to create something that we call a power block, or P-block for short."

P-blocks are inexpensive power supplies that enable students to test circuit behaviour anywhere they want, even at their own kitchen table. "The goal of the P-blocks project is to make it easy for students to build physical prototypes of their circuits and check the accuracy of their mathematical models for themselves," explains Jeff. "This means that students no longer need to depend on a teacher to check their work. Instead, they can check their own work by building their circuits, testing the values and comparing their measured data against the mathematical results they produce in their modelling process."

Power to the students

One of Jeff's students, Natalie Thiel, spent over fifty hours working on the LANA project, and this experience gave her the confidence to apply for her first paid engineering job. After Natalie's successful interview, Jeff received a call from her new manager, asking if he could hire more students who had gone through this type of training.

Another Foothill alumnus, Nick Litvinov, completed the LANA project and later told Jeff that, "It was the most meaningful and memorable experience I had in any of my undergraduate classes." Considering that Nick went on to attend one of the highest-ranked universities in the US, this praise speaks volumes about Jeff's revolutionary teaching practices.

"When students are diligent in this work, they begin to develop a large collection of transferable skills including the ability to make connections between their math classes and their target fields of study," says Jeff. "I love helping students discover that they can use mathematical thinking to improve their world, build their dreams and help the people they love."

About *applied mathematics*

Linear algebra is to mathematical modelling what oxygen is to the human body - essential. It provides us with the mathematical language to model, analyse and improve solutions to real-world problems, and without it, the field of applied mathematics simply would not work.

The engineers, mathematicians and scientists who built the first digital computers did so with the goal of accurately simulating the physical world using mathematical models. "The first computers were paid for by the US military during World War II to simulate atomic bomb shockwaves and calculate the trajectories of missiles fired at Nazis," says Jeff. "However, once they were finished with their bombs and missiles, scientists soon realised that these techniques could be applied across many areas of knowledge. Scientists from different fields used them to model the motion of planets, design rockets, develop new medicines, design buildings and bridges, build social networks, and much more."

The vast scope of applied mathematics means that students can make use of it, whatever their interests. "I believe that learners who take mathematics seriously can use their skills to transform the world and realise their dreams," says Jeff. "Mathematical modelling is like a muscle. For a muscle to be strong, we must train and exercise it often. However, it is also true that once we have strong muscles, we must make conscious choices to use our strength in service of other goals we have."

One question that Jeff likes to ask his students is, "How can you use your mathematical modelling skills to build a better world that aligns with your deepest values?" The answer to this question lies in your own interests, dreams and ambitions. "A fun byproduct of this reality is that we can also earn a living from our ability to create models," says Jeff. "In other words, we can use mathematical models to improve human life while also generating income that can pay for our rent, food and other things we need to live."

Pathway from school to *applied mathematics*

At school, build a solid foundation in mathematics. At the same time, continue to pursue other interests, as you may be able to combine them with your mathematics skills and knowledge.

Jeff recommends learning how to read and do mathematical proofs, and how to solve problems. These books can help you get started:

- **Book of Proof** by Richard Hammack
- **How to Read and Do Proofs** by Daniel Solow
- **How to Solve It: A System of Thinking That Can Help You Solve Any Problem** by George Pólya
- **Thinking Mathematically** by John Mason

"Once you know how to read and do proofs and solve problems, you can teach yourself any math that has ever been written on any subject," says Jeff. "You can create new solutions to problems that have never been solved. By developing those two skills, you will be able to teach yourself as much linear algebra as your heart desires."

Explore careers in *applied mathematics*

"The trick of applied mathematics is to create mathematical models that describe problems in your life that you care about solving and to believe you can make an impact in your world," advises Jeff. "If you do that well, I believe you can transform the world and collect a pay cheque at the same time!"

Explore this careers brochure from The Society for Industrial and Applied Mathematics: **siam.org/programs-initiatives/professional-development/career-resources/careers-in-applied-mathematics/careers-brochure**

To help students explore the connections between applied linear algebra and mathematical modelling in STEM, Jeff is developing a free *Applied Linear Algebra Fundamentals* textbook. Learn more here: **appliedlinearalgebra.com**

Meet *Jeff*

This article was written by Duy Nguyen, a 4th-year undergraduate Electrical Engineering student working with Jeff at Foothill Community College.

From the age of 10 to 14, I survived intense bullying and even received a concussion after being body slammed at school. Post recovery, I started martial arts. By age 23, I had earned black belts in jujitsu and judo. I also won national tournaments and got my amateur boxing licence. During my decade on the mat, I strengthened my body, practised high levels of self-discipline and learned to face my fears.

When making big decisions, I like to imagine the future. I saw that many older warriors had unstable careers, broken bodies and damaged brains. In contrast, older mathematicians had healthy bodies, sharp minds and stable jobs. These mathematicians also practised mental toughness. However, instead of using violence, they used their intellect. I saw that, when done skilfully, we can use mathematical reasoning to help create a better world.

The game of research academia devalues great teaching. College professors are incentivised to do research, win grants, compete for prestigious awards and earn lucrative textbook contracts at the expense of time spent with students. During my mathematics education, several professors told me: "You are stupid," "You do not belong here," "You will never be good at math," "You ask too many questions," "Please just do what I say." However, I know how to protect myself. When professors tried to weed me out, I stood my ground. I showed up. I made these people work. And I promised myself I would do better for my students!

I dedicate my career to the next generations. I want to be part of and help grow a community of educators who shift the culture of college STEM education away from our harmful status quo by transforming teaching policies and practices. I want to help create a world in which students learn deeply, feel inspired and build valuable transferable skills in college classes that feature 100% success rates. This problem is quite hard.

I take lots of pride in making memories with people I love and caring for my health. I have two sons and often say to them, "Being your dad is the best thing I have ever done with my life." I also love to spend time with my amazing wife. In my free time, I enjoy running, exercising, physical training and going for hikes in nature.

Jeff's *top tips*

1. Learn how to read. If you can read deeply, you can teach yourself anything you want to learn, including mathematics. I love a quote I learned from the amazing educator Harriet Bell: "Reading is knowledge. Knowledge is power. Power is money." When students ask me how to make money, my response is always: learn to read!
2. Remember that you are the world's leading expert on your own learning. You know more about yourself, your dreams and your experiences than any teacher ever will.
3. The future is unwritten, so you can play an active role in creating a new world. As you do so, think for yourself. Ask questions. Show up and force teachers, experts and authority figures to work for you and to help you build the types of learning you want to create.

Applied mathematics

with Professor Jeff Anderson

Talking *points*

Knowledge

1. How many US college students graduate within the first four years of their degree?
2. What inspired the creation of the first computers?

Comprehension

3. How did inventors, scientists and engineers test their early prototypes before mathematical modelling tools existed? How do they use mathematical modelling today to test and improve their designs?
4. How does Jeff's work help students connect mathematics with engineering, careers and everyday life?

Application

5. What problems do you notice in your life, community or world that you want to see solved? How might you approach these problems using applied mathematical modelling to find solutions?
6. What steps can you take to learn more about mathematical modelling and build a solid foundation in mathematics?

Evaluation

7. What insights from Jeff's career journey resonate with you the most, and how do they influence how you think about your own future?
8. How has Jeff's work changed your understanding of education and what it means to be successful?
9. In what ways could your life, family, friends and community be transformed through deeper learning and problem solving?

Creativity

10. Imagine a world where people have the freedom to explore their interests and pursue their dream careers. What would need to change to allow this to happen? How might schools and education change to create a world like this?

Activity

In this activity, you will use the same applied modelling process that STEM professionals use to solve real-world problems.

Step 1: Identify a problem that is meaningful in your life.
Choose a problem that you encounter in your daily life. Examples include staying focused during class, managing your time, improving your sleep, spending more time with friends, balancing school and family responsibilities, or feeling less stressed.

Write a few sentences describing the problem you are trying to solve, when the problem arises and why it matters to you.

Step 2: Create an ideal mathematical model
Identify variables of your problem that can be expressed using numbers, such as the number of minutes spent studying, the number minutes spent on your phone, the number of tasks completed, the time you go to bed, the time you wake up, the time spent moving your body, how many new people you talk to during the day, how you feel throughout the day or any other factors that you think matter.

Represent your problem using numbers, an equation, a diagram, a table or anything else that helps you express the problem. This is your ideal mathematical model.

Step 3: Find an ideal solution
Use your model to test ideas on paper. Try changing one element or variable and predict what will happen.
Write: If I change _____ by _____, then ____ will happen.
This prediction is your ideal solution.

Step 4: Enact your meaningful solution
Try your idea out in the real world, record your observations and compare your observations with your ideal solution. This could take hours, days, weeks or even months depending on your problem, but be sure to set yourself a time limit.

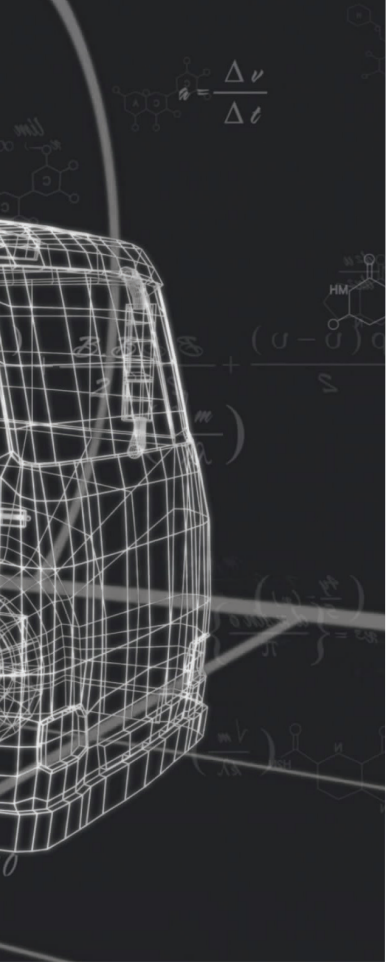
Step 5: Iterate upon your solution
Update your model using what you have learned. Repeat steps 2 to 4 with your improved assumptions and continue refining until you are satisfied with the results.

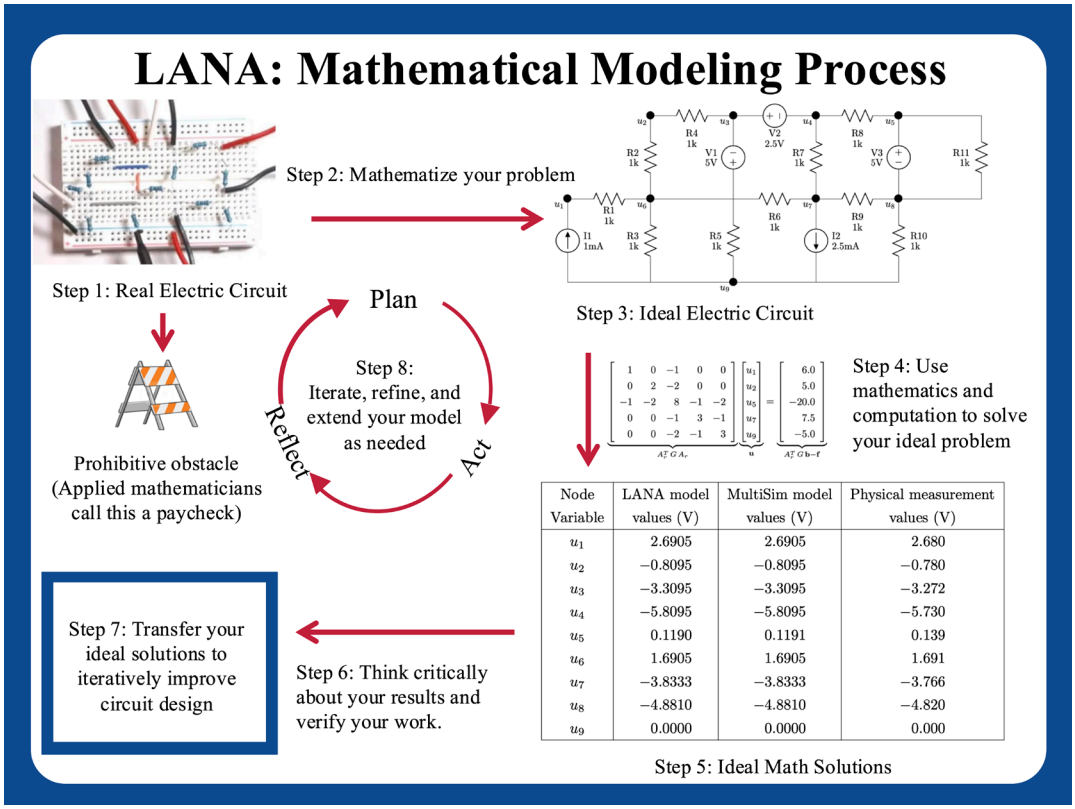
Reflection

- Did your ideal solution successfully predict what happened when you tried it out?
- Has this solution impacted your life meaningfully?
- How could you use this modelling process to improve other areas of your life?

More *resources*

- Subscribe to Jeff's YouTube channel featuring videos about maths and education: **youtube.com/@JeffAndersonMath/featured**
- Explore Jeff's Applied Linear Algebra course to access excellent introductory resources: **appliedlinearalgebra.com/blog/for-students/welcome-to-math-2b**
- Access Applied Linear Algebra laboratory resources on Jeff's website including modelling-based linear algebra curriculum, inexpensive laboratory equipment and more: **appliedlinearalgebra.com/linear-algebra-laboratory-exercises**
- Use Jeff's Strategic Deep Learning Project to build skills to thrive while learning any STEM subject: **jeffandersonmath.wordpress.com/2024/11/30/jeff-anderson-maths-strategic-deep-learning-project**
- Jeff showcases his students' success stories on his Applied Linear Algebra Wall of Fame: **appliedlinearalgebra.com/wall-of-fame**





Node Variable	LANA model values (V)	MultiSim model values (V)	Physical measurement values (V)
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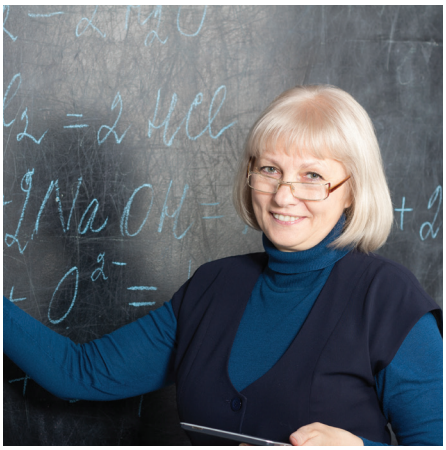
u_2	−0.8095	−0.8095	−0.780
u_3	−3.3095	−3.3095	−3.272
u_4	−5.8095	−5.8095	−5.730
u_5	0.1190	0.1191	0.139
u_6	1.6905	1.6905	1.691
u_7	−3.8333	−3.8333	−3.766
u_8	−4.8810	−4.8810	−4.820
u_9	0.0000	0.0000	0.000



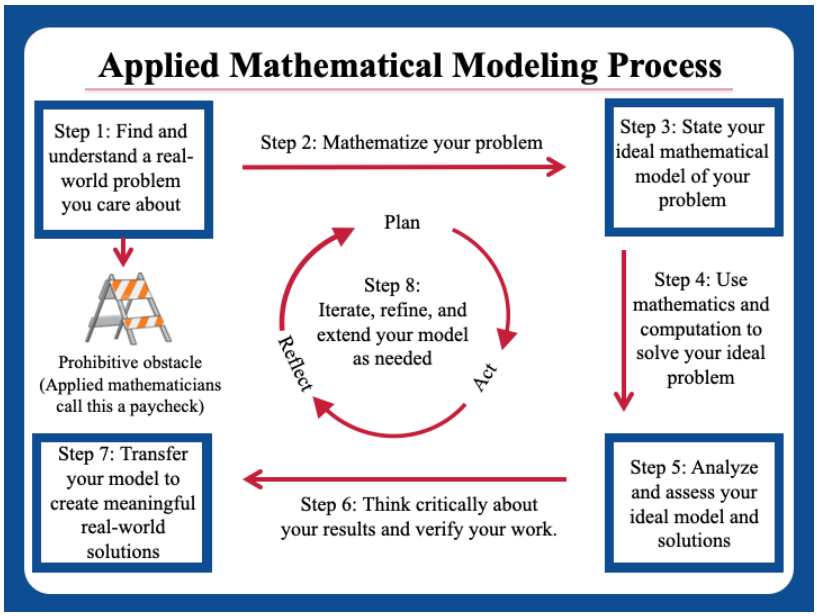


Photo *montage*

Top: *Jeff's diagram explaining the process of the LANA project.*

Middle row: *Left:* *Jeff looked up to older mathematicians and found that they had healthy bodies, sharp minds and stable jobs. © Olga Makedonova/Shutterstock.com*

Centre: *Before mathematical modelling had been developed, the first aeroplanes had to be tested with physical prototypes. © Everett Collection/ Shutterstock.com*

Right: *"How can you use your mathematical modelling skills to build a better world that aligns with your deepest values?" asks Jeff. © vectorfusionart/Shutterstock.com*

Bottom: *Jeff's diagram explaining the applied mathematical modelling process.*

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