Bridging the gap between multidisciplinary knowledge and engineering education through project-based learning: case of Neuromorphic Engineering

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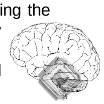
Abstract

Neuromorphic engineering is an emergent discipline at the interface between brain sciences and engineering, with the aim of designing intelligent systems to emulate brain functions and behaviors. Such cross-disciplinary field is not readily available in classic curricula, nor is it amenable to traditional classroom settings. Project-based learning is an instructional approach that involves indepth study and rigorous investigation of challenging and multifaceted problems; making it very pertinent for a cross-disciplinary discipline such as neuromorphic engineering. We have been applying such project-based methodologies in a summer workshop setting; and are exploring ways to bring the successes of the workshop experience into the classroom.

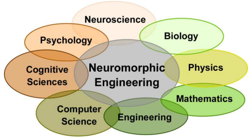
This effort falls into the project-based learning pedagogical topic.

What is Neuromorphic Engineering?

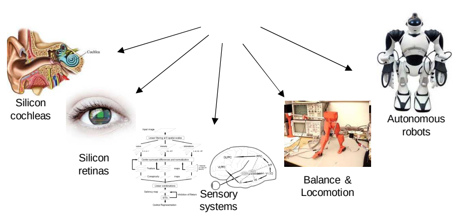
<u>Neuromorphic engineering:</u> Reverse engineering the information representation used by neurobiology and developing artificial systems that mimic the function, structural organization and physical foundation of biological neural systems.



Neuromorphic engineering is an interdisciplinary field



<u>Goal:</u> cross-fertilization across all disciplines in order to design systems that attain intelligent behavior through adaptation and learning in their interaction with the environment, and that are more robust and orders of magnitude more energy efficient than conventional approaches using digital electronics and user-programmed intelligence.



- ✓ Rather than write a computer program from the top down to simulate brain functions, such as object recognition or navigation, neuromorphic engineering aims at building machines that work (it is thought) in the same way as the brain.
- ✓ Unlike conventional AI, the intelligence of many neuromorphic systems comes from the physical properties of the system itself, not from a modeling formula.

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The payoff for this "biological validity", comes in size, speed and low power consumption. Millions of years of evolution have allowed nature to come up with extremely efficient ways of extracting information from the environment.

The Economist, Technology Quarterly Q3 (2001)

Need for new pedagogical approaches

Overall, engineering education is inherently a challenging endeavor. It aims at educating students who are able to:

- ✓ Master a deeper technical knowledge of technical fundamentals
- ✓ Lead in the creation and operation of new products, processes and systems
- ✓ Understand the importance and strategic impact of research and technology development on society

Crawley E et al. (2010) "Rethinking Engineering Education", Spinger.

Yet…

- ✓ Most engineering courses (aside from few laboratories) emphasize concepts rather than facts;
- ✓ Fail to cater to the wide diversity of engineering students (intuitive, sensory, inductive/deductive, active/reflexive, sequential/global learners)

Felder R, Silverman L (1988) "Learning and Teaching Styles" In Eng. Educ., 78(7).

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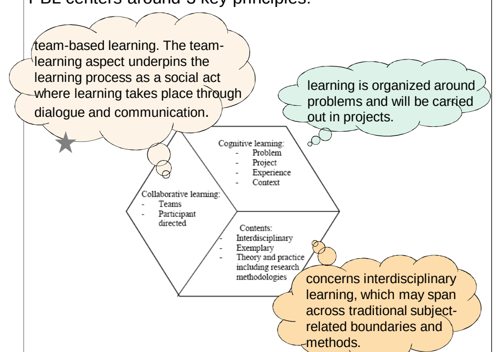
Project-Based Learning (PBL):

PBL centers around 3 key principles:



Du X. et al. (2009) "Research on PBL Practice in Engineering Education", SensePublishers

<u>Case of neuromorphic engineering:</u>

The pedagogical pertinence of PBL is even more pronounced when dealing with a field that bridges the gap between traditional (discrete) disciplines:

- ✓ Learning is organized around themes, problems, or issues
  - ❖ students seek knowledge and skills from a variety of disciplines to provide an expanded and more complex understanding of the topics at hand.
- ✓ Interdisciplinary learning eliminates fragmentation and learning of isolated skills.
  - ❖ Students access particular themes from different entry points and appreciate contribution of different disciplines
- ✓ Interdisciplinary teaching increases students' motivation for learning as well as their level of active engagement.
- ✓ Students working in teams learn from each others' skills and improve communication between disciplines

Mills and Tregust (2003); Thomas (2000)

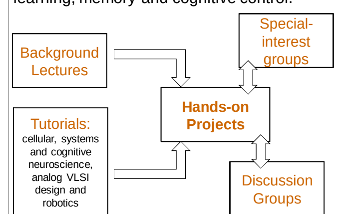
The Telluride workshop experience

<u>Workshop idea</u>

The Telluride neuromorphic Engineering Workshops arose out of a strategic decision by the US National Science Foundation to encourage the interface between Neuroscience and Engineering. In 1993, the Brain Working Group recommended that NSF organize and fund a hands-on workshop that would draw together an international group of scientists interested in exploring multi-disciplinary research and educational opportunities that integrates biology, physics, mathematics, computer science and engineering. This field was dubbed neuromorphic engineering by its founder, Prof. Carver Mead. The first Telluride Workshop was held in 1994, and has been held annually in telluride Colorado as a 3-week hands-on workshop.

<u>Workshop format</u>

Unlike conventional workshops, the telluride workshop brings together an unlikely mix of participants covering a wide range of disciplines from signal processing, robotics, circuit design, machine learning to cell biology, neuroanatomy and electrophysiology. All participants have in common an interest in understanding and possibly mimicking various aspects of brain function including sensory processing, intelligent behavior, learning, memory and cognitive control.



The workshop is an intensive hands-on learning experience where students have to learn to communicate critically and effectively, articulate their ideas, and collaborate together to complete numerous projects

<u>Workshop participants</u>

Participants are generally drawn from academia (about 2/3), government laboratories, and industry. The diverse backgrounds of the participants span medicine, biology, computational neuroscience, neurophysiology, engineering, computer science, and robotics from US and non-US organizations.

<u>Example activities from 2011 and 2010 workshop</u>

- Cognitive robots for object detection using sound, language, and vision
- Guided Reinforcement Learning
- Attention-Driven Scene Analysis
- Neuromorphic Asynchronous Circuits
- jAER: event-based sensory-motor processing
- SMD Soldering Tutorial
- Hands-on Overview of FPAA Chips and Tools
- Spike-based robots
- Multimodal sensory fusion
- Brain machine interfacing

<u>Evaluation & Feedback</u>

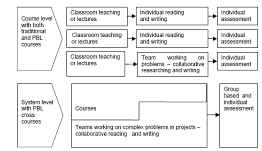
- ❖ Every year, the workshop generates an enormous amount of scientific output: new collaborations, research publications …
- ❖ Student evaluations and self-assessments are overly positive and reflect an ownership and engagement in the process
- ❖ Student feedback particularly praises the project-based approach of the workshop (~70% of participants in 2011), its broad focus (~70%) as well the openness and chance to interact with different fields (~60%)
- ❖ Overall, Interest and popularity of the workshop stems from its synergistic integration of multidisciplinary and project-based learning

Translating the experience into the classroom

PBL has many variables and layers throughout the educational system. It is not a methodology but a taxonomy of pedagogical approaches.

What is the right balance between course-level and system-level approaches:

- Course approach (typically used in the traditional system) lets the lecture decide on the specific learning objectives and the teaching and learning methods.
- System approach is a more global view of the educational experience where lectures from various courses must coordinate objectives, content taught, project types and assessment methodologies. It involves a common institutional-level vision…



but how much flexibility does it allow? And how does it fit in an interdisciplinary setting?

Du X. et al. (2009) "Research on PBL Practice in Engineering Education", SensePublishers

Discussion Points

- ❖ Exploring ways to bring the successes of the workshop experience into the classroom.
- ❖ One of the challenges facing this effort is the multidisciplinary nature of neuromorphic engineering, which is in itself one of its strengths.
- ❖ Having a team with mixed backgrounds compels students to learn to communicate effectively and learn from each other.
- ❖ However, it also pushes the frontier of traditional instructional methodologies to incorporate a much wider multidisciplinary knowledge base which can be challenging in classic classroom settings.

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