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Transformative Initiatives: How iFoundry Reimagines STEM Education for the 21st Century

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THE FOUNDATIONAL BEGINNINGS OF IFOUNDRY

The origins of iFoundry can be traced back to "The Engineer of 2020 Project," which forecast the needs of civilization, as well as the education, training, and perspective necessary for the next generation of engineers to succeed. The first phase of the project, *The Engineer of 2020: Visions of Engineering in the New Century,* published by the National Academy of Engineering (NAE), set forth "a vision for engineering" and the scope of work to be done (2004, p. xi). The second phase, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century,* examined how "to enrich the education of engineers who will practice in 2020" (2005, p. xii).

As the project noted, the frontiers of science are on the cusp of life-altering advances in "nanotechnology, logistics, biotechnology, and high-performance computing" (*The Engineer of 2020*, 2004, p. 1). Meanwhile, technological advancements in developing nations present both opportunities and challenges.

These circumstances warrant initiatives to fostering transformative innovation. Here in the College of Engineering at the University of Illinois, we seek to address these issues in an effort to anticipate the educational needs of the next generation of technological leaders to invent "the new new thing" (Lewis, 1999).

iFoundry was born in the summer of 2007. It was co-founded by Andreas Cangellaris and David Goldberg, faculty in the College of Engineering.[1] It was conceived as a "cross-disciplinary curriculum incubator" ("Who We Are", n.d.). Initially called the Illinois Foundry for Tech Vision and Leadership, it was soon renamed the Illinois Foundry for Innovation in Engineering Education with the notable tagline "Transforming Engineering Education for the 21st Century" (iFoundry website, 2012).

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1. Cangellaris was promoted to department head of the Electrical and Computer Engineering Department at the University of Illinois in 2008 before becoming dean of the College of Engineering in 2013. Goldberg is the Jerry S. Dobrovolny Professor Emeritus in Entrepreneurial Engineering.

Because of concerns that traditional engineering and associated computer science curricula that dated back to the cold war might be ill-equipped for the "radical changes in transportation, communication, and computer technology" that rendered today's society "a very different world", Cangellaris and Goldberg wrote a white paper ("Whitepaper for an Illinois Foundry for Tech Vision and Leadership", 2007). Their report highlighted some of the driving influences prompting the creation of iFoundry: enhancing engineering diversity, emphasizing excellence and analytical insight, strengthening the curriculum to nurture creativity while promoting professionalism and leadership acumen critical for success in the "civic arena"—what in an earlier era C. P. Snow would have referred to as the "corridors of power" (Snow, 1964).

> If the United States is to continue its leadership in technological innovation and the creation, regulation and management of new technologies and new markets, its engineering force needs to be rejuvenated by a more diverse talent pool, where excellence in scientific education and analytical skills is complemented by a broader curriculum that inspires creativity and innovation and includes training in the professionalism and leadership traits needed for successful participation in the civic arena. ("Whitepaper", 2007)

What capabilities does *The Engineer of 2020* suggest that engineers should possess? They should not be circumscribed by disciplinary boundaries. Engineers should embrace "creativity, invention, and cross-disciplinary fertilization to create and accommodate new fields of endeavor" including the "nonengineering disciplines" (2004, p. 50). They should be responsive to global trends. Their education should equip them with the skills and know-how "to address the technology and societal challenges and opportunities of the future" (2004, p. 51). The engineering curriculum needs to be responsive "to the disparate learning styles" characteristic of our increasingly diverse student populations (2004, p. 52).

The training and attributes of engineers will determine their success. If they aspire to leadership and management positions, they need analytical capabilities, as well as ingenuity and creativity. They must communicate and possess business and management acumen (*The Engineer of 2020*, 2004). Their education should include "interdisciplinary learning" and "case studies of engineering successes and failures" (*Educating the Engineer of 2020*, 2005 pp. 2–3).

iFoundry was conceived as a pilot program, an educational enrichment environment where new courses and programs could be tested and evaluated before introducing them into departments within the College of Engineering.

Modeling its mandate from "The Engineer of 2020 Project", iFoundry fosters courses and programs that nurture "a variety of cross-cutting skills and disciplines: communications; leadership; teamwork; arts & design cross-fertilization; better utilization of humanities and social science hours; more general understanding of the societal and human contexts of engineering and technology" ("Whitepaper", 2007).

PROGRAMS IMPLEMENTED BY IFOUNDRY

iFoundry began its spiritual awakening at the "Workshop on the Engineer of the Future" held at the University of Illinois in September of 2007 (Goldberg, Cangellaris, Loui, Price, Litchfield, 2008b). Keynote speakers were William Wulf, retiring president of the NAE, and Sherra Kerns, founding vice president for innovation and research at Franklin W. Olin College of Engineering (Goldberg, Cangellaris, Loui, Price, & Litchfield, 2008a).

During the 2007–2008 academic year, a team of faculty and students at iFoundry reviewed the undergraduate programs and courses internally in the College of Engineering and with respect to other programs offered throughout the country. The first incubator course, ENG 498, was introduced in Spring 2008. Its objective was investigating innovation initiatives in America's engineering programs ("History of iFoundry", n.d.).

iFoundry was formally integrated into the undergraduate program of the College of Engineering in August that year. The following month iFoundry formed a partnership with the Olin College. This led three years later to a formal Olin-Illinois Exchange program where students can spend up to two semesters in residence. The program enables Illinois engineering undergraduates to development entrepreneurial design concepts at Olin in "a practical engineering environment where students attempt to solve real engineering problems" in an entrepreneurial setting with approximately 400 like-minded students (Lamb, n.d.).

In the fall of 2009, 75 entering students in the College of Engineering joined iFoundry. They participated in iLaunch, a pilot program to familiarize them with the opportunities available and jumpstart their first-year experience. iLaunch, held at a university retreat center known as Allerton Park, encouraged students to take the initiative. They connected, worked on projects, and took David Goldberg's workshop ENG 198, "The Missing Basics: What Engineers Don't Learn & Why They Need to Learn It" (Goldberg video, 2008). The workshop fostered the "critical and creative thinking skills of engineering" with the express purpose of creating "a whole new engineer" (Goldberg and Somerville, 2014, p. 52).

"The Missing Basics" exposed students to critical thinking and creative solutions. They learned the seven essentials to every successfully executed project: (1) Ask the right questions, (2) Label and categorize, (3) Model the problem, (4) Break down a project to its manageable parts, (5) Collect data and analyze it, (6) Visualize solutions, and (7) Communicate outcomes (Goldberg video, 2008).

iLaunch was a success. It was subsequently renamed the Illinois Engineering First-Year Experience (IEFX). The following year 300 iFoundry students participated. By 2011 the pilot program was rolled out to all 1,500 entering first-year students in the College of Engineering ("Introduction to: iFoundry and IEFX", 2013).

Today, IEFX is administrated through the College of Engineering Undergraduate Programs Office. Corporate involvement with entering students is nurtured through the IEFX NETWORK. Freshmen are offered one-credit "mini" elective courses to showcase their opportunities. IEFX collaborates with the NAE to feature "Grand Challenges" to encourage students to collaborate and design instructional approaches to solving important global issues ("IEFX electives", n.d.).

The iFoundry offerings continued. In 2009, Olin College and the University of Illinois jointly sponsored a conference, "The Engineer of the Future 2.0". Woodie Flowers, an MIT professor, gave the keynote address. He discussed student research suggesting that recent graduates in mechanical engineering at MIT felt that "soft skills" were more critical to their professional development than many of their required courses. This confirmed the findings of a recent NAE report in which soft skills were characterized as "teamwork, leadership, creativity and design, entrepreneurial thinking, ethical reasoning, and global contextual awareness" (Miller, 2010).

That conference was followed in November of 2010 with "The Engineer of the Future 3.0" held at the University of Illinois. Daniel H. Pink, the celebrated management and motivational expert, was the keynote speaker ("iFoundry Encourages Creativity in Education", 2010). Some 300 students, faculty, and educators attended the meeting, which emphasized the creative potential of "student-centered learning" ("History of iFoundry", n.d.).

Three years later "The Engineer of the Future 4.0" Conference was held. The focus was "Community and how it matters in engineering education". In each of the four conferences the focus was "to probe radical new ways to transform the student experience in engineering education" ("Engineer of the Future 4.0 Conference", n.d.).

By Fall 2011, iFoundry was empowered. IEFX had been introduced to all first-year students in the College of Engineering. Several new courses were rolled out including "Aspirations to Leadership" and "Interdisciplinary Senior

Design." The following year Intrinsic Motivation (IM) Course Conversion was unveiled, which fosters student self-taught mastery of selective courses in the core curriculum.

In November of 2013, an Innovation Certificate was initiated in conjunction with the iFoundry Technology Entrepreneur Center (TEC). The admission process for this program is partially based on a creative essay and an interview. Enrollment is limited to 25 students who apply during their first year in what amounts to a three-year program with potentially 75 students in all. The focus: "entrepreneurship, innovative product design, and transformative technical products and services" in order to create "breakthrough new products" ("Innovation Certificate", n.d.). Specially designed courses—12 credits in all—are featured, as well as coaching and support. Students learn how to understand customer problems, create solutions, meet timetables for deliverables, and work in real-world situations with entrepreneurially-driven companies.

In the Campus Honors Program, which accepts less than one percent of all undergraduates, engineers account for approximately one third of its students. In addition, the College of Engineering offers other qualified students an opportunity to enroll in the James Scholar Honors Program. iFoundry introduced the James Scholar Quest in 2013. It customizes the James Scholar Honors program to specific engineering departments ("James Scholar Quest", n.d.).

At some point the list of associated programs and opportunities in iFoundry become almost too numerous to mention. Nevertheless, CUBE Consulting, a Junior Enterprise organization, merits attention. It is a student-initiated engineering consulting group pioneered in 2013. It offers engineering and business undergraduates the opportunity to work on project teams for businesses, including startups, nonprofits, and research organizations.

It is these kinds of programs and initiatives within iFoundry that offer the students within the College of Engineering the possibility to obtain not only one of the best technical educations imaginable, but also to maximize personal opportunities for enrichment.

"HEROIC SYSTEMS" BLOCKBUSTER COURSE CREATED BY IFOUNDRY

In many respects, the Blockbuster Course[2] (Notes: 2) "Heroic Systems: Pushing the Boundaries of Greatness, Past, Present and Future" (ENG 298), introduced in Fall 2014, encapsulates the mission of iFoundry. It is a cross-disciplinary

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2. The concept of Blockbuster courses is "multidimensional", a general education class approaching a theme from several disciplines including the "humanities, social science, and science to address real-world problems" (http://cee.illinois.edu/node/2967).

offering taught by faculty in the College of Engineering, the humanities, and business. The opening lecture, with its overarching perspective, is given by Andreas Cangellaris, dean of the College of Engineering.

"Heroic Systems" represents a new type of undergraduate course, one that consciously reinvents STEM education as a transformative initiative for the 21st century. Its purpose is to reimagine the engineering experience so that our graduates become the movers and shakers of strategic global policy, the very essence of "a whole new engineer", rather than narrow technical experts typically relegated to the backroom.

The faculty consisted of a culturally diverse group of scientists and humanists. They discussed a variety of "heroic systems" from Roman antiquity to the creation of the Midwest, to the rejection of a craft society in favor of an engineered outcome. The course examined the telecommunications, the electric grid, the space program, business analytics and its intersection with sports, and current developments in bioengineering and biomedicine, as well as the possibilities for heroic systems in developing marketplaces. The outcome: Students were exposed to big ideas, strategic thinkers, and creative intersections linking the science and the humanities. Recent results of a survey questionnaire indicate the course's strategic value ("ENG 298 Heroic Systems Survey Results", 2015).

THE IFOUNDRY TEAM: THE FINANCIAL AND ADMINISTRATE CHALLENGES TO IMPLEMENTING THE PROGRAM, PAST, PRESENT, AND FUTURE

The iFoundry team is small and dynamic. The dean of the College of Engineering, Andreas Cangellaris, remains involved, as does David Goldberg. Ray Price, who along with Goldberg serves as co-director, keeps a watchful eye on iFoundry's operations. Price, who works on creativity and innovation, collaborated with Abbie Griffin and Bruce Vojak in a study on how "tech visionaries" sustain their innovation in mature firms (*Serial Innovators,* 2012). Goldberg's book, *A Whole New Engineer,* examines the creative impetus at iFoundry and Olin (2014).

Karen Hyman serves as associate director. Bruce Litchfield, an assistant dean in the College of Engineering, is an iFoundry Fellow, as are approximately twenty other academics who participate. Geoffrey Herman, a visiting assistant professor, is engaged in programs related to engineering curriculum reform including the Intrinsic Motivation Course Conversion.

The administrative mandate for iFoundry is simple. Keep costs minimal. iFoundry funding is about $250,000 annually. It has been maintained through

the College of Engineering with support from corporations and foundations. Some of these generous sponsors have included the following: Advanced Micro Devices (AMD), Autodesk, The Boeing Company, Hewlett-Packard Company (HP), International Business Machines Corporation (IBM), National Collegiate Inventors and Innovators Alliance (NCIIA), Procter and Gamble Company (P&G), Shell Oil Company, and the Severns Family Foundation (R. Price, personal communication, February 10, 2015).

Administrative appointments have been mostly part-time, as in the case of David Goldberg and Karen Hyman. Ray Price's position is largely supported through his academic appointment as the William H. Severns Chair of Human Behavior. One full-time administrative staff position was created in 2009. iFoundry Fellows are selected based on their expertise, interest, and support for the iFoundry mission. Their compensation is minimal (R. Price, personal communication, February 10, 2015).

Much of the financial support for the programs developed within iFoundry is borne by the academic units, whether TEC or specific departments, or even by the College of Engineering, where these innovative courses, when successful, become embedded into a reinvigorated curriculum.

Thus, in the case of the Innovation Certificate, iFoundry coordinates efforts with TEC, which sponsors most entrepreneurial courses in the college. One creative outcome is that engineering students not enrolled in the Innovation Certificate program can, nevertheless, take many of these course offerings and pursue entrepreneurial opportunities independently through TEC.

The same principle applies to the educational opportunities at Olin. Students from the College of Engineering at the University of Illinois can study for one or two semesters there and have the opportunity of working closely with Olin's faculty and students in an interdisciplinary "hands-on" environment where student ideas are formalized into conceptual designs for potential implementation into the marketplace. These exchange opportunities are reciprocal, allowing Olin students to participate in programs offered by the College of Engineering at the University of Illinois.

The benefit for students in our College of Engineering at the University of Illinois is that they obtain "the Olin effect" without the university having to "change the whole curriculum" or "build new buildings" or "remake the classrooms" or "overhaul the teaching or teachers" ("Introduction to: iFoundry and IEFX", 2013). Thus, academic excellence is maintained while students have the opportunity and entrepreneurial freedom to participate in Olin College's pathbreaking design and development environment.

The largest cost associated with the iFoundry initiatives thus far was the development of IEFX. The first year 75 students participated and the budget was

$120,000. When 300 students participated, $275,000 was allocated. When IEFX had 1,500 students participating, the budget was $500,000. Since 2012 IEFX has been incorporated into the College of Engineering where the costs are directly born by the college (R. Price, personal communication, February 10, 2015).

What has made the iFoundry experience work is its pilot stature as a curriculum incubator. It is small and nimble. It can be responsive to student interests and needs. Their voices can be heard and acted upon. Programs and courses and be tried without great expense or protracted discussion about the long-term implications for the curriculum. If successful, they can become part of the curriculum. iFoundry provides an intimate environment where individual student needs can be addressed. The experimental and innovative nature of the iFoundry incubator nurtures the development of "a whole new engineer", one uniquely equipped with the skills and outlook to address the "grand challenges" of the 21st century.

CONCLUSION: THE IMPACT OF IFOUNDRY

What makes the iFoundry experience so transformative? Upon arrival to the College of Engineering, students are immersed into IEFX. Along the way they weigh the entrepreneurial potential of the iFoundry Innovation Certificate or the entrepreneurial TEC programs or the Olin experience. They pursue internships, personalized courses of study, consulting opportunities, and work with faculty advisors on research or design projects. They consider overseas opportunities. They take courses recommended or developed, as in the case of "Heroic Systems", through iFoundry. All told, the sum of these experiences—some with the college, some with the departments, some with TEC, and some specifically created in the iFoundry incubator—is transformative. The outcome dramatically reshapes the perception students have of what it means to be an engineer in the 21st century and empowers them to invent the future.

Consult the iFoundry website for more information, (http://ifoundry.illinois.edu/).

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