Proceedings of the Design Society, Volume 5: ICED25
https://doi.org/10.1017/pds.2025.10321

The pioneering role of Stanford DesignX and legacy of Larry Leifer on the field of engineering design

Tamara Carleton [1,✉], **William R. Cockayne** [1] **and John Feland** [2]

[1] *Blekinge Institute of Technology, Sweden,* [2] *CableLabs, USA*

✉ tamara.carleton@bth.se

ABSTRACT: This retrospective paper explores the profound impact of DesignX at the Stanford Center for Design Research (CDR) on engineering design research and education. Through a historical lens, the authors examine the evolution of the DesignX laboratory and its role in fostering interdisciplinary collaboration, innovative research, and team-based research by highlighting key milestones and influential projects over time. The authors also discuss the pioneering role of Stanford Professor Larry Leifer, whose leadership of CDR for much of its history shaped the practices and methodologies of engineering design from the 1980s up through the 2020s. This paper underscores the significance of Leifer's contributions to the academic community and the enduring legacy of DesignX in advancing the field of engineering design research and education.

KEYWORDS: design engineering, design education, design history, case study, multi- / cross- / trans-disciplinary processes

1. Introduction

This paper describes the pioneering influence of DesignX, a laboratory and research forum at the Center for Design Research (CDR) at Stanford University, on the field of engineering design. Directed by Stanford Professor Larry Leifer for much of its recent history, CDR marked its 40-year anniversary in 2024. DesignX is a formative part of CDR's identity and research foundation, where DesignX researchers have studied how engineering design teams create, collaborate, and communicate. In its early years, CDR researchers adapted research methods from the social sciences, even pursuing behavioural interventions, to study engineers and engineering design practices before the use of these methods became commonplace in engineering research. Moreover, CDR has an extra connection to the International Conference on Engineering Design (ICED), hosting the 17th ICED conference in 2009.
Like any research organization, much of CDR's energy and evolution at any given time was based on the researchers involved then. This truth is the strength and limitation of this paper. While we as authors aim to present a synthesized and factual retrospective of CDR, focusing on the evolution of DesignX and Leifer's contributions, we obviously bring our own biases to this narrative. We share these biases with our readers to be transparent and further to reveal Leifer's intellectual courage in embracing ambiguity—particularly seeing the shape of a sculpture before the rough stone is carved.
Each of us came to CDR midcareer to pursue a doctorate. Cockayne studied as a mechanical engineer, then moved to industry. After several years at Apple Computer and from working on pioneering virtual reality projects, Cockayne had become an unknowing fan of CDR's early invention work. He then met Leifer and his family informally at a local swimming pool, and this poolside chat led to Cockayne joining CDR as a doctoral student. After completing his bachelor's degree at MIT, Feland went to Stanford for his master's degree, becoming Leifer's teaching assistant for the ME210 course. After stints as a product designer at IDEO and an officer in the US Air Force, Feland joined CDR's doctoral program. Carleton left the world of management consulting to explore questions being raised in her practice area of organizational innovation, which sparked Leifer's curiosity and an invitation to add her knowledge of

communication theories to CDR's practice. All three of us have embraced the CDR mantra, further contributing to the trailblazing work that Leifer had started.

Our roundabout and serendipitous road to CDR is very appropriate to the spirit of Leifer. He celebrates taking the road less travelled. In his talks, he delights in showing a visual metaphor of hunting as a messy path from start to target. In practice, hunters rarely take the direct path to what they seek and instead must purposefully wander as they track cues and sense the environment. In Leifer's view, researchers should similarly recognize that a direct path is unrealistic and instead be responsive and open to meandering toward the desired goal, which includes multiple cycles of prototyping and learning (Steinert & Leifer, 2012). Moreover, Leifer firmly believed that you should "*never go hunting alone*" because teams have the advantage over individuals by combining their diverse skills and experiences, especially when pursuing the big game. We have taken this advice to heart, including adopting a team-based approach to this book chapter.

2. Premise of DesignX

Leifer founded CDR in 1984, inviting new professors Mark Cutkosky in 1985 and Sheri Sheppard in 1986 to join as co-directors. Leifer soon established DesignX as a laboratory and research forum for his growing circle of students and visiting scholars at CDR. Before he had taken up the hunting metaphor, he was already embodying the belief to explore. The X in the DesignX name refers to any possible or new independent variables related to engineering design—such as *design in manufacturing* or *design in teams*—as well as the cross-disciplinary aspect of many questions raised within the community. The DesignX name was also partly inspired by other discussions surfacing in academia at the time, though like often, DesignX quietly led the way. In subsequent years, several other groups at Stanford added X to their names in similar fashion. For example, Stanford Bio-X was formed in 1998 as an interdisciplinary biosciences institute, and mediaX was an industry affiliate program of Stanford's H-STAR Institute from 2006 to 2022, studying the mix of media, technology, and the human experience.

DesignX meetings were typically held weekly during the academic year to share research updates and spotlight any interesting work underway. Leifer brought his belief in wandering to DesignX, so as individual research questions moved and became more clarified, the meeting topics evolved. Over the years, DesignX discussions have spanned a broad range of topics in design engineering, including understanding existing practice, testing emerging technologies used by design engineers, and charting the course of design education and project-based learning. (Feland once led the logo design of DesignX with several researchers, making it orange because someone insisted that was the color of high design!) At CDR, DesignX created a safe space for researchers to study how teams of engineers design new products and solutions, often by adapting tools and lenses more common to social science disciplines. Within the broader academic department, Stanford's Design Division had earlier broken with the status quo when it placed engineering design teaching on the same level as engineering analysis. CDR carried on this tradition to investigate engineering design from a scientific research perspective. As importantly, Leifer has never been strict about DesignX boundaries. Research could cross over from sister labs on campus—either within the CDR community like the Designing Education Lab (led by Sheri Sheppard) or from other groups on campus like Stanford's Project Based Learning Laboratory (PBL LAB). As we personally became involved in several research areas of DesignX from the late 1980s on, we must rely on our colleagues to fill in gaps for the starting years.

3. Leifer's three laws of design

While much work occurring within DesignX focused on thinking about designers' doing, Leifer ensured equitable attention on thinking about designers' thinking. He believed that practice begets theory and theory changes practice. The most persistent representation of his view on how engineering designers should consider the practice of design were codified by Leifer as three core laws of design—which he interchangeably referred to as provisional theories or axioms. Law 1 states that *design is a social process*, where often the team is the unit of analysis. His reoccurring hypothesis was that the shortest path to better products, businesses, and experiences is through better design teams. Law 2 is that *all designing is redesigning*. He was constantly finetuning his own thinking, recognizing and stating publicly that 50 years of design thinking and 30 years of design research is an evolving paradigm. Leifer would often expand on these laws, so law 2 would include extensions, such as *all learning is re-learning*, *all coaching*

is re-coaching, and *all learning requires UN-learning*. Law 3 is that *designers must preserve ambiguity*, especially as an overreliance on certainty may shut out opportunity. While these laws are referenced and restated in various ways over the years, and sometimes there are four or three versions presented, each one has influenced the intellectual engine of DesignX and CDR more broadly. These laws are cited in many presentations (e.g., Cutkosky, 2000) and publications (e.g., Lande, 2012).

4. Electronic design notebooks in the 1980s

Now almost forgotten as a research area, DesignX researchers helped pioneer studies on electronic design notebooks (EDNs) as early collaboration tools for engineering teams. In the late 1980s, EDNs put traditional paper-bound notebooks into a digital environment alongside computer-aided design (CAD) solutions (Baya, V. et al., 1990), while today's engineering teams might use Autodesk's cloud solutions. CDR was openly publishing its work on the pre-web internet beside academic papers. Cockayne stumbled onto this early EDN research and shared his notes with colleagues at Apple Computer. During this time, Apple had transitioned from being a California tech company to a global manufacturer, opening factories in Asia, Europe, and other US locations beyond engineering and manufacturing operations distributed across the state of California. In this era, international phone calls and an internal email system were considered cutting-edge collaboration tools for Apple engineers who needed to design, discuss, and iterate shared work using CAD, CAM, and spreadsheets. Apple's global manufacturing teams were excited by CDR's vision of a collaborative design space, which featured a digital notebook that could capture conversations and team decisions and a rich media platform that could collect technical designs, project plans, real-world data, and eventually audio and video files.

These early EDN research studies and inventions occurring in places like Stanford were highly influential in Apple's practice of global engineering collaboration, even with the limited tools available then. A number of these early studies were led by DesignX researchers. For example, Leifer oversaw a study (Lakin et al., 1989) that investigated how EDNs could serve as both a performing medium and computer processing medium. Bill Chapin and T. Lacey assessed how CAD tools like DesignSpace supported mechanical design representations online, predating today's work in digital twins (Chapin, Lacey, & Leifer, 1994). With Leifer, Jack Hong and George Toye (1995) developed and deployed a personal electronic notebook with sharing, while Maria Yang and Mark Cutkosky (1997) worked on an EDN system called Dedal. With Feland and several other Design researchers, Leifer summarized many of these efforts for capturing and reusing design knowledge in a position paper (Leifer at al., 1999).

5. Virtual Reality and Augmented Reality in the early/mid-1990s

This EDN research crossed over with work occurring at the bleeding edge of an emerging field of virtual reality (VR). By the late 1980s, Stanford doctoral student Jim Kramer had developed an instrumented glove as a means of recognizing hand gestures in American Sign Language (ASL). He called the project Talking Glove because he synthesized ASL gestures into speech, which Stanford University soon patented (Chapin, 2018). Bill Chapin met Kramer in 1990 within Leifer's graduate student group. Chapin saw the potential to use the glove in VR for whole-hand manipulation, ultimately developing a software driver and virtual-hand model. By 1990, Kramer and Chapin co-founded Virtual Technologies to commercialize the glove, renaming it as the CyberGlove.

Cockayne discovered this early CDR spin-off because he had been publishing an online resource called the vr_sites list that covered first- and second-generation VR tools (Cockayne, 1993). In 1995 as part of his master's work, Cockayne was involved in a DARPA-funded research project that put a military field medic into a fully immersed virtual environment (George et al., 2018). Through this project, he purchased two CyberGloves—a right hand and left hand—that resulted in multiple publications and breakthroughs in virtual environment interactions. CyberGlove is only one example of the VR-related invention occurring within the larger CDR community of that era. Fellow student Louis Rosenberg started haptic interface company Immersion in 1993 before even graduating. All this research fit Leifer's long-time interests in adaptive mechatronic systems because he also was the founding director of the Stanford Rehabilitation Engineering R&D Center at the nearby US Department of Veterans Affairs from 1978 through 1989, which became foundational to Stanford's later programs in biomechanics and bioengineering (e.g., Van der Loos, 1995; Leifer, 2018).

6. Studying virtual team learning in the 1990s

A parallel research thread in DesignX was studying teamwork dynamics in Stanford's ME210 course taught by Leifer and Cutkosky. Established in 1967, ME210 is a long-running and award-winning engineering course where student teams work on corporate-sponsored projects, building a technical concept into a functioning prototype solution in the academic year (Carleton, 2019). ME210 served as a rich laboratory for DesignX researchers and visiting scholars. Leifer instigated new questions on how digital collaboration could be better studied and supported within teams, including as remote learning—years before the rise of massive open online courses (MOOCs) in the mid-2010s. We recall some of Leifer's efforts working with the Stanford Instructional Television Network (SITN), which at the time, was known as the world's largest single university provider of live televised graduate-level engineering courses. In fact, SITN was recognized in 1993 as the *Most Outstanding Distance Education Network in the US* by the United States Distance Learning Association (Stanford, 1993). Before Cockayne joined Stanford, he had participated in several SITN courses in computer science as an Apple employee. Plus, long-time Hewlett-Packard (HP) employee Chuck House—as an aside, House was one of Carleton's thesis advisors and the only recipient of HP's Medal of Defiance—brought HP employees to ME210. However, Stanford required these industry students from SITN to stay off campus during the course, despite being located at a member company only a few miles away from Stanford. Many of these remote participants then created their own tribe online alongside the ME210 matriculated students who were attending on campus. As early pioneers of distance learning, SITN students watched ME210 and other Stanford lectures in real-time at their company offices on television via closed microwave broadcast. Alternatively, they could request a VHS videotape copy of the course to watch later. The ME210 curriculum demanded constant team interaction and prototype development, so SITN students had to improvise how they could collaborate remotely in a manner similar to on-campus students. For the infamous ME210 paper bike assignment (see Carleton, 2019), the remote teams built their own paper bike in creative ways, recorded their participation on videotape, and mailed these videotapes to campus. This early SITN partnership for ME210 proved that remote collaboration and team learning could work, which DesignX researchers studied from various angles (e.g., Hong & Leifer, 1995). Through one of Leifer's numerous international connections, by the 1995-96 academic year, ME210 extended the regional setup globally to an industry student from Norway, who was working on a surgical tool for brain surgery. Even part of that project sponsorship came from a remote team member. Based on the project's success, this prototype of international project-based learning in ME210—renamed by the department as ME310 in 1999—laid the groundwork for what eventually became the SUGAR design network of international partners by the mid-2000s (Carleton & Leifer, 2009; Carleton, 2019).

7. Design metrics in late 1990s and early 2000s

By the mid-1990s, much of the scholarly research in the engineering design field had moved to determining the optimal set of performance metrics in the design process. This academic jostling had been heavily influenced by the German-structured design methodologies of Gerhard Pahl and Wolfgang Beitz, which pushed for a theory of systematic engineering design and practice (Pahl & Beitz, 1993). More broadly, this push toward a proper design science aimed to leverage the scientific method to make engineering design practice repeatable, plus gain acceptance by other engineering disciplines as being rigorous and, thus by extension, more scientific. True to Leifer's spirit of poking at assumptions and preserving ambiguity, he simultaneously embraced these structured methods—for example, Clark and Wheelwright (e.g., 1992) was a required text of ME210 during this era—while pointing out where and how these methods failed to truly support team collaboration.

Several DesignX researchers pursued the topic of design metrics. For example, Vinod Baya (1996) measured how long a concept sits in the mind of design team members before shifting to another topic—every 13 seconds on average. Drawing on concepts of natural language processing, Ade Mabogunje (1997) predicted team performance based on counting the number of unique noun phrases they used in their ME310 course documents and found that this relationship correlated to an external performance metric of design awards. Andrew Carillo (2003) took this focus on metrics further, collaborating with Stanford Professor Doug Wilde on using the Myers Briggs Temperament Indicator (MBTI) personality assessment to measure the diversity of design teams, which Carillo found was correlated to increased team performance. As part of this research cohort, Ozgur Eris (2002) explored the impact of questions on team design performance and their relationship to convergent or divergent thinking.

All the emphasis on instrumenting design teams had its roots in Leifer's own doctoral work from the late 1960s, when he had studied voluntary muscle contractions in humans (Leifer, 1969). At DesignX, he encouraged this journey in his research circle for instrumenting design teams through the 2000s, focusing on the team as the unit of performance more than the project or process used. This focus led to the development of the Design Observatory in 2002. Known to the DesignX community simply as the "DO," this was a dedicated research space at CDR, where researchers used video and audio recording tools to study engineering design teams. The DO followed a process introduced earlier by another DesignX researcher to "*observe-analyze-intervene*" (Tang, 1989), which helped influence similar research spaces by other research groups worldwide (Törlind et al., 2009). Inspired by multiple DO experiments, DesignX researcher Andrew Milne spun up a sister research space called the iLoft, which included the construction of multiple physical prototypes, as he aimed to understand how to better support engineering design teams working in both co-located and distributed scenarios (Milne & Winograd, 2003). By 2004, Milne had spun out the iLoft work as a startup called Tidebreak.

From our vantage point, DesignX's relentless focus on teams challenged prevailing beliefs at the National Science Foundation in the United States, particularly then design program manager George Hazelrigg who was intent on deterministic design research. We watched Leifer turn to research funds from other sources, including exploring the crossover between education and design. By 1997, sparked by the Stanford President's Commission on Technology in Teaching and Learning, Leifer jointly established the Stanford Learning Lab (SLL) with humanities professor Larry Friedlander (Leifer, 1997). Taking a multidisciplinary approach, "Larry and Larry" led a staff of researchers, technologists, educators, and teaching specialists to sponsor new research and study how to enhance student learning. When Leifer stepped away from SLL by 2000, his influence had indirectly influenced the language of teams and design processes related to the future of learning at Stanford.

8. Multidisciplinary design directions through the 2000s

Alongside a growing interest in design science, several other scholars took DesignX research into new areas, largely due to their industrial backgrounds influencing their academic work. This divergence was fitting to Leifer's willingness to explore new conceptual territories. For example, Cockayne followed this arc of applied research. Coming from industry roles at Apple, Mercedes-Benz R&D Center, and Kodak, plus taking a gap year midway through his dissertation to gather further evidence in the wild, Cockayne investigated the formative twinning process between emerging teams and incipient ideas that occurs in informal networks pre-patent and pre-incorporation (Cockayne, 2004). As other DesignX highlights, Kurt Reiner had spent several years working as a game software developer, including at Electronic Arts, before joining CDR. For his doctoral research, Reiner (2006) investigated what tools distributed gaming teams used to help them collaborate and manage shared knowledge, and he found that external observers can reliably use design history to model and understand how a team will perform. Or Michael Helms, who left his engineering career at Lockheed to pursue a doctorate at CDR and examined anomaly detection as a source of creative insight among geographically distributed automotive design workers (Helms, 2011).

During the late 1990s into the early 2000s, the quest to capture and use a design rationale became the focus of much design research, both at Stanford and beyond. Hundreds of papers were published exploring the best way to capture and reuse the design rationale, which is the explicit documentation or team justification for decisions made throughout the design process. In the DesignX community, Sam Yen studied Recall, an initial effort at mixing video capture of design team collaboration with a layer of tools that indexed progress based on the state of the team's whiteboard activity, and his study focused on capturing as much of the nascent creation effort of new designs (Fruchter & Yen, 2000). Feland started his design research while on active duty in the US Air Force, where he was managing the requirements for multi-billion-dollar satellite programs. Based on his experience in defense acquisitions, Feland posited that focusing on the design requirement rationale was potentially more impactful and lower cost to capture, yet it required additional overhead at the time the requirements were formalized. To understand the impact a design rationale requirement might have on team performance, Feland returned to a popular DesignX data set—ME310 design documents—to study the impact of requirement changes and requirement volatility on team performance. Similar to Mabogunje's finding (1997) that teams developed richer language over time, Feland found that teams that made opportune changes experienced better outcomes (Feland, 1999; Feland, Leifer, & Nowack, 1999). Teams with few changes were not learning fast enough to uncover risk and those with excessive requirement volatility had not

yet narrowed their scope sufficiently to achieve their stated goals. Feland soon returned to Stanford with a focus on instrumentation in the wild.

During this time, much of the performance metrics for experiments conducted in CDR's iLoft were based on design juries, which gathered subjective opinions of design experts. Feland's experience at IDEO and the US Air Force drove him to find external, more objective measures of performance to better assess how designs impacted the ultimate customer. Conversations with Leifer and fellow DesignX members were critical in shaping Feland's understanding in exploring not only how to find these objective metrics but also what the value would be to understanding innovation by using evidence in the wild rather than the controlled environment of the iLoft. Buoyed by peripatetic brainstorms with Cockayne, Feland eventually hit upon the notion of using consumer reviews as a means to measure whether or not a design met the requirements of the user. Borrowing metrics of innovation from economics and metrics of business performance from accounting, plus leveraging the growing availability of consumer perceptions provided via online user-submitted product reviews, Feland implemented a way of measuring design performance using external data without the subjective views of design juries. In Feland's research (2005), the most surprising result was the ability to predict consumer adoption one to two fiscal quarters into the future based on metrics derived from online consumer reviews. By 2009, Feland leveraged his research to start an agile analytics startup called Argus Insights, which operationalized the metrics from his dissertation to help companies worldwide—beating Wall Street estimates of iPhone sales almost every quarter for five years straight.

9. ME310-global and the SUGAR network through the 2000s & 2010s

Leifer's unwavering support of these types of cross-disciplinary approaches—and ensuring both lab-based and evidence "from the wild" were equally recognized and rewarded as valid research models—proved fertile ground for the broader DesignX community. Leifer frequently encouraged novel research questions from visiting scholars, who came to CDR from universities and research centers around the world, including Finland, Norway, France, Germany, Japan, and Brazil. Almost every academic quarter, the DesignX community would welcome someone new to the discussions, who added their questions and insights to the mix while also discovering the legacy and wonder of ME310 (Carleton, 2019).

At this point, the ME310 course under Leifer's direction was running like a well-oiled machine: 10 sponsoring organizations would bring 10 engineering design briefs to 10 design teams of Stanford engineering students. Each student team spent the autumn quarter becoming a team before choosing one of the industry projects as a starting point for two intense quarters of human-centered problem solving and invention. Each team had a sizable budget (not insignificant for students!) to buy materials. As part of building shared community and supporting knowledge spillover across teams, every week ME310 sponsored a large family-style dinner—called SUDS, short for "*slightly unorganized design session*"—for the students, team coaches, and sponsors, which was open to the DesignX community and others. This ongoing SUDS experience created a shared team feeling and informal culture that deeply reinforced the team-based research agendas at DesignX and further disseminated Leifer's three laws of design.

For many visiting scholars, ME310 seemed to be the ideal course for teaching the skills in critical thinking, collaboration, and problem-solving that industry was demanding from university graduates. As these visiting scholars returned to their home universities, they often posed a question to Leifer, as such: how can we create a partnership between our school's design course and ME310? Leifer saw these foreign partnerships as an opportunity to keep Stanford students at the forefront of engineering education by introducing them to long-distance collaborations as part of their coursework. Starting in the mid-2000s, each ME310 team at Stanford was partnered with a student team counterpart at an international university or educational institution. Oftentimes, the corporate partner sponsoring the team project was also from an international market, which made ME310 a good reflection of the global work environment the students would soon graduate into. In addition, these ME310-global partnerships helped transfer much of Leifer's design laws to other universities and design communities worldwide.

As more CDR visiting scholars met each other and connected through ME310 student projects, they gradually began to partner with one another on their own projects—inspired by and following ME310 doctrine, but not involving Stanford directly. With input from two visiting scholars from Columbia, Leifer soon dubbed this resulting international network outside ME310 as the SUGAR network (see the back story in Carleton, 2019). Participation in the SUGAR design network soon grew to over two dozen universities worldwide working on dozens of corporate projects with international sponsors. Initially anchored by ME310, SUGAR gradually took on a community life of its own from 2016 on. With the help

of 70 contributors, Carleton (2019) later edited a commemorative book about ME310, showcasing the course's evolution and influence over 50 years since it was first taught at Stanford in 1967.

10. Design foresight in the 2000s and 2010s

Based on his SLL efforts and ME310 success, Leifer frequently encouraged active intervention in the classroom, encouraging DesignX students to try new ways of teaching teams and problem-based learning. The seminar course ME397 (formerly ME297), Design Theory and Methodology Forum, was often the choice of educational intervention. For example, Ade Mabogunje and Ozgur Eris combined a case study approach with design interviews to explore the cognitive basis for designer behavior and design tool development in fall 2004 (*Stanford Bulletin*, 2004, p. 208). In 2006, Mabogunje switched to address the use of information and computer tools to augment the performance of design teams through global collaborative design scenarios and distributed design exercises (*Stanford Bulletin*, 2006, p. 15). With Leifer's support in spring 2002, Cockayne and Feland introduced a special topics engineering course about emerging technologies at Stanford, which combined their respective experiences across MIT, IDEO, the US Air Force, Apple, and various product roles. This course led to a series of new courses that Cockayne designed and taught through the mid-2000s in a new area of *design foresight*—exploring models and frameworks adapted from long-range planning and innovation to teach students how they could anticipate when new innovations and emerging technologies were ready to harvest. Course titles included: *Designing the Future*, *Long-Range Design*, and *Case Studies in Strategic Foresight* (Stanford Foresight, 2021). At their core, these courses helped students to critically explore a human-centered future in which they were challenged to imagine, research, and build. Cockayne continued these themes in subsequent courses and programs he taught overseas on high-tech entrepreneurship, corporate scenario planning and envisioning, organizational models of invention and innovation, future design prototypes, and design thinking for tomorrow's customers.

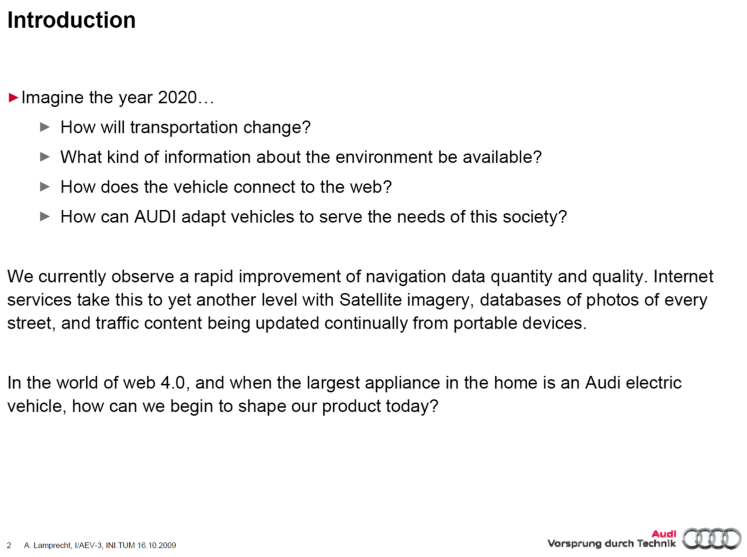

Figure 1. Audi 2009 project brief to students (courtesy of Stanford ME310 archives)

In 2007, Leifer brought a curious ME310 project to Cockayne that seemed to fit the design foresight approach. German car manufacturer Audi had challenged an ME310 student team to reimagine the driving experience for a car that would ship in 12 years using technologies and features that would be developed along the way; see the original design brief in Figure 1. Several other briefs from ME310 corporate sponsors also had aspects of future-oriented solutions, requiring students to ask long-range, ambiguity-ridden questions during their early design process that was outside the scope of classic engineering. Leifer invited Cockayne to provide guest lectures about foresight methods and concepts in the ME310 course and to coach several student teams. Cockayne launched ME410 as a sister course to ME310. The ME410 course first focused on helping teams with futuristic ME310 projects in 2007-08 and soon expanded to its own distinct curriculum based on growing student interest, taught for multiple years (Stanford Bulletin, 2022). ME410 drew diverse students from undergraduate through postgraduate

levels, alongside Stanford Distinguished Fellows and Knights Fellows, from almost every degree area across the university; a quick roster scan shows participation from all seven schools at Stanford
In late 2007, Cockayne invited Carleton to help him standardize the design foresight methods, and together they created and prototyped several versions of a foresight framework with various partners over the next several years in parallel with Carleton's doctoral work. The ME410 model launched several years of experiments and workshops with industry collaboration and international groups. For example, the Stanford Center for Professional Development (SCPD) approached Leifer, Cockayne, and Carleton to bring the ME410+ME310 approach to an international professional audience: first to Pune, India, and then to Seoul, South Korea. Notably in 2015, the Swiss Consulate in San Francisco, Calif., asked Leifer to host a session for a visiting group that included Swiss Federal Councillor Johann Schneider-Ammann, who became president of the Swiss Confederation in the next year. Leifer engaged Cockayne and Carleton in this effort, which was well received. Not everyone has the privilege to share their insights with national presidents, so this session was a special memory for Leifer; see Figure 2.

Figure 2. Soon-to-be Swiss President Johann Schneider-Ammann speaking with Larry Leifer on right (image courtesy of William Cockayne)

During this period in 2010, Tekes—the Finnish funding agency for technology and innovation (later renamed as Business Finland in 2018)—asked Carleton and Cockayne if they would document their foresight methods as part of a grant. Working with Finnish colleagues, Carleton and Cockayne published an open-source handbook called the *Playbook for Strategic Foresight and Innovation* (2013) describing a set of 15 original tools, a subset of which had their roots in Carleton's doctoral work (2010). Hundreds of teams worldwide have used these tools since, and Carleton has continued the application of the foresight work in her executive education programs and with clients in industry and government.
Other research explorations occurred in these years too, notably tied to new X variables in DesignX for tech ventures and neuroscience. Three DesignX senior researchers—Ade Mabogunje, Neeraj Sonalkar, and David Cannon—pursued one exploration that became the Real-time Venture Engineering Lab (ReVeL) at CDR. They aimed to apply engineering design theories and models to forming technology-based innovation ecosystems. They set up one test site at Abeokuta, Nigeria, in collaboration with Fate Foundation and another site at Ahmedabad, India, in partnership with Ahmedabad University. A parallel exploration considered the intersection of engineering design and neuroscience. Stanford medical professor Manish Saggar saw links with Leifer's doctoral work, where he had investigated a neurology topic as design research, noting that "*Leifer was one of the first researchers at the intersection of Design and Neuro at Stanford*" (Stanford Center for Design Research, n.d.). Saggar's interactions with DesignX led to the NeuroDesign Research initiative by 2018, involving Sonalkar and others from DesignX.

11. Conclusion

As authors, we carry much of this DesignX history forward in our own work. Empowered by Leifer's belief in intellectual hunting, Cockayne and Carleton have been able to take ideas born of engineering to

non-engineers, helping them see the importance of this type of integrated thinking. Likewise, Feland has brought Leifer's philosophy to other communities outside higher education, such as The Nueva School, a K-12 private school in Northern California organized around design thinking tenets, where he has inspired youth in team-based projects, makerspace activities, and challenging the status quo.

As Leifer transitioned to emeritus faculty status by 2022 and CDR has added new faculty, the research efforts of DesignX have been passed to other groups across the CDR community. More than being the senior hunter-sage, Leifer embodies the leader who truly leads from behind. Instead of the classic leader out in front, he has used indirect power to move everyone forward, inspired by seeing what fills the X in DesignX. Whether or not people know the true origin of DesignX's wealth of work, Leifer has sparked many new threads beyond Stanford's DesignX ecosystem. Looking back at DesignX's history, Leifer has inspired dozens and dozens of other faculty, scholars, and students to define their own paths, embrace the chase, and put the team at the center of engineering design. To all we say: happy hunting!

References

Baya, V. (1996). *Information handling behavior of designers during conceptual design: Three experiments* [Doctoral dissertation, Stanford University]. Retrieved from https://www.proquest.com/openview/0b70ba1baf507f6a8b5ed08d75906a7c

Baya, V., Cannon, D., & Leifer, L. (1990). The Electronic Design Notebook(TM). *Stanford University, Center for Design Research online archives*.

Carleton, T. (2010). *The value of vision in radical technological innovation* [Doctoral dissertation, Stanford University].

Carleton, T. (Ed.) (2019). *ME310 at Stanford University: 50 Years of Redesign (1967-2017). Innovation Leadership Publishing*.

Carleton, T., Cockayne, W., & Tahvanainen, A. (2013). *Playbook for Strategic Foresight and Innovation*. https://foresight.stanford.edu/methods

Carleton, T., & Leifer, L. (2009). Stanford's ME310 course as an evolution of engineering design. *Proceedings of the 19th CIRP Design Conference*. Cranfield University, United Kingdom, March 30-31.

Carrillo, A. G. (2003). Engineering design team performance: Quantitative evidence that membership diversity effects are time dependent [Doctoral dissertation]. *Stanford University. Retrieved from* https://www.proquest.com/openview/920469fb620a716594fa2759bb3fee39/

Chapin, W. L., Lacey, T. and Leifer, L. (1994). DesignSpace: A manual interaction environment for computer aided design. *DEMONSTRATIONS: Virtual reality multimedia. Proceedings of ACM CHI'94 Conference on Human Factors in Computing Systems*, 2, 33-34.

Chapin, W. (1994) *Virtual Technologies' CyberGlove*. Stanford University, Center for Design Research archives.

Chapin, W. (2018). Personal website. http://ausim3d.com/wlc/CDR_media.html

Clark, K. B., & Wheelwright, S. C. (1993). *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*. New York, NY: The Free Press.

CockayneW. (1993) "vr_sites list". In KadreyR. *Covert Culture Sourcebook*. St. Martin's Press. New York, NY.

Cockayne, W. R. (2004). *A study of the formation of innovation ideas in informal networks* [Doctoral dissertation, Stanford University].

Cutkosky, M. (2000, March 29). Developments in (global) project-based design education [talk presentation slides]. Tokyo Metropolitan University, Tokyo, Japan.

Feland, J., & Leifer, L. (1999). Requirement volatility metrics as an assessment instrument for design team performance prediction. *Proceedings from Designing Design Education for the 21st Century*, Mudd Design Workshop II, 1999.

Feland, J., Leifer, L., & Nowack, M. (1999). Requirement volatility: How lessons learned can be applied in the design of new requirements. *Proceedings of the 12th International Conference on Engineering Design*, Munich, Germany, August 24-26.

Feland, J. M. (2005). *Product capital model: Modeling the value of design to corporate performance* [Doctoral dissertation, Stanford University].

Fruchter, R., & Yen, S. (2000). RECALL in Action. *Conference Proceedings from the Eighth International Conference on Computing in Civil and Building Engineering (ICCCBE-VIII)*. DOI: https://doi.org/10.1061/40513(279)131

Helms, M. (2011). *Anomaly detection as creative insight* [Doctoral dissertation, Stanford University].

Ozgur, E. (2002). *Perceiving, comprehending, and measuring design activity through the questions asked while designing* [Doctoral dissertation, Stanford University]. Retrieved from https://www.proquest.com/openview/1666faa352c6ecdd763cf79fc79bf9f2

George, E. I., Brand, T. C., LaPorta, A., Marescaux, J., & Satava, R. M. (2018). Origins of robotic surgery: From skepticism to standard of care. *Journal of the Society of Laparoendoscopic Surgeons*, 22(4), e2018.00039. https://doi.org/10.4293/JSLS.2018.00039

Hong, J., & Leifer, L. (1995). Using the WWW to support project-team formation. *Proceedings from Frontiers in Education 1995 25th Annual Conference: Engineering Education for the 21st Century*. Atlanta, Georgia, USA; November 1-4. https://doi.org/10.1109/FIE.1995.483079

Hong, J., Toye, G., & Leifer, L. J. (1995). Personal electronic notebook with sharing. *Proceedings 4th IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE '95)* (pp. 88-94). IEEE. https://doi.org/10.1109/ENABL.1995.484552

Lakin, F., Wambaugh, J., Leifer, L., *et al.* (1989). The electronic design notebook: Performing medium and processing medium. *The Visual Computer* 5, 214-226. https://doi.org/10.1007/BF02153751

Lande, M. (2012). Work in progress: Making Room: Creating design spaces for design practice. *In 2012 Frontiers in Education Conference Proceedings* (pp. 1-5). IEEE. https://doi.org/10.1109/FIE.2012.6462347

Leifer, L. (1969). *Characterization of muscle fiber discharge during voluntary isometric contraction of the biceps brachii muscle in man* [Doctoral dissertation, Stanford University].

Leifer, L. (1997). The Stanford Learning Laboratory: a prospectus. *Proceedings of the National Institute for Multimedia Education Conference on Higher Education in the 21st Century: Bringing Today's Education into the Hi-Tech World of Tomorrow*. Chiba, Japan, November 10-13.

Leifer, L. (2018, October 23). Curriculum vitae.

Leifer, L. J., Liang, T., Cannon, D. M., Feland, J. M., Mabogunje, A., Yen, S., & Yang, M. C. (1999). Experience capture and reuse for complex system design-deployment: position paper based on our experience using the internet. *Proceedings of the International Conference Problems of Control and Modeling in Complex Systems* (pp. 14-18).

Mabogunje, A. O. (1997). *Measuring conceptual design process performance in mechanical engineering: A question based approach* [Doctoral dissertation, Stanford University].

Milne, A., & Winograd, T. (2003). The iLoft project: A technologically advanced collaborative design workspace as research instrument. *Proceedings of the International Conference on Engineering Design (ICED'03)*. Stockholm, Sweden: August 19-21.

Pahl, G., & Beitz, W. (1993). *Engineering Design: A Systematic Approach. Springer.*

Reiner, K. (2006). *A framework for knowledge capture and a study of development metrics in collaborative engineering design* [Doctoral dissertation, Stanford University].

Stanford Bulletin. (2004). ME 397. *Stanford University*. http://web.stanford.edu/dept/registrar/bulletin_past/bulletin05-06/pdf/MechEng.pdf

Stanford Bulletin. (2006). ME 397. *Stanford University*. http://web.stanford.edu/dept/registrar/bulletin_past/bulletin06-07/pdf/MechEng.pdf

Stanford Bulletin. (2022). ME 410. *Stanford University*. https://explorecourses.stanford.edu

Stanford Center for Design Research. (n.d.) *About NeuroDesign*. https://neurodesign.stanford.edu/about

Stanford Foresight. (2022). Past courses. https://foresight.stanford.edu/teaching

Stanford University. (1993, November 29). *Stanford Instructional Television Network honored* [press release].

Steinert, M. & Leifer, L.J. (2012). 'Finding one's way': Re-discovering a hunter-gatherer model based on wayfaring. *International Journal of Engineering Education*, 28(2): 251-252. Retrieved from https://www.ijee.ie/contents/c280212.html

Tang, J. (1989). *Toward an understanding of the use of shared workspaces* [Doctoral dissertation, Stanford Univ.].

Törlind, P., Sonalkar, N., Bergström, M., Blanco, E., Hicks, B., & McAlpine, H. (2009). Lessons learned and future challenges for design observatory research. *Proceedings of the International Conference of Engineering Design (ICED'09)*. Stanford, California, USA, August 24-27.

Van der Loos, H. F. M. (1995). VA/Stanford rehabilitation robotics research and development program: lessons learned in the application of robotics technology to the field of rehabilitation. *IEEE Transactions on Rehabilitation Engineering*: 3(1), 46-55. https://doi.org/10.1109/86.372891

Yang, M., & Cutkosky, M. (1997). Automated indexing of design concepts for information management. *Proceedings International Conference on Engineering Design (ICED 97)*. https://web.mit.edu/~mcyang/www/papers/1997-ICED.pdf