Artificial Intelligence for Engineering Design, Analysis and Manufacturing (2007), *21*, 13–14. Printed in the USA.

DOI: 10.1017/S0890060407070060

REFLECTIONS

A look at the emerging science of innovation

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Over the past 20 years I have focused on the synthesis process, the process of creation, of bringing together ideas and objects to fulfill and enable needs. Synthesis is a core engineering activity, the partner in the design and analysis cycle of engineering (and other) design. Synthesis is the basis of innovation, the enabler of creating that which is new. Over the past 20 years, research and practice in the area of synthesis and innovation has become more intricate, more complex, and more complete in its breadth of exploration and depth of understanding and delivery. Research in the area that was started over the past 10 to 20 years is now being commercialized, beginning to impact the way design is practiced. The state of the art of algorithms, theories, and processes for the computing basis of synthesis research today can be found in *Formal Engineering Design Synthesis* (Antonsson & Cagan, 2001). This discussion is not a review of the literature or state of the art, but rather my views of the field of innovation, its emergence into a scientific study, areas of focus for future research, and some of my experiences in each of these areas.

Innovation has become a hot topic, but one of substance, not a passing fad. Global competition of today has highlighted that cost-cutting efficiencies and quality improvements focused on in the 1980s and 1990s have peaked, putting pressure on businesses to find new avenues to grow revenue.

The scientific basis of innovation is emerging. In May of 2006 the National Science Foundation organized a workshop entitled *The Science of Individual and Team Innovation and Discovery*. Bringing together key engineers, cognitive psychologists, and social psychologists to present initial findings in this area of research, the group laid out directions of research that, over the next 10 to 20 years, will bring progress to articulating the mechanisms of innovative design (Schunn et al., 2006). The workshop highlighted that engineering innovation often occurs in teams, but within the teams through the creative input of individuals. Understanding the cognitive mechanisms of how the individual is able to design, and how the interrelationships between the minds of individuals function effectively in a team, provides fodder for new tools and methods of innovation.

I see four areas of investigation to reach this understanding. The first is the area of cognition. We must better understand how the human mind is able to be so creative. What are the mechanisms that occur in the brain that allow people to reach that "aha," that point where all of a sudden an insight leads one down a path toward a new solution? What is the structure and process that allows for insight, analogy, and learning, and how does that enable design? This research cannot happen intradiscipline; it must be interdiscipline, in a collaborative relationship between engineering and cognitive psychologists.

The next area, social organization, is based on a deeper understanding of the structure, organization and effectiveness of teams. Organizational behavior studies the way that teams function, from their mechanics to their social context to the personality of the individuals and their affinity for the others. I am part of a team of faculty that teaches a course in Integrated Product Development where, in a semester, students learn to overcome the prejudices and routines of the individual to evolve into a high performing team that produces patentable (and often patented) products based on an open-ended problem area. The course is a living laboratory to study teams from a multidiscipline perspective (teams of engineers, industrial designers, and marketers). It is one of many approaches to study design teams. Models of how teams best perform in different contexts, and how the cognition of the individual contributes to the effectiveness of the group remains a rich area of interdisciplinary research.

The impact of society on the innovation process and outcome is another critical area of study. Engineers, trained in the rigor of math and physics where analytical models produce repeatable outcomes, have difficulty accounting for the dynamic, distant ramifications of political and cultural change. Yet, societal expectations and desires influence the

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success of products, services and systems. Understanding the "product requirements" from a user point of view requires methods initially developed by anthropologists, another forum for collaborative research. Ethnographic methods and other approaches to observation, interview, and behavioral modeling provide tools to understand the emergence of new categories of products and services. Research into new and formal methods for understanding societal influence on the innovation process remains a rich area for advancing the state of design practice.

The final area of focus in research on the process of innovation, and one that ties together the previous three areas of cognition, social and society, is computation. Of course, this is the area that might more immediately be of interest to readers of *AI EDAM*. The role of computation in the process of innovation is multifold. Better computer tools to assist innovation will enable better efficiencies and effectiveness in its practice. There are some formal findings that best reduce to practice through computation and research results from the community are being transferred to the commercial sector today.

However, computational forums also provide a rich research environment to study and advance our understanding of the processes of innovation. Translating cognitive findings into models of design that can be studied through statistical exploration enables better insight into the cognitive findings themselves and how they might influence the design process. My early work with Ken Kotovsky (Cagan & Kotovsky, 1997) used a simulated annealing algorithm that dynamically updated its objective function to simulate findings from cognitive studies of people solving tavern problems such as the Tower of Hanoi. This (indirectly) led Campbell et al. (1999) to investigate the use of cognitively motivated agents to synthesize electromechanical devices. Computation also enables new research into team behavior and, eventually, improvement in team-based processes. After implementing an extensive algorithm to computationally design spacecraft concepts, Olson et al. (2006) recently completed a simulation of Jet Propulsion Laboratory's Team X conceptual design environment, resulting in a research platform to study variations in how a team is structured, with the goal of improving its performance. Although many findings from research in innovation will directly impact design practice, the computational work will continue to lend new, repeatable insights into the field, and, hopefully, new commercially available tools to help the practitioner with the synthesis process of engineering design.

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