Integrating Computation into STEM Curriculum

CALVIN BERGGREN

TEXAS LUTHERAN UNIVERSITY

ENGAGING PEDAGOGY CONFERENCE

17 MAY 2017

Physics

"The American Association of Physics Teachers urges that every physics and astronomy department provide its majors and potential majors with appropriate instruction in computational physics."

"almost all undergraduate students who take physics courses will use computational tools in their future careers even if they do not become practicing physicists."

AAPT Statement on Computational Physics

"a curriculum in which computation is absent or plays a minor role is inauthentic to the contemporary discipline."

Wolfgang Christian and Bradley Ambrose, "An Introduction to the Theme Double-Issue", *Am. J. Phys.* **76** (4&5), 293-294 (2008).

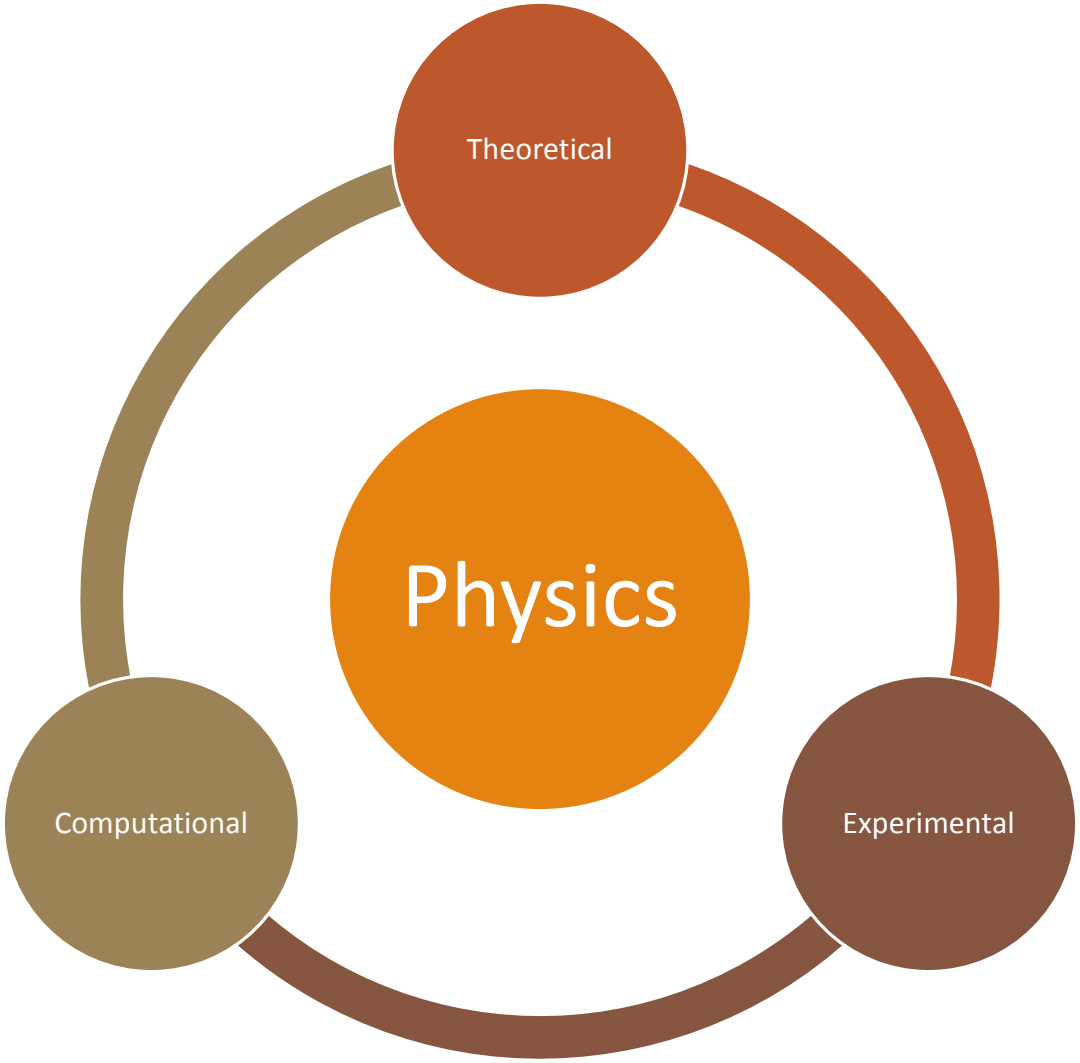
Math

"An excellent mathematics program integrates the use of mathematical tools and technology as essential resources to help students learn and make sense of mathematical ideas, reason mathematically, and communicate their mathematical thinking"

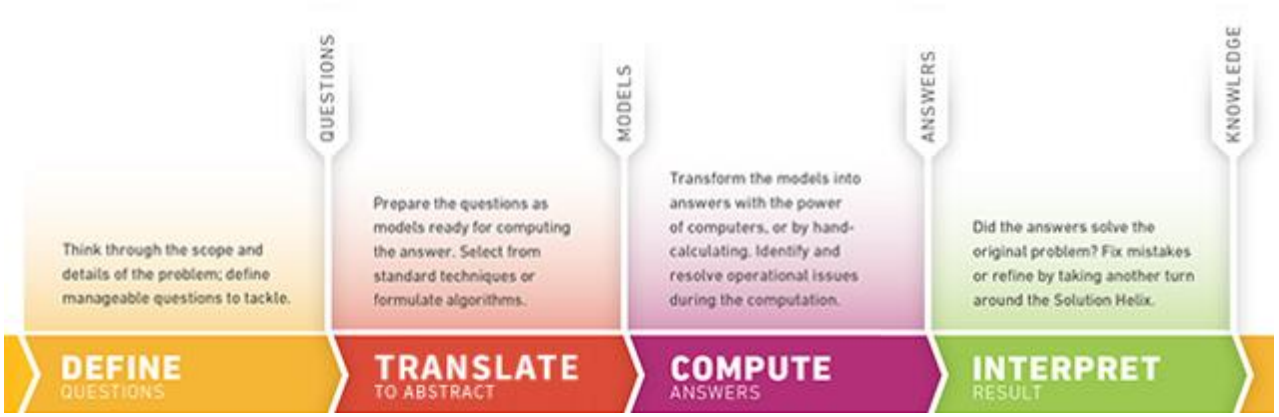
NCTM and AMTE statements

"The importance of maths to jobs, society and thinking has exploded over the last few decades. Meanwhile, maths education is … diverging more and more from computational thinking–based problem-solving required by countries, industry, further education… and students"

computerbasedmath.org


Theoretical
Physics
Computational
Experimental

Math



computerbasedmath.org

Skills

Fundamental computer skills

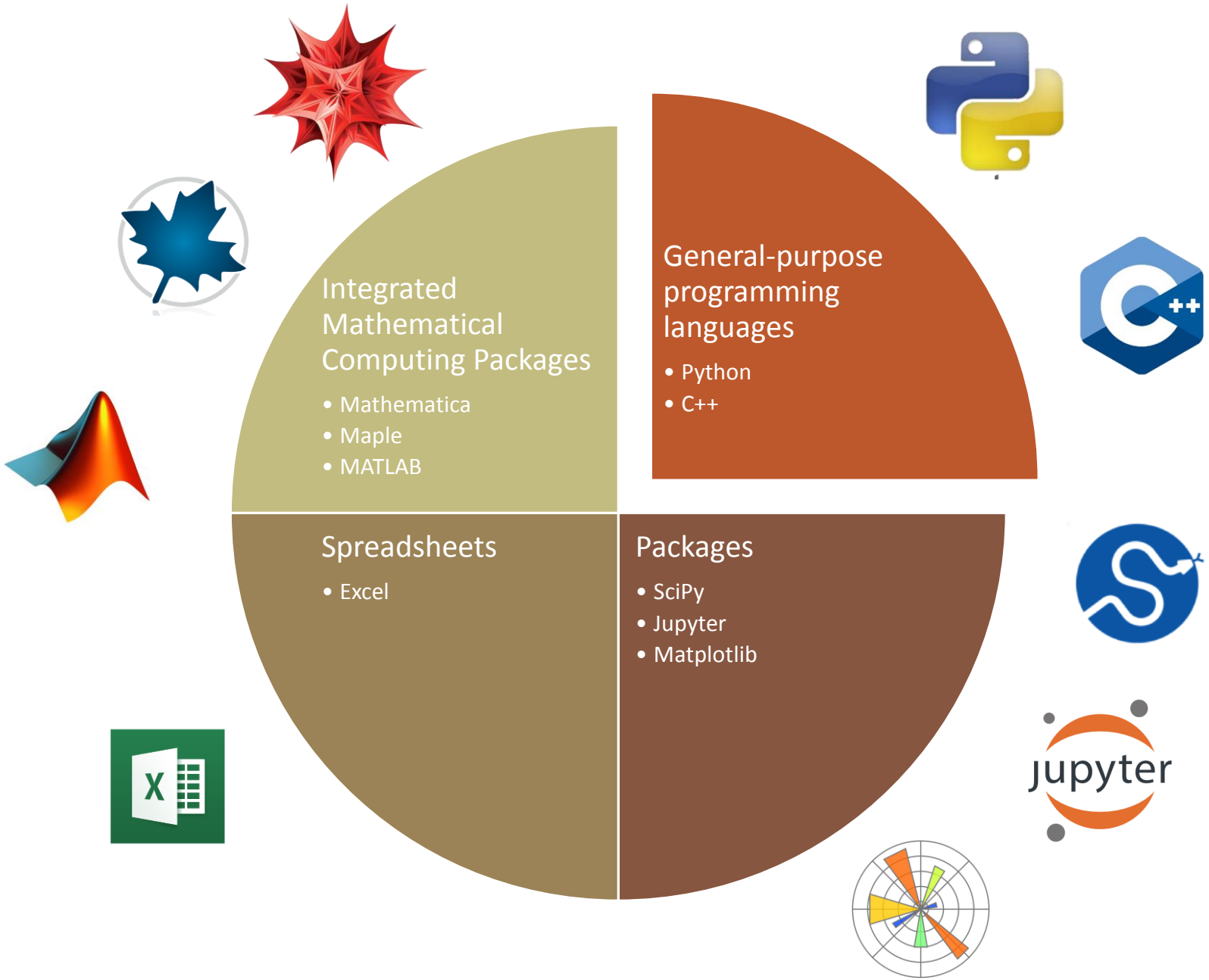
- operating systems
- file systems
- coding
- using computational tools

Technical computing skills

- process data
- visualize data

Computational skills

- translate models or algorithms into code
- write/test/debug code
- divide problem into manageable computational tasks
- make meaning of results


Integrated Mathematical Computing Packages
• Mathematica
• Maple
• MATLAB
General-purpose programming languages
• Python
• C++
Spreadsheets
• Excel
Packages
• SciPy
• Jupyter
• Matplotlib
jupyter

Rationale

"Physics degree programs should reflect the contemporary practice of physics — and computation is now ubiquitous in that practice."

"Students gain a deeper understanding of physics"

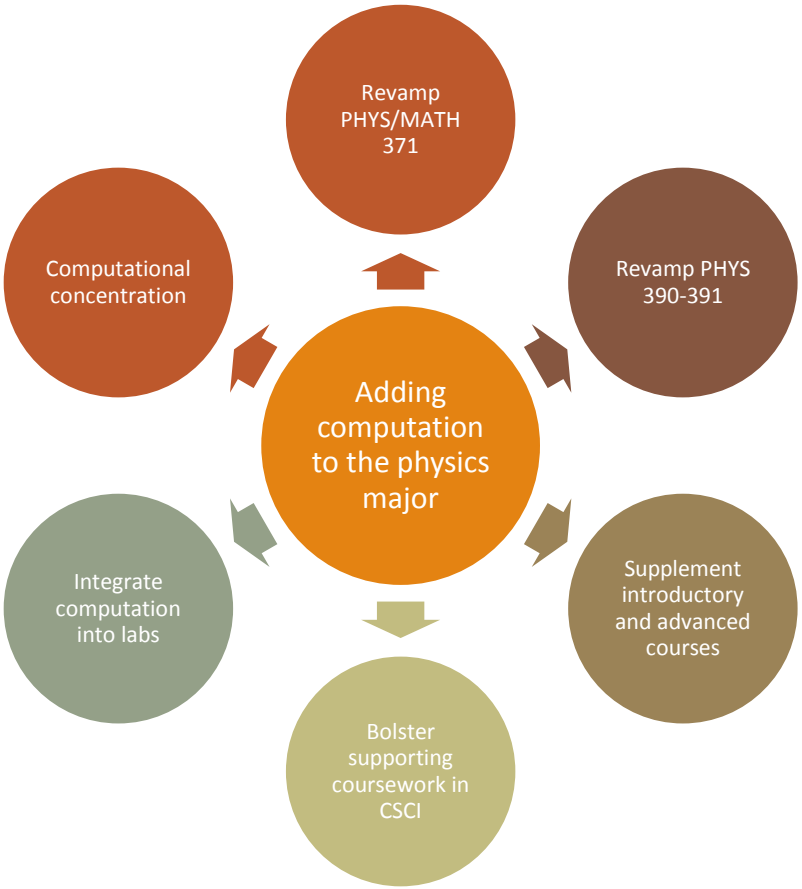
"Students using computation can develop a more exploratory approach to studying physical systems"

"Students using computation can solve a much wider range of problems"

"Students using computation can develop critical skills and knowledge necessary for doing fundamental and applied research, better preparing them for a wide variety of careers."

AAPT UCTF Computational Physics Report (online)

Comprehensive update to the physics major



Revamp PHYS 390

PHYS 390: Applied Computational Physics I

Emphasis on computational modeling

Emphasis on using computational techniques to solve physical systems, especially differential equations

Emphasis on designing, writing, and analyzing algorithms

Emphasis on computational topics important for physics

Revamp PHYS 391

PHYS 391: Applied Computational Physics II

Project-based course, some in teams

Emphasis on practical experience with tools and skills used in industry

- Data analysis, data processing
- 3D modeling, 3D printing
- Physical computing and microcontrollers
- Control systems

Emphasis on presentation of results

Supplementing other courses

Development of computational skills should be integrated into the curriculum, rather than taught as isolated skills.

Working with data

Visualizing data

Automated data collection

Symbolic calculations

Large numerical calculations

Example – Freshman Physics II

Topic: Solving for current throughout a large multi-branch circuit

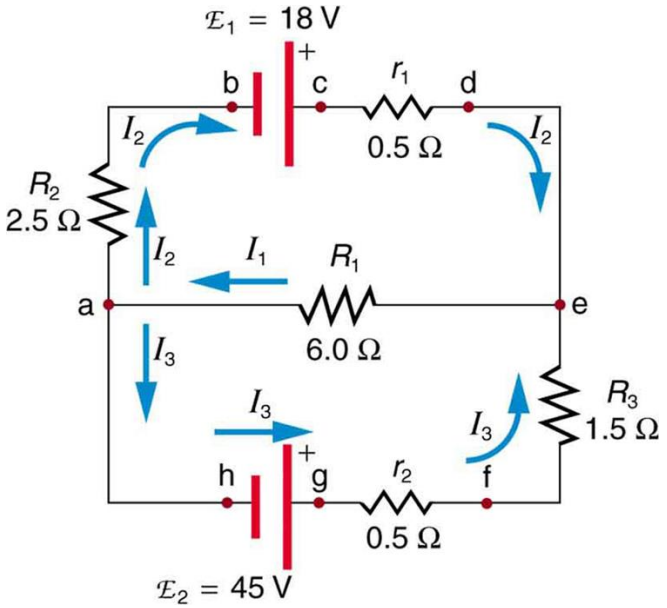
Problem: Resulting system of equations is computationally intensive in all but the simplest and least interesting circuits

Computational skills:

- Translate Kirchhoff's laws into matrix form amenable to computation
- Leverage linear algebra package to solve

Computational tools:

- Python – NumPy



Example – Quantum Mechanics

Topic: Solving Schrödinger equation for a potential barrier

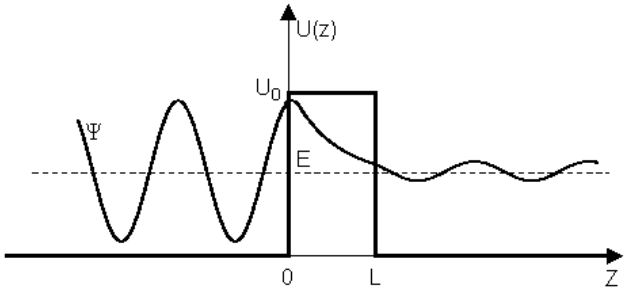
Problem: System of equations is very algebraically intensive

Computational skills:

- Leverage computer algebra system to solve

Computational tools:

- Python – SymPy
- Mathematica
- Maple



$$A + B = C + D$$

$$ikA - ikB = \kappa C - \kappa D$$

$$Ce^{\kappa L} + De^{-\kappa L} = Fe^{ikL}$$

$$\kappa Ce^{\kappa L} - \kappa De^{-\kappa L} = ikFe^{ikL}$$

Example – PHYS/MATH 371

Topics: derivatives, integrals, eigensystems, Fourier series/transforms, power series, Laurent series, residues

Problem: All of these can quickly become intensive by hand, and computers are used in real world

Goal: Achieve parity between conceptual, work-by-hand, and work-by-computer

Computational skills:

- Computational modeling
- Making meaning of results

Computational tools:

- Python – SymPy

Challenges

Every tool, language, package, etc. you use at all requires overhead

→ Standardize on tools

Adding new material to curriculum

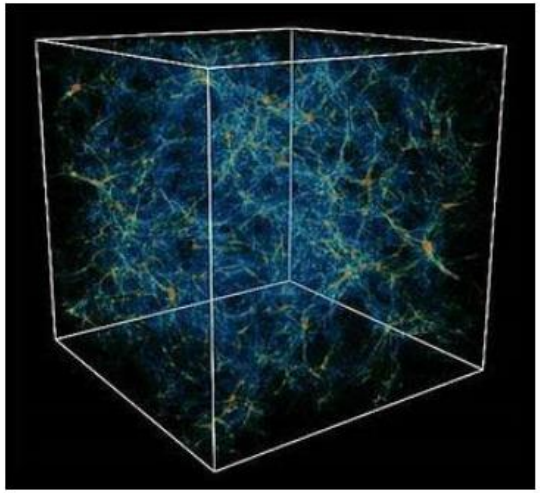
→ Augment existing topics where it makes sense

→ Be strategic

Coding is hard and students have variety of backgrounds

→ Scaffolding

Lack of textbook support



MONDAY, 9/19
6:00PM
PYTHON / SCIPY WORKSHOP

Presented by Dr. Berggren