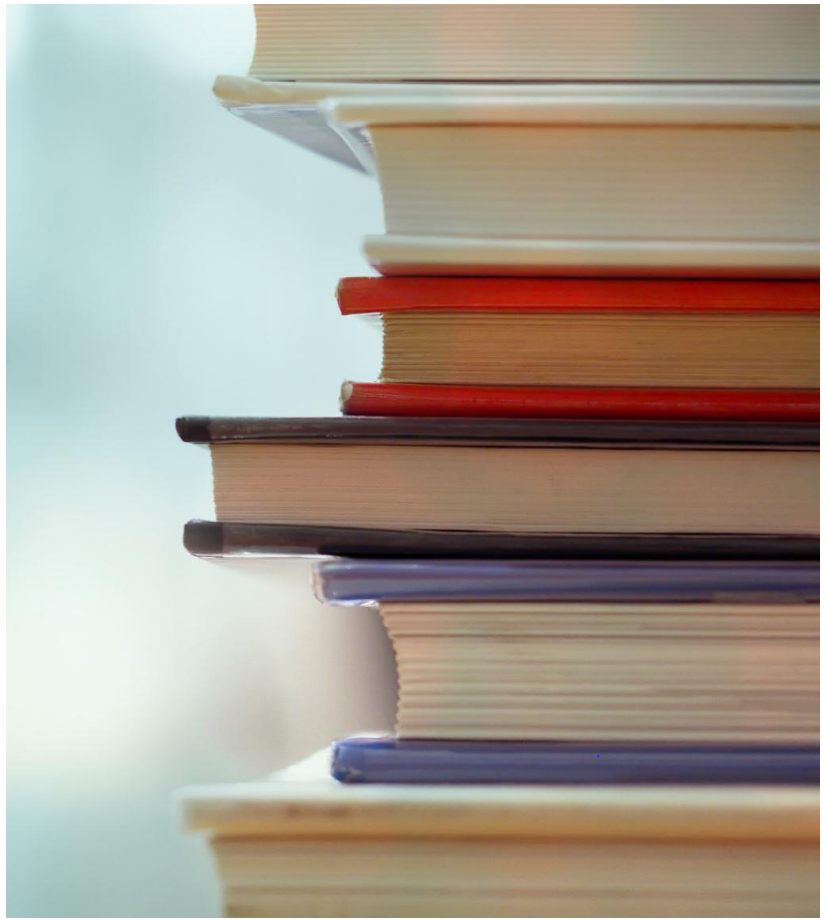
Landscape of CPS Education

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See ACM Transactions on CPS Paper

Outline

- Overview of Success
- NAE CPS Education Study
- 4 Examples
- Challenges
- Next Steps
- Summary



Overview of CPS Education Success

Degrees and Certificates

- UG
  - Univ. of Maryland
- MS
  - UC Irvine
  - Northeastern
  - Vanderbilt
- Certificates
  - Univ. of Virginia
  - Johns Hopkins
- New concentrations/tracks

Classes and Texts

- Entire curriculums
- Collections of Specialized Classes
- Integrated into current curriculums
- Texts
  - Fundamentals
  - Application areas
  - Specialized Topics
  - Edited Volumes

Worldwide - Examples from Around the World

- HAN Univ – Netherlands – MS with CPS Track
- Jean Monnet Univ. – France – MSc
- Cyber Physical Learning Alliance - Asia
  - Singapore Univ of Technology and Design
  - Hong Kong Univ of Science and Technology
  - Zhejiang Univ.
  - International partners
- Monash Univ. – Australia – Engineering classes with CPS focus



Remarkable: Almost every CS/Engin school has CPS Education in some form

NAE Study – A 21st Century CPS Education (NSF funded)

- Academia and Industry
- 3 years in the making
  - Many SC meetings, 2 major open workshops, reviews, NAE reviewers, etc.
- 92-page report
- Various shorter articles
- Influenced many classes and curriculum designs

NAE Report Contents

- The need and what's new
- UG and Grad education (MS and PhD)
- Examples of full curriculums (see upcoming slide)
- K-12, vocational and community colleges
- CPS in Introductory classes
- Survey classes
- Drawing students into CPS
- Developing needed faculty
- What texts, lab materials etc. are needed
- Need for Professional Training

Full Curriculum Templates as Examples

- Model for a 4-year Undergraduate Degree in Mechanical Engineering with CPS Emphasis
- Model for a 4-year Undergraduate Degree in Civil Engineering with CPS Emphasis

- Model for a 4-year, 40-class Undergraduate BS Degree in CPS
- Model for a 4-year, 40-class Undergraduate BS Degree in CPS, Electrical Engineering Program
- Model for a 4-year, 40-class Undergraduate BS Degree in CPS, Computer Science Program

Six Foundations (Principles)

- Basic Computing Concepts
- Computing and the Physical World
- Application Discrete and Continuous Math
- Cross-cutting application of sensing, actuation, control, communications and computing
- Modeling heterogeneous and dynamic systems and integrating control, computing and communication
- CPS System development

References for the NAE Report

- NAE Full Report (on website)
  - A 21st Century Cyber-Physical Systems Education, Report. National Academies Press, 2016, 92 pages.

- Magazine article
  - J. Stankovic, J. Sturges, and J. Eisenberg. A 21st century cyber-physical systems education. IEEE Computer, pages 40–43, 2017.

Examples

- UVA - entire curriculum with 5 new interdisciplinary and integrated classes – grad level certificate
- Vanderbilt –entire curriculum – MEng degree

- USC – UG interactive text-based class that serves as introduction to CPS
- CMU/KIT – class on safety and correctness focus and accompanying textbook

UVA – Certificate Program

- Entire curriculum based on NAE report including professional development
- 5 entirely new classes – each interdisciplinary

- Themes
  - Emphasize the intersection of the cyber and physical
  - Application motivations
  - Hands-on Testbeds
  - Cannot just collect current classes

5 New CPS Classes

CPS 1	Testbeds, Applications, Policy
CPS 2	Embedded and Real-Time Systems
CPS 3	Signal Processing, AI/ML, Control
CPS 4	Dynamical Systems
CPS 5	Formal Methods, Safety and Security

Reference

John A. Stankovic, Homa Alemzadeh, Brad Campbell, John Lach, Feng Lu, Cody Fleming, Jonathan Goodall, Toluwalogo Odumosu, Daniel Quinn, Yuan Tian, Kelley Tobler, A Graduate Curriculum in Cyber Physical Systems, *IEEE Design and Test*, Vol. 38, Issue 3, pages 112-120, June 2021..

Vanderbilt – MEng in CPS

- 30 credits – 12 months
  - Includes summer capstone
- Offered by the School of Engineering
- Faculty from 5 departments

- Address the training gap between Cyber and Physical
- Closely connected to research and Industry

Vanderbilt Curriculum Design

- CPS Foundations
- CPS Engineering
- CPS Applications
- Project Management and Leadership
- Summer Capstone Project

- MS degree

USC – Class that spans the full CPS stack

- UG class that serves as gateway to CPS
- Enrolls 80 students per semester
- 6 Thematic units (next slide)
- Progressively build from foundational technologies to advanced topics
- Hands-on lab activities
- Interactive on-line text
- Integrates with other classes at USC

USC Class Thematic Units

- Foundations
- Networked Applications
- Wireless Communications
- Embedded Systems
- Intelligence and Control
- Security and Scale

CMU and Karlsruhe Institute of Technology

- Concentrates on CPS Foundations
- Textbook created
- Formally design and analyze CPS
- Focuses on safety and verification

- Versions of the class have been transferred to other Univ.

Design of Class (and textbook)

- Elementary CPS
- Advanced CPS
- Adversarial CPS
- Comprehensive CPS Correctness

- For details see the Text: A. Platzer, Logical Foundations of Cyber Physical Systems

Challenges

- Department structures and resources (including faculty teaching time) complicate implementations
  - Who owns CPS
  - Changing administration needs to see value of CPS
  - Universities struggle with interdisciplinary programs



- Tension between deep domain expertise and interdisciplinary knowledge and skills

- Who should teach CPS (AI, Control theory, Calculus, …)

Next Steps

- More “degrees”
- More Movement to UG programs
- Continual refinement of class content
  - Example: LLMs and World Models
- More administrative models
  - Who owns CPS
  - Where do resources come from

Summary

- Success: Worldwide impact on CS and Engineering education
  - New degrees, certificates, concentrations, …
  - Now ubiquitous – found in almost *every* CS/Engineering school

- Highly Interdisciplinary

- Contributes to support for research
- Contributes to training CPS people for Industry

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