AI and Engineering Education
Report on the Asilomar Workshop

William J. Clancey

Institute for Research on Learning
66 Willow Place
Menlo Park, CA 94025

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A workshop on the topic of "AI and Engineering Education" was held December 13-15 at Asilomar (Monterey, California) under the sponsorship of the McDonnell Foundation. The workshop brought together people familiar with artificial intelligence (AI) and engineering problem solving, in order to provide advice about applications of AI to instruction in this area. In particular, we sought to identify high-quality research related to engineering education, visions for new opportunities in using computers for engineering education, and the key players who might have a major impact in this field. The workshop promoted a diversity of opinion; the meeting was a mixture of brainstorming and informing each other about relevant research.

The fifteen participants prepared short position papers, which were distributed before the meeting (see attachment "Participants"). In our initial session, we listed topics from these papers and organized them into an agenda for our day and a half of discussions (see attachment "Initial list of topics"). Topics range from engineers' views of important instructional problems to effective ways of using computers for engineering education. Although we recognized that engineering comprises different tasks, such as diagnosis and process control, most of our discussions focused on design because the group believed it presented the greatest difficulties and opportunities for improvement.

Our list of topics reveal a breadth of constraints affecting engineering, which can be viewed as different contexts or domains for understanding the practice of engineering (see attachment Figure 1, "Contexts of Engineering Practice"). These domains are: The individual, the team, affiliation, and society (including international considerations).

Most central is our understanding of how an individual engineer reasons about a given problem. For example, how do experiential knowledge and formal scientific laws relate? To what extent can introspection about the design process help students to be more efficient learners and designers?

A step further out (Figure 1) we place the individual in a team focusing on some application project. We include here the process by which engineering expertise is communicated, such as by computer networks or more directly by apprenticeship learning. We include "intelligent tutoring programs" as well as database systems that capture everything from design specifications to operations procedures. Perhaps most important, we are interested in how the *situations* in which people find themselves influence their reasoning and general behavior. For example, the way in which tools remind people about important associations and become a kind of "external memory" is central for understanding both the actual practice of design and how the designed artifact will be used. In this respect, a study of team interactions and engineering knowledge benefit from an anthropological and social perspective.

At the next level, we are concerned with the larger organization that contains the engineering team or the user of the designed system. An affiliation is often a company or university. Such an organization influences engineering practice by its reward structure, allocation of resources, and identity with respect to other affiliations and the society as a whole. For example, a good "corporate memory" of engineering methods can make practice more efficient, while a shield of proprietary secrecy may hinder communication between teams in different companies working together on a single project.

Finally, we consider the constraints imposed by the surrounding society and international setting. Social status, rapid scientific change, and sharp competition all have major impact on our perception of deficiencies in engineering education today. Indeed, as we proceed outward from team to affiliation to society, we find that constraints increasingly *drive the need for change.* The larger contexts imposed by other societies (e.g., international competition) and affiliations (e.g., scientific discoveries) both force and leverage changes in the practice of engineering teams and individuals. A number of workshop participants exemplified this by their interest in applying AI methods used in medical diagnosis to engineering design.

Through the discussions, it became apparent that a great deal of work is already underway in applying AI to engineering. "Expert Systems" have clearly provided a focus for the study and formalization of design knowledge in particular. Examples were given of design aids, analysis tutors, expert systems for site-planning, control, etc., and formal cognitive studies. The group was enthusiastic about early results, but was unanimous in the belief that the work has just begun.

Central to our concern was the importance of advancing a sense of community and seeking the largest possible audience for our tools and perspective. In this respect, we saw ourselves as a promoters of a new society with which project teams and individuals might identify, with the aim of encouraging them to try new tools and be creative in new ways. Many of the participants felt that the confluence of international pressures, rapid improvement of computational tools, and radically different understanding of the nature of knowledge and reasoning provided an unparalleled opportunity and need to take action.

We kept fairly detailed notes of our discussions and have annotated them to reflect individual points of view (see attachment "Discussion Notes"). It is beyond the scope of this report to provide proposals for specific research projects that could realize the promise we have described above. However, the individual interests of the participants suggest that the following are typical projects that might be proposed.

- Prototype formation of a national engineering "knowledge bank" for sharing design knowledge through computer networks.
- Systematic construction of expert systems for "redesign," seeking to integrate design and diagnosis knowledge.
- Reconceptualization of the existing structural analysis curriculum, with tutoring systems using apprenticeship methods to merge laws, analysis, and experiential knowledge in a project-oriented way.
- Study of extremely complex systems, such as in software engineering, to determine the limitations of current tools and practice, emphasizing cognitive strengths and weaknesses.
- Formalization of protocols for integrating interdisciplinary expertise and facilitating design team communication.
- Formalization of differences between "routine" and "creative" design, with systematic mapping to curriculum design.

These examples are illustrative of strong-impact, AI-based projects that we are ready to begin now. Dozens more could be listed if we polled the workshop participants.

Finally, in reflecting on our two days of discussion at Asilomar, many of us were struck by the high intensity of the group's interaction and the seamless integration of our interests. Engineering applications of AI offer the advantage, over medicine for example, that computers are commonplace in the engineering environment. Engineering students begin using computers in their first days of classes. Engineers have used computer-aided design (CAD) tools and databases for several decades. But beyond the technology, we find that engineers at design research centers--such as at

Stanford, Xerox-PARC, and CMU--have been engaged in introspective studies for several years. Perhaps because of their profession's long-standing interest in understanding and promoting creativity, these design centers are eager to participate in cognitive and social research.

Nevertheless, like all interdisciplinary research, the goals and potential of this new collaboration are not well understood.

- Researchers face continual difficulties in establishing career paths that straddle two and often three university departments.
- The necessarily blurred distinction between applications and research, as well as between practice and education, confuses government funding offices.
- Researchers across the country find themselves tediously bootstrapping the formalization of engineering knowledge, leading to redundant and unshareable results.

For these and related reasons, we concluded that a coherent research program should give primary emphasis to giving this new community a clear identity. We believe that the use of computers for communication through the various contexts of engineering practice offers the greatest potential. To this end, to establish a national network, we advocate special attention to the development of prototype tools and instructional aids, based on empirical work that seeks to reconceptualize the engineering process.

Initial List of Topics

1. Pace of rapid change.
2. Value engineering; assessment of designs, engineering economics.
3. Not enough teaching of process.
4. Not enough preparation for lifelong learning.
5. Teaching methods and material are out of date.
6. Problems in academic reward structures.
7. Low perception of engineers (social status)
8. Apprenticeship is needed but hard to deliver.
9. Engineers don't take charge of their own productivity and development process.
10. The problem is not engineering, the problem is management.
11. Faculty are not prepared for interdisciplinary approaches.
12. Imbalance between analysis and synthesis; too much analysis and too little synthesis.
13. Too little team activity and too much individual projects.
14. Problems are not realistic or complex enough.
15. Increasing international needs that U.S. engineers are not trained for.
16. Not enough evaluation and introspection.
17. Curriculum overload.
18. Students don't learn enough about their discipline.
19. Engineering education too narrowly technical.
20. Absence of foundation for education.
21. Interdisciplinary techniques are not taught.
22. Mechanisms are needed for rapid propagation of ideas concerning education. (Numbered "22A" in notes)

23. More studies are needed to clarify distinction between analysis and synthesis. (Numbered "22B" in notes)

24. Not enough preparation for lifelong learning. (Numbered "23" in notes)

25. Need to transfer AI techniques to engineering community.

26. Corporate memory is short (people move around).

27. Need to evaluate purpose of courses (some are useless or repetitive).

28. Proprietary methods/products interfere with joint projects.

29. Not enough training in the medium of the field.

30. Not enough U.S. students are going to graduate school in engineering.

Workshop Attendees

John Bruer, McDonnell Foundation

Hal Abelson, MIT (Computer Science)

Alice Agogino, Berkeley (Mechanical Engineering)

Christina Allen, CMU (Computer Science)

Phil Barkan, Stanford (Mechanical Engineering)

John Seely Brown, Xerox-PARC

William Butcher, NSF

William J. Clancey, Stanford University (Computer Science)
and Institute for Research on Learning

Lynn Conway, Michigan

Clive L. Dym, University of Massachussetts (Civil Engineering)

Larry Leifer, Stanford (Mechanical Engineering)

Ray Levitt, Stanford (Civil Engineering)

John Slater, MIT (Civil Engineering)

Elliot Soloway, Yale (Computer Science)

Mark Stefik, Xerox-PARC

Marty Tenenbaum, Schlumberger Palo Alto Research Center

William J. Clancey
Workshop Organizer

Senior Research Associate
Department of Computer Science
Stanford University

and

Senior Research Scientist
Institute for Research on Learning

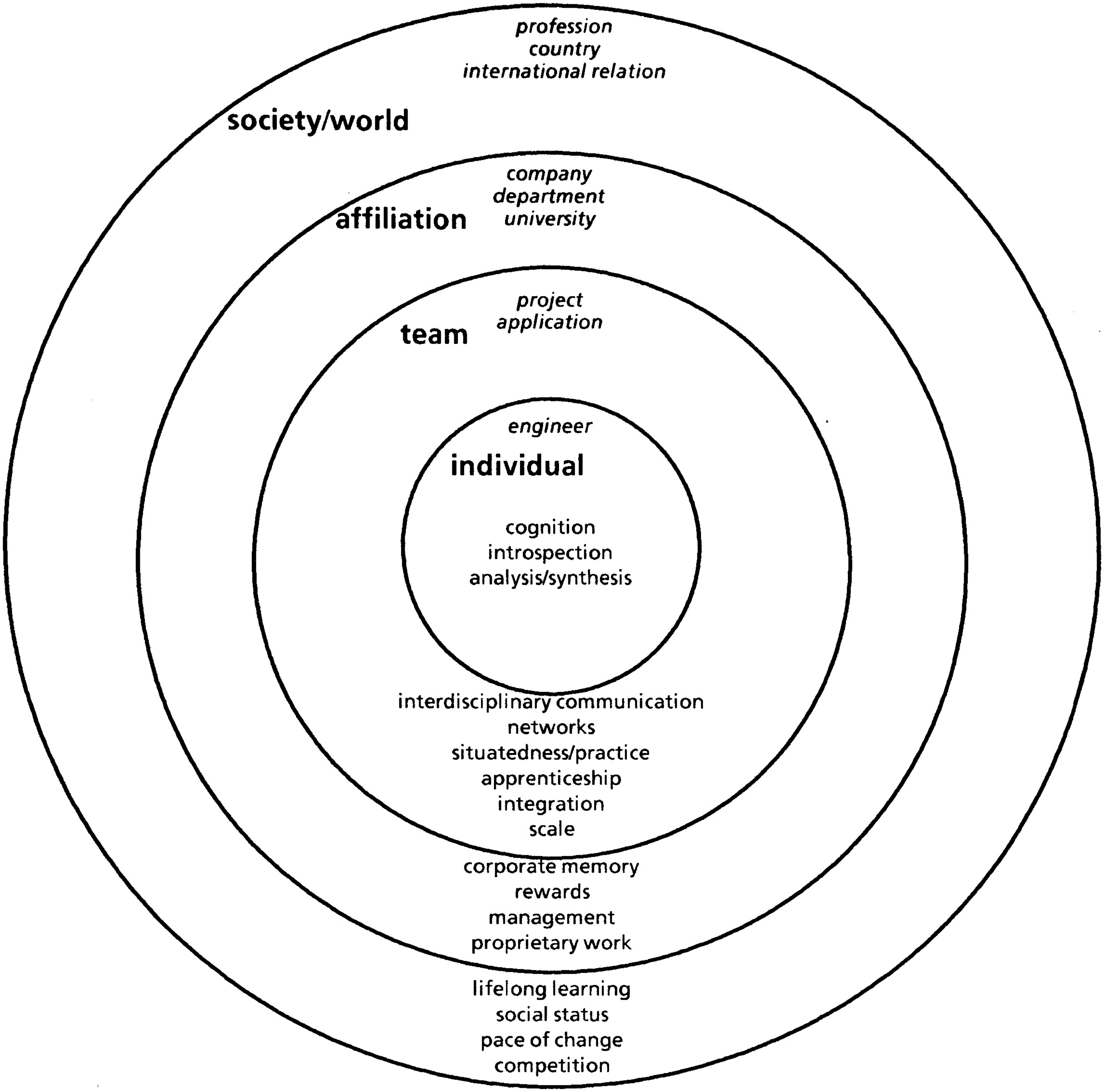

Figure 1

The Contexts of Engineering Practice