ACME at BYU

Restoring confidence in the value of mathematics

Brigham Young University

Brigham Young University

- 35,000 students (32,000 undergraduates)
- Sponsored by the Church of Jesus Christ of Latter-Day Saints
- R1 but priority for undergraduate education
- Separate Departments for
  - Math (345 ugrad, 34 MS, 12 PhD, 39 permanent FT fac, 5 PT adjuncts)
  - Math Education (115 ugrad majors)
  - Statistics (413 ugrad majors)
  - Computer Science (1258 ugrad majors)

15 years ago…

- Suspicion/antagonism from other departments
- Antagonism from administration
- Low number of math majors (≈40/year)
- Student jobs mostly NSA, non-math jobs, or MS prepping to teach

15 years ago…

- Suspicion/antagonism from other departments
- Antagonism from administration
- Low number of math majors (≈40/year)
- Student jobs mostly NSA, non-math jobs, or MS prepping to teach

Lacked confidence in the value of mathematics

Today at <u>many</u> universities…

- Suspicion/antagonism from other departments
- Antagonism from administration
- Low number of math majors
- Student jobs mostly NSA, non-math jobs, or MS prepping to teach
- **Looming demographic cliff (4.2M↓3.5M)**
- **Potential drop in foreign students**
- **Uncertain economic environment**

Today at many universities…

- Suspicion/antagonism from other departments
- Antagonism from administration
- Low number of math majors
- Student jobs mostly NSA, non-math jobs, or MS prepping to teach
- **Looming demographic cliff**
- **Potential drop in foreign students**
- **Uncertain economic environment**
- **Huge risk to math departments**

administration/students/legislature

lack confidence in the value of mathematics.

Now at BYU math

- Good relations with other departments
- Good relations with administration (more faculty lines, and $)
- Number of math majors doubled (40/yr to 80+/yr)
- MAA 16 top calculus programs
- AMS “2024 Exemplary Program” Award for ACME
- Many employers are eager to recruit our students
- Many faculty from other departments recruit our students
    - Finance, MechE, EE, Bio, Econ, CS

What caused the trouble?

- Dept claimed to value teaching, but rewarded research
- Ugrad mission of university was taken to mean
  1. prepare “good” ugrads for academic career
  2. tolerate the rest
- Entire curriculum essentially unchanged for 45 years
- Focus on the pure beauty of math (proud to be useless)

Initial Steps

- Listen to and address client department concerns
  - Curriculum
  - Teaching quality
- Take teaching seriously
  - Measure
    - student ratings
    - common exams
    - peer reviews w/ defined rubric
  - Reward good teaching (faculty and grad TAs)
    - Raises
    - Awards (with money) and attention
  - Address Poor teaching (faculty and grad TAs)
    - Support for improvement: peer mentoring, workshops, training
    - Real consequences for not improving

Initial Steps

- Listen to and address client department concerns
- Take teaching seriously
- Undergraduate mentored research
- Best teachers in early courses (calculus 1 & 2, proofs)

Asked the Students

- Why did you major in math?
- Why aren't others majoring in math?

  - "I like it, but I know I can't get a job if I don't want to teach"
  - "I'll just do something I enjoy now and worry about a job later"

Asked the Students

- Why did you major in math?
- Why aren’t others majoring in math?

  - “I like it, but I know I can’t get a job if I don’t want to teach”
  - “I’ll just do something I enjoy now and worry about a job later”

Lacked confidence in the value of mathematics

1st Attempted Solution: Advertise Careers "Math is Useful"

- Traditional math jobs:
  - Engineering (Raytheon)
  - Actuarial
  - NSA
- Modern math jobs:
  - Google
  - Amazon, Walmart
  - LinkedIn
  - Pixar
  - Intermountain Healthcare
  - Goldman, WellsFargo, CapitalOne

That helped some, but…

- Some students got good jobs, mostly traditional
- Number of majors didn’t improve much

That helped some, but…

- Some students got good jobs, mostly traditional
- Number of majors didn’t improve much

Our advertising was not entirely accurate

Weren’t delivering what was promised

- Many employers were not interested in our students
- What we were teaching was not what was being used
- Alumni: “I wish I had been better prepared for my job”

Weren’t delivering what was promised

- Many employers were not interested in our students
- What we were teaching was not what was being used
- Alumni: “I wish I had been better prepared for my job”

Needed a new curriculum

- Teach the math that is used
- Prepare students to use math effectively

Needed a new curriculum

- Surveyed our alumni, other industrial mathematicians, faculty
- National Survey of industrial leaders
  - Better **modeling and simulation** methods and technologies.
  - More **interdisciplinary** design.
  - Better tools for analyzing **uncertainty and risk**
  - Greater capabilities for handling and understanding **data**.
  - Methods for coping with **complex systems**.
- Clear trends: Most of modern tech is <u>Math + Computing</u>

Needed a new curriculum

- Rigorous foundation in mathematics and statistics
  - Prepared for both graduate school and industry
  - Effective at modeling and problem solving
- Strong technical skills: computation and data
  - Able to convert deep mathematical ideas into good code
  - Able to wrangle and analyze data effectively
- Interdisciplinary
  - Applications across multiple quantitative disciplines
  - Identify common mathematical core across various disciplines

Applied and Computational Mathematics Emphasis (ACME)

First two years:

- Same as regular math major
- Math and programming prerequisites

Junior and Senior years :

- Lockstep cohort (“core”) of 2 theory and 2 lab classes per semester
- Student-chosen application (“concentration”) classes

Capstone:

- Internship or Mentored research

Lockstep Cohort

Same classmates for 2 hours every day, for 2 years

Lockstep Cohort Benefits

For Students

- Teamwork & group support
- Leadership & soft skills
- Networking opportunities
- Social identity
- Develop strong friendships

For the Program

- Improves retention
- Academic interconnections
- Loyal, enthusiastic alumni
- Efficient use of resources

Labs

- Build general programming skill (Python)
- Convert complex mathematical ideas into good code
- Solidify mathematical understanding
- Learn exciting applications of the theory

Lab Examples

- Bacon (Erdös) number
- Gaussian quadrature
- Monte Carlo integration
- Facial recognition using SVD
- Multi-armed bandits
- SIR epidemic models
- HMM Speech recognition
- Random Forests
- Kalman Filter
- HIV treatment
- Color quantization with K-means
- Inverted pendulum control
- Deep Neural Networks
- Reinforcement Learning

ACME Results

- They sign up: Math majors almost double, 2/3 ACME
- They like it
- They win contests
- They help each other
- They recruit others
- They get good jobs
- They give back—time,
  opportunities, money

“It’s HARD…but so powerful.”
—J. Casillas

No other major will satisfy my desire to learn”
—C. Herrera

"…globally optimized our learning, happiness, and personal growth. That's all you really need to know, since this is an optimization class."

Internships

- Amazon, Apple, Google, Microsoft, Facebook
- Livermore, Sandia, Los Alamos, PNNL, NASA
- MIT Lincoln Labs, Johns Hopkins APL
- NSA, FBI
- Goldman-Sachs, Wells Fargo, Capital One
- IHC, MedicLife, United Health, Harbor Health, Recursion Analytics
- Raytheon, Fortem
- Ancestry

Grad Programs

- Berkeley: Biostatistics, Math Education
- Chicago: Economics, Applied Math, Marketing
- Columbia: Electrical Engineering, Applied Math
- Duke: Machine Learning, Computational Biology, Statistics
- Georgia Tech: Machine Learning, Comp. Sci, Mathematics
- Rice: Geology, Machine Learning for Medicine
- Texas A&M: Mathematics, Petroleum Eng.
- Stanford: Economics
- UCLA: Mathematics
- U of Texas: Mathematics, Applied Math (Oden), Comp. Sci
- U of Michigan: Mathematics, Applied Math

Job offers

- Google, Amazon, Apple, Intel, Microsoft, Facebook,
- Oracle
- Goldman-Sachs, CapitalOne, Wells-Fargo, Tanius, Emergent Trading
- United Health, IHC, Epic, Recursion Pharm.,MedicLife, Owlet, Tula Health
- Domo, Fast Enterprises, Innosight, Vicarious
- Lyft, Apple Maps, Google Maps
- Ancestry, FamilySearch
- NSA, USAF, US Navy, Space Force, FBI
- NASA, Los Alamos, Sandia, PNNL
- Raytheon

Challenges implementing ACME

- Limited resources: Faculty, classrooms
- No appropriate curriculum materials
- Faculty didn’t know the material
- Pure faculty suspicious of applied math
- Students unaware

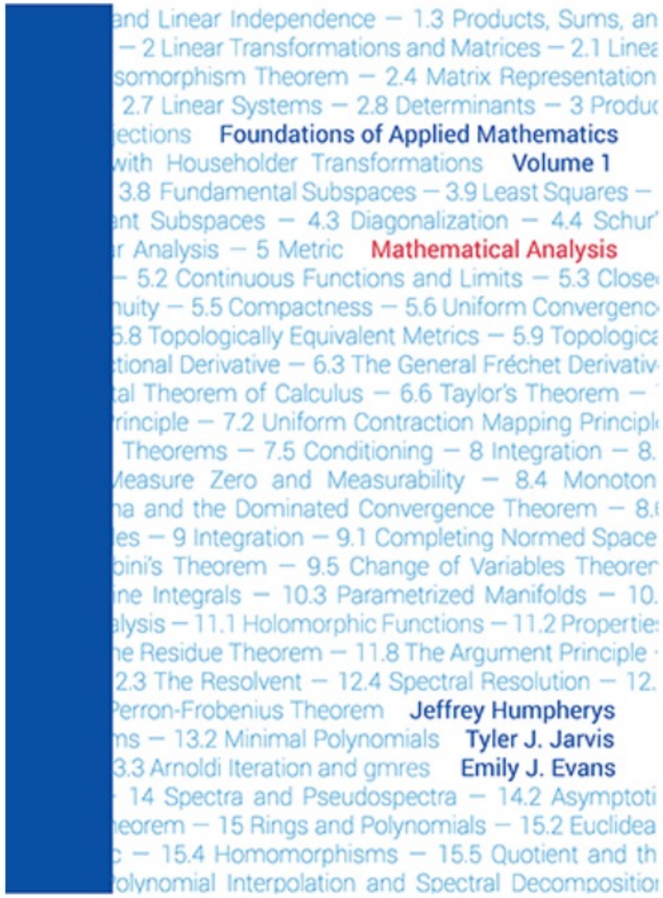
Limited Resources

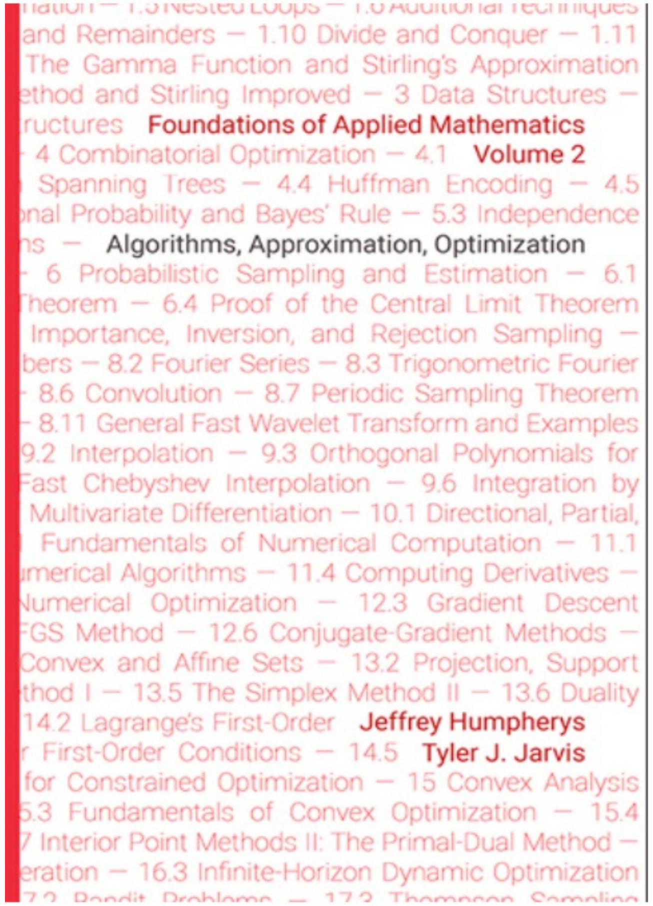
- Cohort model is efficient: 2 faculty for 8 courses
- Labs run by student TAs (grad and ugrad)
- VP —> 1 faculty line on condition of growth target
  - Five-year goal: 40 enrolled/yr and 25 graduate/yr
  - Actual 65/yr enrolled and 55-60 graduate/yr
- More resources (3 more FT lines) came as program grew

No Curriculum Materials

- NSF grant to write them
- SIAM published texts

(cheaper than photocopy)





- Labs are open source

Faculty didn’t know material

- Faculty knew some of it (analysis, linear algebra, probability, harmonic analysis)
- Textbooks are for faculty as well as students
- Student TAs teach labs (faculty need not code)
- Most who taught the courses have loved it

“Pure” faculty suspicious

- Assign them to teach it: most love it
- Attracts more & better students to math
- Spillover to pure math, grad program
- More resources because more, happier students

(and alumni)

Students unaware: Advertise!

- Visit basic math classes
- Posters
- Video display
- Letters to incoming freshmen with good math scores on SAT/ACT/AP Calc
- Also advertise to employers

“Very challenging, but it is all worth it.”

“I chose ACME because it challenges me.”

“The most engaging and exhausting mental challenge of my life.   I Love It.”

Why is ACME successful?

- Relevance builds trust
- Coding math helps learning math
- Modeling—not just models
- Cohort is powerful
- Challenge is invigorating
- Student TAs: role models + efficient
- Dedicated faculty

ACME.byu.edu

ACME Program Website: http://acme.byu.edu

Labs: http://labs.acme.byu.edu

Textbooks: http://epubs.siam.org

Too much to adopt it all?

If you can add only **one class** to your undergraduate curriculum, I recommend something on **Algorithms and Optimization**.

Possible text:

Algorithms, Approximation, Optimization. Humpherys and Jarvis, SIAM 2020
https://epubs.siam.org/doi/10.1137/1.9781611976069

Program Overview

- Freshman & Sophomore Years
  - General Education Requirements
  - Minor in Mathematics (3 Calculus, Linear Algebra, ODE, proof)
  - Intro Computer Programming (Python)
  - First Semester of Real Analysis (Abbott/Blue Rudin)
- Junior Core
  - Mathematical Analysis—Linear and Nonlinear
  - Algorithms, Approximation, and Optimization
  - Concentration classes
- Senior Core
  - Modeling w/ Uncertainty & Data (Math Prob Stat + ML)
  - Modeling w/ Dynamics and Control (Diff Eq, Calc of Var, Control thy)
  - Concentration projects

CORE PROGRAM

First Year Sequences

Mathematical Analysis

- Vector Spaces
- Linear Transformations
- Inner Product Spaces
- Spectral Theory
- Metric Topology
- Differentiation
- Contraction Mappings
- Integration
- Integration on Manifolds
- Complex Analysis
- Adv. Spectral Theory
- Pseudospectrum

Algorithm Design & Optimization

- Intro Algorithms
- Graph Algorithms
- Discrete Probability
- Fourier Theory
- Wavelets
- Interpolation
- Unconstrained Optimization
- Convex Analysis
- Linear Optimization
- Nonlinear Optimization
- Dynamic Optimization
- Markov Decision Processes

First Year Labs

Mathematical Analysis

- Intro Python
- Scientific Visualization
- Linear Systems
- QR
- Markov Chains
- Facial Recognition (SVD)
- Newton Cotes vs. Monte Carlo
- Complex Analysis
- Profiling and Wrapping
- PageRank on Tournaments
- Arnoldi Iteration and GMRES
- The Pseudospectrum
- Relational databases and SQL

Algorithms, Approximation, Optimization

- Data Structures
- Depth/Breadth First
- Nearest Neighbor Search
- FFT and Applications
- Wavelets
- Chebychev Polynomials
- Polynomial Interpolation
- Optimization Packages
- Line Search Methods
- Simplex Method
- Dynamic Optimization
- Multi-Armed Bandits

Second Year Sequences

Modeling with Uncertainty & Data

- Random Variables
- Distributions & Expectation
- Markov Processes
- Information Theory
- Kalman Filtering & Time-Series
- Principal Components
- Clustering
- Bayesian Statistics (MCMC)
- Logistic Regression
- Random Forests
- Support Vector Machines
- Deep Neural Nets

Modeling with Dynamics & Control

- ODE Existence & Uniqueness
- Linear ODE
- Nonlinear Stability
- Boundary-Value Problems
- Hyperbolic PDE
- Parabolic PDE
- Elliptic PDE
- Calculus of Variations
- Optimal Control
- Stochastic Control

Second Year Labs

Modeling with Uncertainty & Data

- Regular Expressions
- Web Scraping
- Pandas
- Kalman Filtering
- Time Series
- Naïve Bayes
- Discrete HMMs
- Continuous HMMs (speech recognition)
- Gibbs Sampling and LDA
- MCMC
- PCA and LSI
- Clustering with k-means
- Random Forests
- Deep Neural Nets

Modeling with Dynamics & Control

- Harmonic Oscillators and Resonance
- Weightloss Models
- Predator-Prey Models
- Shooting Methods and Applications
- Compartmental Models (SIR)
- Lyapunov Exponents and Lorenz Attractors
- Hysteresis in population models
- Conservation Laws and Heat Flow
- Anisotropic diffusion
- Poisson equation, finite difference
- Finite Volume Methods
- Finite Element Methods
- Scattering Problems
- PID Control
- LQR and LQG Control

Some of the Concentrations

- Biology
- Business Management
- Chemical Engineering
- Chemistry
- Computer Science
- Data science & machine learning
- Economics
- Electrical & Computer Engineering
- Electromagnetics
- Financial Markets
- Geological Sciences
- Manufacturing Systems Design
- Mathematical Biology
- Mathematical Theory
- Mechanical Engineering
- Natural Language Processing/Linguistics
- Physics
- Political Science
- Signals and Systems
- Statistics
- Statistics: Actuarial Science
- Statistics: Biostatistics