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Mathematical Modeling in High School: How It Begins and Where It Can Go

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For most American high school students, interaction with mathematics involves progression through the standard high school math curriculum — typically the higher-level sections of algebra, geometry, trigonometry, precalculus, statistics, and calculus. Students who enjoy challenge and variety sometimes partake in a math club, math circle, or competition team. These extracurriculars typically provide participants with the opportunity to individually solve problems in search of a correct answer, though certain supportive classroom and competition settings allow students to work together to address harder, more complex questions that require teamwork. Many of my students have successfully pursued degrees and careers in various science, technology, engineering, and mathematics (STEM) fields. Unfortunately, few of them actually use mathematics to determine a best course of action or educate themselves about a non-STEM topic until they begin professional internships or careers.

Though I have taught and coached competition mathematics for over 16 years, my previous 15-year career as a control systems engineer found me working with and learning about optimization of locomotive fuel consumption, signal switching at television networks, air traffic path planning, and DVD manufacturing, among other applications. These experiences prefigure my goal that students learn about other fields besides mathematics, consider math's applicability as a decision-making tool, and talk to each other in the process.

While it is possible to create small labs and explorations in the traditional math sequence that let students work toward these goals, SIAM's MathWorks Math Modeling (M3) Challenge[1] implements this on a larger scale. When I first learned about M3 Challenge, I reached out to some of my strongest students who enjoyed mathematics, were omnivorous in their interests, and could write and communicate effectively. The annual contest also inspired me to begin the process of launching a math modeling culture at my high school, the Emma Willard School in Troy, NY.

Apart from student curiosity and persistence, I have identified three important prerequisites for launching a math modeling culture in high school: a thorough understanding of the general process, competency with a basic tool set, and a multitude of interesting problems on which to work.

Although I spent the first part of my professional career developing mathematical models of dynamic systems, I was initially unsure where to begin in teaching the process. The *Guidelines for Assessment and Instruction in Mathematical Modeling Education* (*GAIMME*) report[2] and SIAM's math modeling handbooks[3] helped me create a walk-through for my students. I would also highly recommend notes from the 2019 SIAM-MfA Math Modeling Workshop[4] for high school teachers, which draw on and distill these materials. All high school students are capable of browsing the internet to obtain information on unfamiliar topics, and Google's suite of collaborative tools facilitates collective contribution to a problem's initial mind mapping. While I do teach basic spreadsheet use for function exploration and data analysis in precalculus, I developed short workshops to familiarize my M3 Challenge teams with the processes of creating more complex formulas and charts and using random functions to simulate outcomes. I have also begun teaching MATLAB, which I particularly enjoy as it is a technology bridge that spans my careers. Because M3 Challenge is only open to juniors and seniors, I ask experienced seniors to provide new team members with a summary of their participation by breaking down, researching, analyzing, developing, quantifying assumptions for, and validating their model from the prior year.

What makes this all "real," of course, is finding motivating problems on which to practice. These problems should be topical and real; it is even better when they touch on subjects about which the teacher can cheerfully admit to knowing very little! One of the nicest aspects of M3 Challenge is that both past competitions and the website[5] provide numerous different problems, all of which comprise a multilayered "story" whose relevance extends beyond the competition. One of my students who participated in this year's contest[6] praised the topic's real-world relevance. "I knew absolutely nothing about electric trucks and very little about charging stations before this experience," she said. "I really enjoyed being able to apply my math skills while learning about new topics. Although at times the amount of data felt overwhelming, it was so rewarding to see all of our observations and calculations come together in the final product. I will definitely be keeping tabs on the evolution of vehicles and their environmental impact in the future."

While my school's teams have yet to make it beyond the second round of competition, student response has been remarkably positive. "Being able to apply the knowledge I've gained from my math classes to a real-world scenario really interested me, especially given that there wasn't one concrete answer to each question," another student said. "We could really apply the organizational and math modeling skills—as well as the communication and collaboration skills—that we used during this process to any field or numerical situation."

The contest's benefits seemed so clear that I suggested that Emma Willard offer a semester-long, project-based course in mathematical modeling for seniors, accessible to any student who has completed precalculus or an advanced algebra course that focused on functions. The course plan, which I developed with several

continued on reverse


With the right team and the right attitude, 14 hours of math modeling can still include moments that are as fun as a slumber party. Photo courtesy of Alexandra Schmidt.

[1] https://m3challenge.siam.org/

[2] https://www.siam.org/publications/reports/detail/guidelines-for-assessment-and-instruction-in-mathematical-modeling-education

[3] https://m3challenge.siam.org/resources/modeling-handbook

[4] https://m3challenge.siam.org/newsroom/2019-siam-mfa-math-modeling-teacher-workshop

[5] https://m3challenge.siam.org/

[6] https://m3challenge.siam.org/archives/2020/problem

colleagues, introduces students to the use of models to capture the behavior or most important aspects of a messy, real-world problem with many contributing factors. The class's inaugural semester is set for the fall of 2020.

After introducing the basics of the modeling process, the course will allow students to practice defining problems, researching contributing factors, quantifying their assumptions, and developing and testing models. It will also emphasize quantitative writing and oral presentation skills, as these are important components of any high school curriculum or professional setting.

The class will culminate in an individual project that each student chooses for herself, with guidance from the instructor. Students will decide whether experimental or empirical modeling is most appropriate for their problem, and select from model types that correspond with both the problem and their level of mathematical experience. For some, the projects will bring depth and relevance to second-year algebraic models, such as those originating with exponential, power, sinusoidal, and logarithmic functions. Difference equations, smoothed polynomial or spline models, and probabilistic simulations will provide additional depth and challenge for students who have completed a year of calculus. Most (if not all) participants will already be familiar with Desmos or GeoGebra from earlier courses, and we plan to teach and extend existing knowledge of spreadsheets. We may even include MATLAB or Python if enough students have coding experience. As developers of a new course, we as teachers will also be learning from our initial model and changing it to incorporate novel data as it becomes available. While our plan is to utilize *GAIMME*-based rubrics to assess student models, I expect that the process will require patience, critical thinking, and a willingness to regularly amend small details as necessary.

As a final note, I want to reflect on the very specific experience of teaching math modeling to young women (Emma Willard is an all-girls' high school). As one of my students observed, "an all-female team like ours is a rarity, and we have created a special sisterhood." Despite the intensity of working within M3 Challenge's regulated time window—which gives participants 14 hours in which to educate themselves on an unfamiliar topic and produce a substantive paper—my students found the process motivating, stimulating, and even empowering. By practicing regularly before the competition, the team developed a collaborative and supportive bond and became comfortable sharing and challenging each other's ideas. As I stopped by during Challenge Weekend to bring the competing students fancy coffee drinks and baked goods and laugh with them during "vibe checks," I was struck by both the productivity and camaraderie in the room. At the end of the day, my students came away from M3 Challenge with an enhanced sense of math's applicability to their future studies.

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Whiteboard walls are the best tools for mind-mapping a problem when the clock is ticking and everyone has something to add. Photo courtesy of Alexandra Schmidt.