

ESE 313

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(Pilot Version)

Robotics and Bioinspired Systems

Course Philosophy

D. E. Koditschek, Lecturer

J. D. Weingarten, Lab Instructor

S. Russem, Lab TA

Lifelong Learning and Critical Thinking for Twenty-First Century Engineers

It is generally accepted by engineering educators, most notably, by [ABET](#), the formal engineering accreditation body, that technical knowledge has exploded to the point where no four year BE program, however intense, can provide a comprehensive introduction to a contemporary practice-level understanding of an engineering field. Moreover, the pace of change in engineering disciplines has become so rapid, that many details appropriate to today's practice may no longer be nearly as relevant within a decade's time. The emerging response from engineering educators is to recognize that pedagogy for twenty-first century engineers must primarily stress the process of how to learn technical material over the course of an entire career.

Continued decades of inquiry by cognitive psychologists and education researchers [1,2,3] affirm that the successful independent learner is a critical thinker. Driven by some personal sense of *curiosity*, armed with a patient *skepticism of received authority*, acquainted with the unremitting demands of *evidentiary reasoning*, and comfortable with the *social construction of reality*, critical thinkers are **innovative problem solvers** who **work effectively in groups** to **find tools that fit their problems**, developing the **new skills required along the way** to wield them.

The Research Scientist as a Paradigm for Lifelong Learning

This course is an attempt to scaffold the process of learning how to learn required for a successful career in Twenty-First Century Engineering. In particular, we adopt the scaffold of scientific research [4] as offering a prime model of the critical thinking paradigm – and one exactly suited to the competence of a major research university such as Penn. We will pursue a particular version of this pedagogical notion, introduced by some of the [instructor's biology collaborators at UC Berkeley](#). We adapt the general paradigm of research scientist as the model for learning how to learn complex and highly technical knowledge to the specific problems of legged robotics.

Because of the instructor's background and expertise, and because robotics is among the most compelling aspects Twenty-First Century Engineering, we will use a recently developed instructional tool, the NSF FIBR/ESE112 EduBot hexapedal robot [5], as our primary evidentiary tool. However, we take the view that robotics ought to be pursued as an interdisciplinary activity, merging groups with varied expertise from mathematics, biology, engineering, and beyond. Accordingly, this document outlines the nature of the research scientist's undertaking with particular emphasis on the process of bioinspired engineering science. The assignments laid out in the Course Process and Project Mechanics document attempt to make explicit the way these activities function in scientific discourse.

Scientific Knowledge

In general, the scientific paradigm presents the realm of human knowledge as the *social creation* of a *never-ending* web of *technical* hypotheses about what will be observed in the world by any group or individual that records specific measurements according to a specific method or preparation. The term "*social creation*" emphasizes the reality that knowledge is constructed by groups, careers are played out against the backdrop of groups, hence group competence is vital for any professional success, particularly for Twenty-First Century Engineers. In consequence, a large part of the course will entail a group research-modeled project.

The term "*never-ending*" connotes the understanding that the refutation (or not) of prior hypotheses inevitably leads to new hypotheses. Thus, no one data set or prediction can ever be understood without a clear linkage to the larger body of hypotheses and outcomes to which it is related. In this view, the task of communicating new research lies equally in stating the new hypothesis and its measured outcomes as in connecting the present set of results against those prior known, and future possible. This course will emphasize the "*never-ending*" web of science by stressing the importance of making the right connections to prior literature as well as advancing proposals for future inquiry.

The "*technical*" nature of scientific knowledge encompasses three generally acknowledged components: a delimited, empirically observable domain; a mathematical model of the relationships between measurable phenomena in that domain; and a computational representation of that mathematical model. This course will address the inter-related nature of these three technical components. Students will be expected to perform independent experiments in the empirical domain of legged mobility. They will be expected to relate those experiments to some appropriate mathematical model encountered in the literature. They will be expected to exercise that model in some computational form using coding skills developed in the earlier engineering curriculum. They will be invited to communicate the outcomes to the peer community (class as a whole) according to the standards of contemporary scientific discourse

Bioinspired Engineering Science

The major distinction that marks engineering science from the older and more traditional trunks of science is the insistence that description – matching the mathematical model and its computational representation to the empirical observations – is not a sufficient level of understanding. Rather, the test of new knowledge is met by showing what new artifact can be designed and built in consequence of the correctness of the new hypothesis. This class will engage the prescriptive style of engineering science that holds synthesis to be the true arbiter of

understanding. Students will be expected to propose concrete improvements to some aspect of a physical artifact that plays a role in machine locomotion. They will be expected to defend the value of the proposed improvement and invited to try to devise experiments testing the hypothesis that the proposed improvements result in the desired benefits.

Finally, the course is focused on the very particular “*bioinspired*” mode of engineering science. This paradigm abandons the idea that engineering design can be completely rational (that is, driven by top down specification of behavior and implemented in a sequence of logically consequent steps guided by the available mathematical models). However, rather than retreating all the way back into the realm of pure intuition (wherein the design is *art* which pops miraculously into the creator’s head), bioinspiration seeks to find examples in the biological world of the desired synthetic behavior, to identify and extract the scientific principles that underlie it, and then to adopt those principles in the designing the engineered artifact. In this course students will be asked to engage as individuals and as group contributors the process of bioinspiration and will be expected to document in scientifically valid form the biological source of the design inspiration, the evidence that its underlying principles have been understood, and the efficacy of their application to the artifact of interest.

References

- [1] D. Kuhn, *Education for Thinking*. Harvard University Press, 2005.
- [2] W.G. Perry, *Forms of intellectual and ethical development in the college years*. Holt, Rinehart and Winston New York, 1970.
- [3] B.K. Hofer and P.R. Pintrich, "The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning," *Review of Educational Research*, vol. 67, pp. 88-140, 1997.
- [4] C.E. Nelson, "Skewered on the unicorn’s horn: The illusion of tragic tradeoff between content and critical thinking in the teaching of science," in *Enhancing Critical Thinking in the Sciences*, 1742 Connecticut Ave. NW, DC: Soc. College Science Teachers, National Science Teachers Assoc., 1989, pp. 17-27.
- [5] Joel Weingarten et al., "Robotics as the Delivery Vehicle: A contextualized, social, self paced, engineering education for life-long learners.," *Workshop on Research in Robots for Education*, 2007.