Undergraduate Computational Science and Engineering Education in the USA

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www.siam.org/about/pdf/CSE_Report.pdf

Also available via links from SIAM's Student page or CSE activity group page

The SIAM Report Working Group

- Sponsored by SIAM Education Committee
  - Bill Briggs, then SIAM VP for Education
- Working Group Members
  - Peter Turner (Clarkson University, Chair)
  - Kirk Jordan (IBM)
  - Linda Petzold (UC Santa Barbara)
  - Angela Shiflet (Wofford College)
  - Ignatios Vakalis (Cal. Poly. & State Univ.)

Definition of CSE

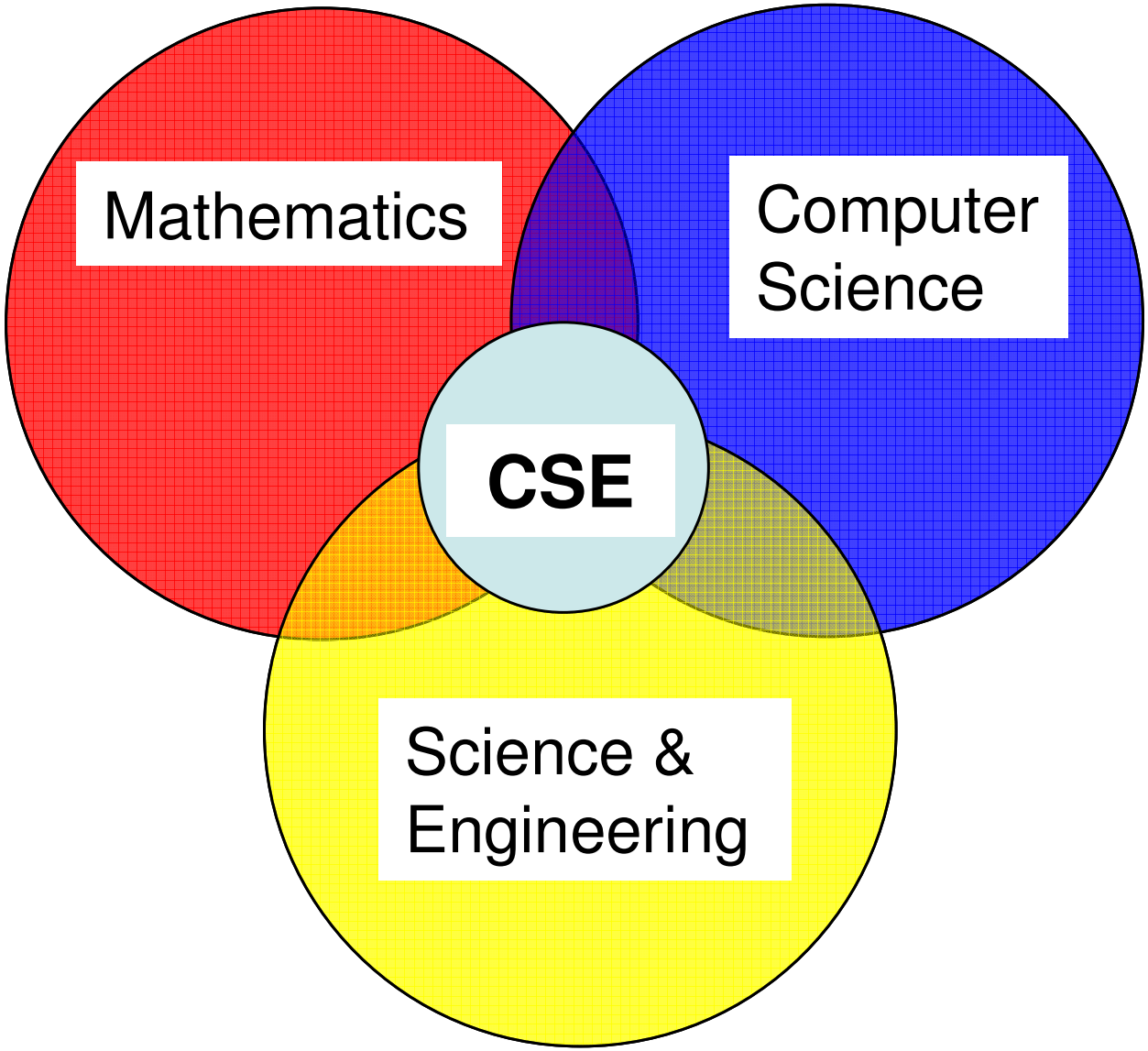
Unchanged from graduate report

A broad multidisciplinary area that encompasses applications in science/engineering, applied mathematics, numerical analysis, and computer science.

Computer models and computer simulations have become an important part of the research repertoire, supplementing (and in some cases replacing) experimentation.

Going from application area to computational results requires domain expertise, mathematical modeling, numerical analysis, algorithm development, software implementation, program execution, analysis, validation and visualization of results. CSE involves all of this.

Or in picture form:



CSE is larger than the pure intersection of the three component pieces, but is nonetheless included in their union.

That is to say CSE provides, and strengthens, the bridges connecting those components but should not become a separate "island".

What CSE is, and is not

- CSE is a legitimate, important academic enterprise
- CSE focuses on integration of knowledge for development of problem-solving methodologies and tools
- CSE is *not* a part of applied mathematics or computer science
- CSE needs input/collaboration from the application domains

What CSE is, and is not

- CSE *differs* from science and engineering in that it focuses on the development of the computational tools for solving complex problems
- Good undergraduate CSE programs respect and foster these properties and attitudes

The Working Group Report

- Nature of CSE Undergraduate Education
  - Introduction
  - Models of Programs
  - Examples
- The Value of Internships
  - Illustrated by examples
- Needs a CSE Education Must Address
  - An industrial perspective

Flavors of Undergraduate CSE Programs in the U.S.

- B.S.
  - SUNY Brockport
- Minor Programs
  - Capital University
- Emphasis or Concentration
  - Wofford College
- B.S. in Computational X
  - X = STEM discipline or Finance
  - Computational Physics @ Oregon State

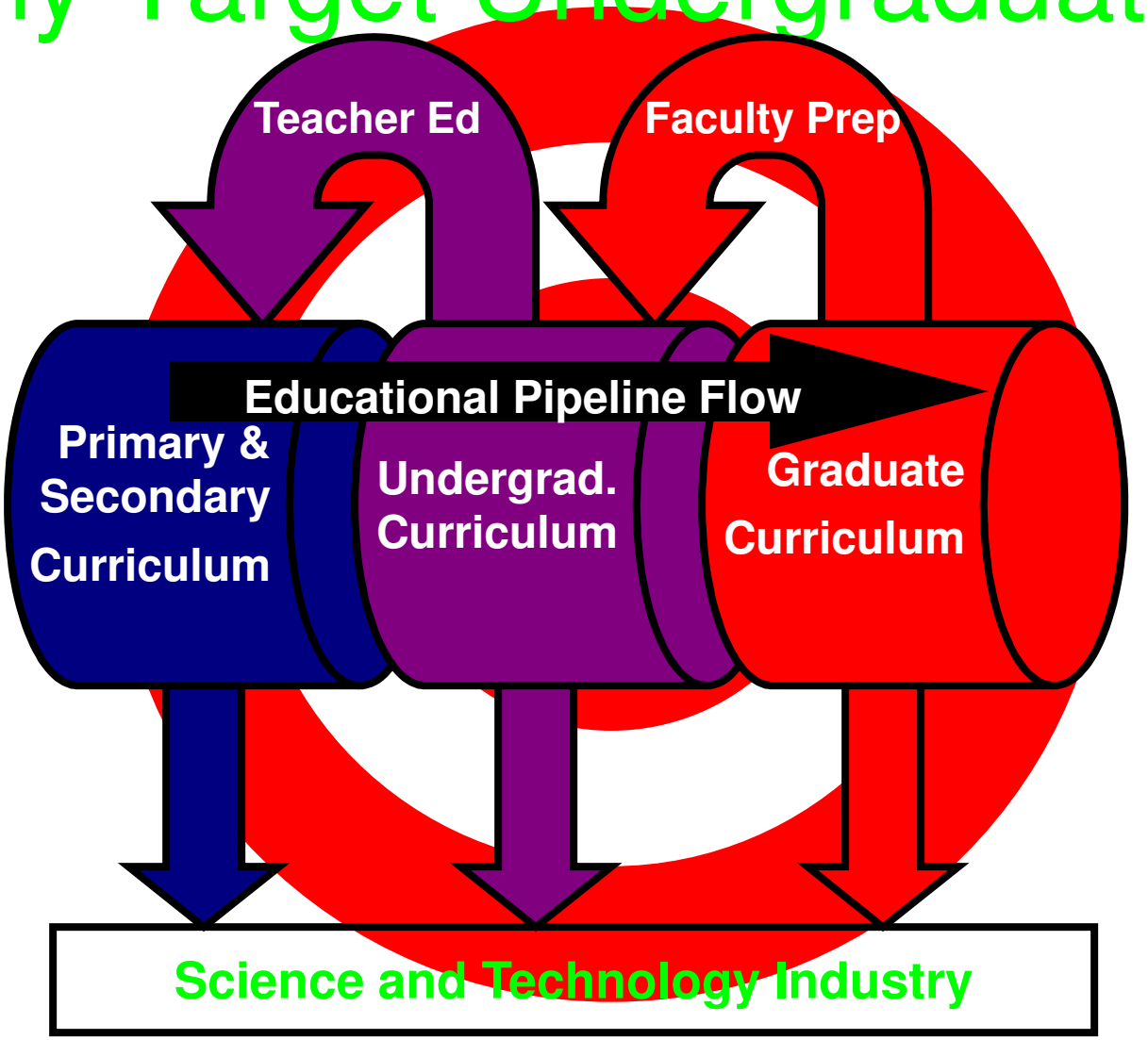
Common Curriculum Content Components (1)

- Simulation and Modeling
  - Conceptual models, accuracy, use of modeling tools, assessment of computational models
- Programming and algorithms
  - A high level language, elementary data structures, analysis
- Applied mathematics
  - Calculus and differential equations, linear algebra, (discrete) dynamical systems
- Numerical methods
  - Errors, nonlinear equations, solving systems of linear equations, interpolation and curve fitting, optimization, Monte Carlo, ODEs, PDEs
- Parallel programming
- Scientific visualization
  - Basics of SciViz., grid representations, pipeline, rendering, vector visualization

Common Curriculum Content Components (2)

- Application domain content
  - At least one major application area of science or engineering
- Team-based projects
- Effective technical analysis and presentation
- Research or Professional Experience
  - Independent research, presentation of solution methodologies, internship
- Of course not all programs will cover all this in depth!

Why Target Undergraduates?



Motivational Factors for Developing CSE Programs

- Future jobs of technical nature require new skills directly related to computational science
- Computer science graduates do not have the modeling, mathematics and science background needed for future technical employment
- STEM fields are becoming more computational; science and engineering are now commonly done *in silico*
- Numerous reports and articles state the importance of computational science
- Funding opportunities for developing computational science curricula and educational materials focus on the undergraduate arena

Common Features of Educational Materials

- Web based
- Self-standing, comprehensive modules
- Problem-based approach centered on applications from STEM disciplines
- Inquiry-based pedagogy, exploring the *what-if* scenarios
- Common paradigm:
  - *Problem → Model → Method → Implementation → Assessment*

Needs Undergraduate CSE Education Must Address

- The u.g. CSE Pipeline has many outputs:
  - Grad Schools
  - Industrial Opportunities
  - K-12 Education
- The basic skill set applies to all of these
  - Disciplinary and cross-disciplinary skills
  - Ability for independent learning
  - Team work
  - Adaptability and interest in problem-solving

Needs Undergraduate CSE Education Must Address

- Professional Experience or Internships
- Projects
  - Interdisciplinary
  - Team-based, including team teaching
  - Extended projects help develop the perseverance needed for the workplace
- Breadth vs. Depth

Needs Undergraduate CSE Education Must Address

- Communication, too
  - Presentations at meetings
  - Educational outreach activities
    - MATHCOUNTS, Science Olympiad coaching etc.
- Career awareness is critical to recruitment
  - Simulation and computer-based engineering (e.g. Boeing 777)
  - All areas of engineering
  - Pharmaceuticals
  - Digital Media
  - Consumer products
  - …

Professional Experience & Internships

- New ideas, techniques, applications
- Enhanced knowledge of CSE in practice
- Makes classroom education more meaningful
- Contributions to host's research
- Team work
- Different places
- Build confidence & Communication
- Contacts and Leverage

Professional Experience & Internships

- Many programs require some form of internship
- Often needs help from faculty or career centers
- Start early in the fall with resume preparation
- Use the Web
  - NSF REU's
- Use Personal contacts
  - Nearby companies
  - Help from professors
- Supplementary funds
- Some excellent examples available from Wofford

Internships: An Industry-based Perspective

- Like hiring full-time employee – not easy
  - Need budget
  - Headcount
  - Timing can be an issue – fiscal year not match academic year
- Internship
  - A job needs to get done – if company pays
  - If company sponsored but others pay
    - Okay – takes time from industry sponsor – Time is the most precious resource

Internships: An Industry-based Perspective

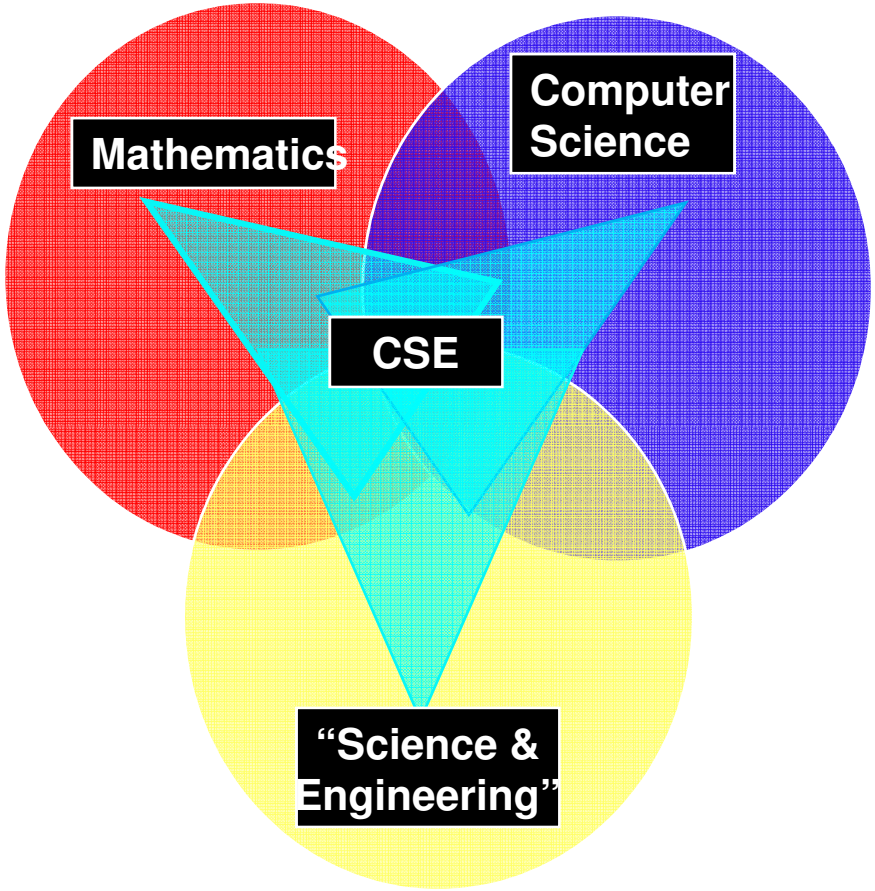
- Internship is work for industry sponsor
  - Need a piece of work done but in short time
  - Student must be a quick learner
  - How to make meaningful experience and not just grunt work
- Best if project with faculty - that intern can get introduction prior to internship start
  - Longer term collaboration
  - Faculty can help prepare the student

Academic, Government Labs, Industry (large & small)

- All have their special characteristics and needs that must be taken into account
- Where might YOU find need for CSE in Industry?
  - The importance of simulation and computation is ever growing – Everywhere!
  - Some examples – not meant to be inclusive

    Automotive, Aerospace, Banking/Finance, Chemical, Consumer Products, Digital Content Creation , Electronics, Healthcare, Life Sciences – Biotech, Manufacturing in different industries, Pharmaceutical , Petroleum (Upstream & Downstream), Transportation

CS&E – An Industry perspective – What Industry Needs



- Need strong foundation in a discipline
- Need computational skills
  - Not just MATLAB
  - Understand Error, Stability, Performance
- Need second discipline "expertise"
  - Speak another "language"
  - Provide added breadth
  - Transition to other problem areas
  - Willingness to Change – and to DRIVE CHANGE

CS&E – An Industry perspective – What Industry Needs

- **Flexibility – Of employee:**
  - Good problem solving skills
  - Ability to work on variety of issues -- do what it takes to get the job done
- Good communication skills to
  - sell ideas/projects/concepts
  - get the point across fast
  - explain ideas
- Show high degree of organization

CS&E – An Industry perspective – What Industry Needs

- Persistence -- willing to stay with something to completion
- Ability to **"TEAM"**
  - Work with a variety of people and disciplines on different aspects of the projects
- Understand work as part of a greater world
  - Work outside one's discipline
  - Life long learning - driving curiosity and change

Conclusions & Recommendations

- Many different models of undergraduate CSE programs can work
  - Local conditions probably dictate what is right for any one institution
- Many curricular items in common
- Many different objectives
  - Education, Graduate Schools, Labs, Industry

Conclusions & Recommendations

Interdisciplinary collaboration must be an integral part of the curriculum and thesis research.

- Courses with multidisciplinary projects and presentations whenever possible.
  - Include different computing environments
- Participation in a multidisciplinary research team.

Conclusions & Recommendations

- Internship at a National Laboratory, a Research Experience for Undergraduates (REU) program, or in industry.
- Conference sessions
  - Growth of undergraduate paper and poster sessions and computational REUs
  - SIAM CS&E Meetings have regularly featured such sessions
  - CSUMS sessions at Student Days here

Conclusions & Recommendations

The Role of SIAM: Current, Future and Continuing

- Define the core areas and scope of this field
- Help educate potential employers and managers on the nature and benefits of CSE
- Outline ideas for curriculum
  - Essential courses
  - Desirables
  - "External fields" dependent on local conditions