Chapter 5

Evolving from Single Disciplines to Renaissance Teams

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5.1 Origins and Motivation

In 1989, Carnegie Mellon University's National Science Foundation (NSF) Engineering Design Research Center (EDRC) brought in-house a stereolithography apparatus (SLA), providing three-dimensional additive manufacturing capability. As an experiment in collaborative multidisciplinary design, we created an SLA housing for a small single board computer that had been automatically generated by an electronic computer-aided design system (ECAD) that synthesizes computer systems from specifications (Gupta et al. 1993). The housing was designed by an electrical engineer (EE) and most resembled a Howe Truss bridge—the mechanical design taught to EE students at the time. In addition, the only way to reach the computer reset button was by thrusting a finger through the cooling fan blade. Thus was motivated the formation of our first multidisciplinary team composed of a software, electrical, and mechanical engineers, and a designer from fine arts to design and build our first wearable computer in 1991. VuMan 1 (Siewiorek and Smailagic 1993) had a shoulder strap supporting a housing with a raised hand rest allowing easy access to buttons for control. The hand rest also served as a chimney for convection cooling from the largest heat producing electronic chips that were clustered under the hand rest.

In the same time frame, Randy Pausch, co-founder of the Entertainment Technology Center (ETC) taught a course on Building Virtual Worlds (BVW) that engaged students from computer science, engineering, social science, fine arts, and design. Five student multidisciplinary design teams were formed that researched themes, wrote scripts, created choreographies, generated graphics, and animated a unique virtual world in only 2 weeks. Then the team membership was scrambled

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and another virtual world was created. The 2-week process was repeated five times in a 15-week semester. No one person could be proficient in the wide diversity of skills required to build a compelling virtual world.

Randy liked to point out to his students that they possessed more science and mathematical knowledge than Leonardo Da Vinci—the model Renaissance Man. But science and technology have advanced so much that no one person could possess all the knowledge to build contemporary systems. Thus students needed to become members of a Renaissance Team learning the vocabulary and appreciating the skills of other disciplines.

5.2 A Multidisciplinary Design Course

From this experience, we developed and employed a User-Centered Interdisciplinary Concurrent System Design Methodology (UICSM) that takes teams of electrical engineers, mechanical engineers, computer scientists, industrial designers, and human–computer interaction students working with an end user to generate a completely functional prototype system during a 4-month long course. Over 25 years of use, the last 20 years in a formal class setting, the methodology has proven robust in creating an increasingly capable applications leveraging state of the art components.

UICSM is web-supported and defines intermediary products that document the evolution of the design. These products are posted on the web so that even remote designers and end users can participate in the design activities. The design methodology proceeds through three phases: conceptual design, detailed design, and implementation. End users critique the design at each phase. Our experience has been that end users often cannot articulate what they want but they are able to critique concepts. By iteratively designing we can elicit functional requirements. Prior to each phase, students are given examples of the work products for that phase. Working in their subgroups they develop their work products and share them during class periods.

During the first phase—Conceptual Design—students work in discipline-specific teams. The Human Computer Interaction and social science students work with the end users to define baseline personas and “day in the life of” activities. Visionary scenarios are also created to explore how technology could improve current practice. The group develops functional requirements and an interaction architecture. In parallel, the technology students research available technologies: sensors, hardware platforms, and software development environments culminating in hardware and software architectures. During the second phase—Detailed Design—functional subsystems are identified and multidisciplinary teams are assigned to design and implement each subsystem. Each team is responsible for ordering components and designing their subsystem to integrate with all the other subsystems. During the final phase—Implementation—the subsystems are finished and integrated into a complete single system.

Figure 5.1 is an example of how the disciplines interact to achieve constraints on user attention, user interaction, manipulation, corporal, and power when designing a portable electronic system. The major design parameters are the functionality, user interface, physical form factor, and power. Electronic and software designers create the functionality taking into account of the division of **Attention** between the physical and virtual world. Software and Industrial designers define the **User** experience. Industrial Design and Mechanical Engineering define the **Manipulation** (e.g., controls quick to find and easy to operate) and **Corporal** (e.g., interface physically without discomfort or distraction) experiences. Electronics (heat generated) and Mechanical Engineering (dissipation of heat) interact on **Power**.

The methodology has been used in designing over three dozen computer systems, with diverse applications including inspection and maintenance of heavy transportation vehicles; augmented reality in manufacturing and plant operations; car/driver interaction; bridge inspection; aircraft sheet metal inspection; offshore oil platform crane operation; and welding nuclear submarine hulls (Siewiorek et al. 1994; Smailagic and Siewiorek 1999; Smailagic and Siewiorek 2002a, b; Siewiorek et al. 2001).

Communications between groups are essential for UICSM to be successful. Kiva combines aspects of both email and bulletin boards to keep threaded discussion intact. Visualization tools allow tracking of group progress and signal areas for instructor attention. We have created analytical methods based on Communication networks to study the content of the communication Isolated groups can be easily identified.

Fig. 5.1 Relationships between disciplines

Fig. 5.2 New noun phrases introduced through three phases of design

For example noun phrases for analyzing how the design vocabulary of student teams expands and contracts during a design project. The expansion and contraction reflect the students brainstorming about different design alternatives for the project and finalizing certain design solutions, respectively. Figure 5.2 depicts the new noun phrases introduced through the phases of UICSM: conceptual design, detailed design, and implementation and integration. Reduction in the number of new noun phrases indicates a convergence in the phase and that the students have established a common vocabulary and vision of the design.

5.3 Lessons Learned

The User-Centered Interdisciplinary Concurrent System Design Methodology (UICSM) is used in a capstone engineering design course with 25–35 students representing 5000–7000 engineering hours for each system.

- The challenge for all the systems was designing an information flow that could utilize then current wireless capability and fit into the existing workflow.
- Several of the systems continued evolution beyond the course: in system maintenance a spin-off company developed Interactive Electronic Technical Manuals acquired by Boeing; formed the specifications for an all-new electric drive boat; formed the concepts for an all-new maintenance approach for Digital Equipment Corporation; and created the framework for tools and analysis supporting UICSM courses.
- Students apply their disciplinary skills in appropriate portions of the design process learning from each other.
- Students often ask what our expectations are for the system. Our response is that we do not want to bound their creativity. We give them example functions to stimulate “out of the box” thinking. The resulting systems always exceed our expectations.
- All the systems led to successful demonstrations through risk management and functional redefinition. We typically achieve about 80% of the visionary

scenario. While the students may feel disappointed, we point out that their system is a major advance over the baseline scenario as reflected by the enthusiastic acceptance by the clients.

- Several of the designs won international design competitions. One of the judging juries stated the design looked good enough to actually work, missing the point that the system was designed to fulfill a real-world application and had been implemented and deployed.
- Perhaps the greatest testimony to the success of the course is that undergraduate engineering students are filling out Institutional Review Board (IRB) protocols realizing that their designs need to be evaluated in the context of human use.

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