Invited Paper

Stanford's ME310 Course as an Evolution of Engineering Design

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Abstract
ME310 is a radical course that has been taught at Stanford University since 1967. The year-long course is a graduate level sequence in which student teams work on complex engineering projects sponsored by industry partners. Student teams complete the design process from defining design requirements to constructing functional prototypes that are ready for consumer testing and technical evaluation. This paper presents the first longitudinal study of ME310 and characterizes the course in terms of nine eras, each with distinctive teaching philosophies and class dynamics. By looking at one engineering design course in its entirety, a rough parallel is gained of how the field of engineering design itself has evolved over the last forty years. Data for this study was drawn from 80 surveys, 28 interviews, and 42 years of historical university enrollment records, course archives, and course bulletins.

Keywords:
Engineering Design Education, Problem-Based Learning, Innovation, Immersion, Simulation

1 INTRODUCTION

Despite its age, ME310 is not your traditional engineering class. Taught since 1967, ME310 has developed a strong reputation at Stanford University as a cross between a senior capstone course, prototyping laboratory, and microcosm of Silicon Valley. The course combines the best of interdisciplinary teaching and problem-based learning for engineering design. ME310 also offers a successful formula of global networked innovation and provides a documented test bed of engineering education. In short, it is remarkable that the same course has been taught continuously for 42 years. Why does ME310 work? What has changed and held consistent over this time span? How has the course influenced other educational practices in the U.S. and around the world? This paper presents the first longitudinal study of ME310, examining the dynamics between engineering design education and practice and the effects on diverse course participants, including faculty, students, project coaches, and industry liaisons.

2 COURSE OVERVIEW

ME310 is a year-long graduate course offered through Stanford's School of Engineering. It is mandatory for Stanford master's students specializing in Engineering Design and an elective for students from other disciplines. Due to various Stanford policies, the course was originally listed as ME201 from 1967 to 1974, then ME210 from 1975 to 1998, and next as ME310 from 1999 to 2009. The course will generally be referred to as ME310 throughout this paper. Students are required to enroll in all three quarters of the academic year.

In this Stanford course, student teams work on complex engineering projects sponsored by industry partners. Example industry partners are Autodesk, BMW, Lockheed Martin, Nokia, Panasonic, and Xerox Corporation. Each team of students selects a real problem or opportunity to pursue, which are provided by the industry partners. Each team also receives a hefty project budget and dedicated lab space (commonly known as the "310 loft"). Teams are typically comprised of three or four Stanford students, and in recent years, each team has collaborated with a similarly sized team at a global partner university. All student teams complete the engineering design process from defining design requirements to constructing functional prototypes that are ready for consumer testing and technical evaluation. Throughout the year, teams may choose to enlist the help of vendors, faculty, or students from other Stanford courses, the latter frequently from computer science, for their projects. The course culminates in a student project showcase, and each industry partner receives detailed documentation and prototypes for their respective projects.

Moreover, a broader network supports the student teams each year. Project coaches are assigned to specific teams, providing relevant expertise and project advice. Coaches are often faculty or industry professionals, many of whom took the course as students. In addition, multiple teaching assistants and a small administrative team coordinate ME310 operations and logistics. In the last ten years, the course has been working available remotely to working professionals through the Stanford Center for Professional Development (SCPD) and to graduate students at global academic partners. Global academic partners for 2008-09 include Pontificia Universidad Javeriana (Columbia), Helsinki University of Technology (Finland), the Hasso Plattner Institut (Germany), and Universidad Nacional Autónoma de México (Mexico). In recent years, several student teams at Stanford have been matched with a corresponding student team from a global academic partner. Every global team also has its own faculty, teaching assistants, project coaches, and dedicated lab space.

Figure 1 presents a visual summary of all key relationships occurring within the course at two key points, when the course was established as a yearlong sequence in 1972 and then in 2009.
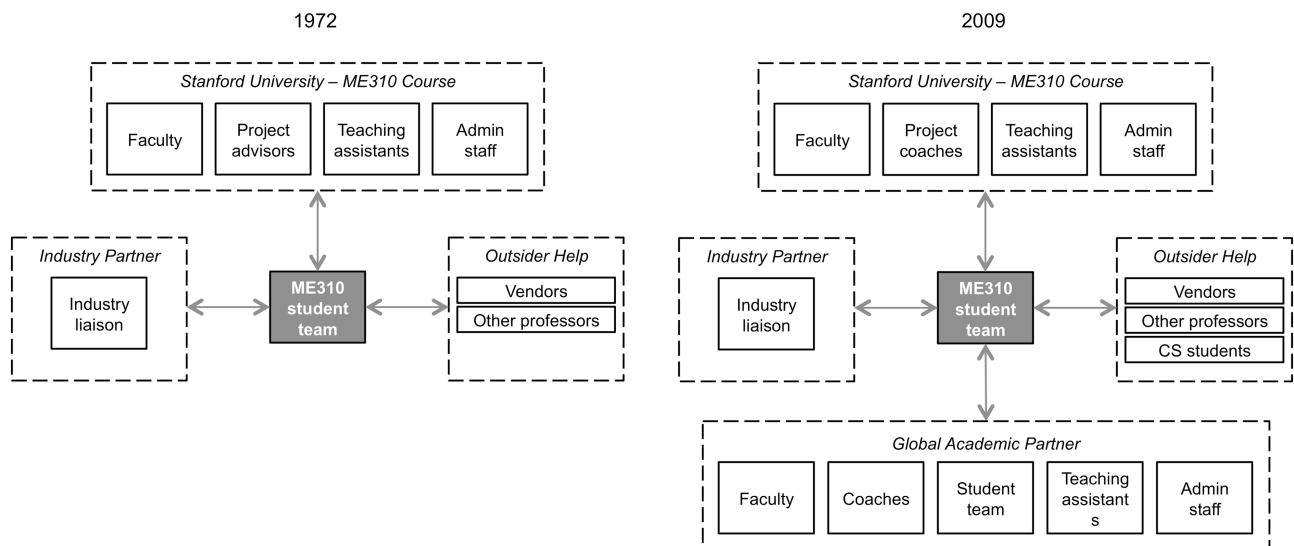
1972

Stanford University – ME310 Course

| Faculty | Project advisors | Teaching assistants | Admin staff |

Industry Partner

| Industry liaison |

ME310 student team

Outsider Help

| Vendors |
| Other professors |

2009

Stanford University – ME310 Course

| Faculty | Project coaches | Teaching assistants | Admin staff |

Industry Partner

| Industry liaison |

ME310 student team

Outsider Help

| Vendors |
| Other professors |
| CS students |

Global Academic Partner

| Faculty | Coaches | Student team | Teaching assistants | Admin staff |

Figure 1. Network view of ME310 in 1972 versus 2009.

3 DATA COLLECTION

3.1 Research Objectives

The objective of this research study is to describe the evolution of ME310 from its inception in 1967 to 2009. Evolution is an apt term because, in order to thrive, the course has had to adapt to multiple conditions arising from within Stanford University, as well as external drivers in the global economy, throughout its history. By synthesizing multiple data sources, a more complete understanding of this dynamic course can be formed. Data sources for the study are described below.

3.2 Web Surveys

The total population of ME310 was not available to survey due to a lack of information about all members. For example, certain faculty members are deceased, older student alumni have drifted from contact with Stanford, and various industry liaisons have changed company affiliations. Two small and carefully chosen samples were used to represent the population for ME310 based on either available sample size or course influence. First, a convenience sample of student alumni was drawn from an online community, composed of 128 members. In total, 47% of the student alumni (n=60) participated in the survey. A large contingent (39%) of them returned in other course roles, namely as project coaches (17%), teaching assistants (15%), or researchers (7%) of ME310 in following years. Sixteen participants (27%) were from global academic partners.

Second, a random sample of 104 industry liaisons and project coaches was generated from a course database. These project coaches were all senior working professionals. Approximately 19% of this industry sample responded (n=20). Interestingly, 35% of the industry liaisons were ME310 student alumni, and two (5%) of the global faculty also served as project coaches to student teams at their respective universities.

Both surveys were conducted online, and all responses were confidential. Although not statistically significant, taken together, the two web surveys (n=80) provide a rough approximation of the total course population. Survey questions addressed prior experience, course participation, lessons learned, and personal outcomes.

3.3 Individual Interviews

Interviews offered a way to gain deeper perspective about specific roles and intervals in course history. Interview candidates were identified by their course role and year of participation in order to generate a greater diversity of viewpoints. Twenty-eight individual interviews were conducted over a five-week period with the entire ME310 network, including: faculty, industry liaisons, project coaches, teaching assistants, student alumni, global academic partners, and administrative staff. Many of the interview subjects served multiple roles over the years, for example, returning as course teaching assistants and later as project sponsors. All interviews were semi-structured and followed a common interview guide.

3.4 Course Archives

Each year, all student teams in ME310 produce detailed documentation about their project, including a final report. All reports are available in hard copy (digital only in recent years) for content analysis. Project reports serve as a valuable body of knowledge about ME310, and at a minimum, reveal information about team size, industry category, project type, and solution timeframe. A representative sample of 135 project reports was reviewed for this study. In addition, all industry partners provide a project proposal to their respective student team at the start of the course, and available proposals from recent years were also examined. Other materials, such as videotapes and prototypes, were not examined.

3.5 University Course Descriptions

In addition, ME310 faculty have updated the course description since 1967. Subsequently, 42 years of course descriptions have been captured in the annual Stanford University Bulletin, the university's official catalog of courses and degree requirements. By analyzing these course descriptions over time, broad trends can be detected in curriculum focus and language use. In other words, has ME310 been communicated differently to students, and what do these changes reveal about the course in light of its overall evolution?

3.6 University Enrollment Records

The University Registrar maintains all student records, including course enrollment. This study examined the change in ME310 enrollment by quarter to help identify

average attendance, peak years, and drop-off rates, as well as changes in faculty and teaching staff. Course records were only available from 1983 to current. The U.S. Family Educational Rights and Privacy Act (FERPA) requires that all student data in academic files remain private, so only general enrollment data was reviewed.

3.7 Additional Research of ME310

Other scholars at different times have explored specific dynamics of ME310, such as team interaction [1], coaching [2], collaboration support [3], and team performance [4]. These studies provided further context.

4 COURSE PEDAGOGY

4.1 Design Engineering Education

Much has been written about the state of engineering education. Recent studies have highlighted growing challenges, specifically in globalization and innovation, which require improved skills in synthesis thinking and system building by engineering students [5][6]. One might argue that this need has been constant in the last century, and by reviewing longitudinal studies, the changes and progress of engineering education over time can be understood, specifically in the field of design engineering. In one of the few examples of a longitudinal study of design education, the authors discussed the need to train students in both hard and soft skills [7].

At Stanford University, ME310 was designed to and continues to address exactly the issues raised by these authors. The course has functioned as a dynamic combination of problem-based learning (PBL), immersion, and simulation, which is illustrated in Figure 2. Most other courses in Stanford's engineering curriculum and broader design program may combine up to two approaches; however, ME310 consistently unites all three approaches for student learning. The hands-on design experience becomes invaluable knowledge for the students' work and research after ME310. Each approach is discussed in more detail.
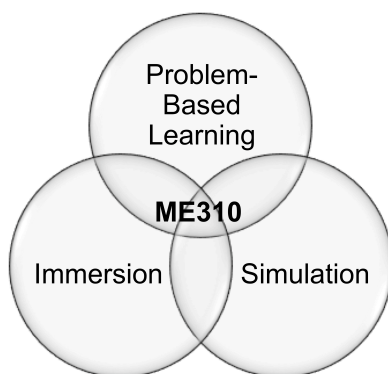

Figure 2. ME310 as the dynamic combination of problem-based learning, immersion, and simulation approaches.

4.2 ME310 as Problem-Based Learning

According to literature, characteristics of PBL include an emphasis on problem solving, a role of a facilitator or coach, and the use of reflection and self-directed exercises [8]. Students are actively engaged in their own learning process, becoming co-responsible for their education. A general finding of PBL is that student levels of interaction and participation increase tremendously. While the origins of PBL are often traced to medical education in the late 1960s [9], their foundations at Stanford date to the mid 1950s, lying at the roots of the ME310 course. Professor John Arnold was recruited from the Massachusetts Institutes of Technology to Stanford's Mechanical Engineering department in part because of his success in PBL teaching. Arnold brought together students from multiple disciplines to work in teams on industry-based (and also future-based) problems [10]. Writing in 1952, Howe noted: "Professor Arnold wants to develop men who can find drastic new solutions to old problems, and discover and solve new problems not yet recognized" [11].

ME310 is a PBL course, in which students analyze real-life problems from industry and synthesize new opportunities. Stefik and Stefik noted that ME310 had adopted a project-based model using coaches instead of traditional product design education [12]. As a variant of PBL, ME310 has been focused on *product*-based learning, in which students are given the opportunity to directly define and build a complex product component or system from concept to prototype [13]. More than evaluate mock scenarios, students are challenged to define real requirements and build solutions for real companies. Several different PBL models have been proposed over the years, recently by Savin-Baden, who posits five models of PBL including Model II, which is "focused on a real-life situation that requires an effective practical resolution" [14]. Model II may come closest to describing the nature of ME310. Savin-Baden has found that this type of model arises from curricula with strong ties to industry and tends to emphasize process skills, such as teamwork and communication, over content skills. The other models typically present sample problem scenarios to students, not necessarily from the real world.

4.3 ME310 as Immersion

ME310 also provides an immersive experience. Students are thrust into a realistic situation that requires their full concentration over three quarters. Every detail in the project, such as vendor selection and billing, requires their real-time attention and decision. It is a time-consuming engagement, often to the detriment of other courses, yet on reflection, nearly all students recall it as one of their best memories from college.

While a preponderance of immersion studies can be found in advanced virtual environment research, several studies have discussed the benefits of immersive environments in other applications [15]. ME310 uses a combination of hardware and software tools to create an immersive physical space that functions as a central base throughout the year. The physical environment strongly influences student behavior, and the objective has been to augment the real space, stimulating the imagination using video and other digital equipment. In addition, all global teams interact with Stanford teams through mediated channels.

4.4 ME310 as Simulation

Lastly, ME310 serves as a simulator. The course is a training ground. Students learn by doing, prototyping the design process and the role of a design engineer. They gain practice in how to interact with other engineers and how to design in context. Beyond testing the prototype, many students also test different project roles, alternating responsibilities within their team. ME310 is a safe environment to experiment, fail, and try again. Simulation training is highly effective and sees extensive use today in medical applications [16] and the military [17]. Kneebone notes, "Simulators can provide safe, realistic learning environments for repeated practice, underpinned by feedback and objective metrics of performance" [16].

ME310 has also often been likened to a pre-incubator. In many ways, this comparison is not surprising because studies show that successful incubators are closely linked

with academic institutions. Ample research has been done in recent years about university-related incubators, which provide a simulation environment for technical entrepreneurs to start a new business with the support and resources of a university. Smilor and Gill documented several case studies of the earliest efforts by American universities [18]. One major finding from their research was that no one ideal model exists, due to multiple variables, and any successful model may not be transferable in its entirety to another area. Another key finding was that many incubators address the need for entrepreneurial training and education through a combination of formal and informal programs. The objective is to instill additional business skills and know-how, so that the entrepreneurs can effectively build their businesses outside the safety of the incubator.

Recent research by Tornatzky, Sherman, and Adkins found that the majority of best-in-class incubators were connected to a research-intensive university, medical research institution, or research laboratory [19]. It proves to be a mutually beneficial relationship. While the incubator provides a mechanism for commercializing university research, the university fulfills an emerging obligation to contribute directly to regional economic development. ME310 industry partners who participated in the study stressed the benefits of their Stanford affiliation and collaboration. In addition, university-related incubators are often used as a source of research for university faculty and students [18]. Similarly, ME310 has served as a research laboratory in its history.

5 COURSE EVOLUTION

5.1 Nine Eras in History

By looking at one course in engineering design in its entirety, a rough long-term parallel is gained of how the field of engineering design itself has evolved over the last forty years. Several trends are apparent, as the course has shifted from phase to phase. The evolution of ME310 is analyzed primarily from an internal viewpoint, looking at the changes driven from within the course that have directly affected course pedagogy.

ME310 has been characterized by nine eras, each with distinctive teaching philosophies and class dynamics. In short, engineering design has been taught (a) as synthesis, (b) as an immersive process, (c) as real world problems, (d) as mechatronics, (e) as redesign, (f) as distributed teamwork, (g) as entrepreneurship, (h) as global innovation, and most recently, (i) as foresight. Although these eras are presented as separate time periods, in actuality, they overlap. Table 1 summarizes the nine eras in the course history.

Smilor and Gill, when examining case studies of university-related incubators, found that "In many instances, the unique character of an incubator is determined by the personality of the management team" [18]. Likewise in ME310, the faculty drove much of the changes to spark each era, often bringing their personal teaching beliefs about engineering design and learning to the forefront. Savin-Baden makes a similar comment about faculty influence in PBL approaches, noting that "the positioning of knowledge in a problem-based learning programme will tell us more about the pedagogical stance of the staff than the forms of knowledge in action" [14]. The nine eras are described in the following sections.

5.2 Era I: Synthesis (1967–1972)

It would help to explain the context of Stanford University during the late 1960s. At this time, the Mechanical Engineering department was organized into three major divisions: Design, Thermosciences, and Nuclear. The

Design Division was largely concerned with "comprehensive systems design, product design, mechanical analysis and mechanisms design, and design components" [20]. In 1966, the actual development of student designs in any course was optional, subject to the instructor's approval. The precedent was set in 1967 with ME219, a three-quarter series that allowed graduate students to gain practice designing a machine: "The intent of the series is to involve the student in a major portion of the design-development process". The class was updated to stress multi-disciplinary thinking, and students turned working drawings into functioning systems. Also in 1967, Professor Henry Fuchs and other faculty introduced a new graduate course, in which students analyzed real-life case studies from industry using a combination of interviews, artifacts, and other records. This course also fulfilled a degree requirement in "Engineering Synthesis", which emphasizing the value of integrating analytical skills with creative skills. This provided additional exposure to how practitioners worked and the problems they faced in engineering design.

Professor Jim Adams became the director of Stanford's Design Division in 1970. Adams and Fuchs were invited to Harvey Mudd College, a small private college in Southern California, to tour the Engineering Clinic, which had been established in 1963 as a series of required courses "in which junior students form interdisciplinary teams to tackle company-sponsored design and research projects" [21]. Similar programs in cooperative "co-op" education were underway at other universities at the time, providing students with practical work experience. The visit provoked Adams to reconsider Stanford's course.

5.3 Era II: Immersive Process (1972–1974)

Both Adams and Fuchs were impressed with these existing practical models and decided to expand ME 201 into a three-quarter sequence that fit Stanford's design culture in 1972. They took the synthesis focus a step forward by emphasizing the immersive process of design in the second era of ME310. Not only was it important to unite multiple knowledge areas, it was also beneficial for students to directly experience the design process. The course was focused on learning by doing. Each quarter built on knowledge from the prior quarter, so the entire year was integrated. In particular, product testing and debugging was an important belief to Adams, helping students to understand "the difference between theory and actuality". From prior industry experience, he knew problems in hardware were complex, and the earlier a student could learn how to prototype and test, the more successful the final result could become. The new course appealed to local industry partners, and Adams explained, "It was a good way to bootleg ideas."

Looking back, one student, whose degree specialized in engineering design, reflected, "For me, it was the first time I had ever really done an engineering design project." In terms of structure, each student team typically worked independently as a unit and had little interaction with other project teams. A Stanford Design Division faculty member served as a project advisor to every student team, so the entire division was engaged with the student projects. Aside from general metrics, course success was primarily measured by annual reviews conducted by Tau Beta Pi, the engineering honor society.

5.4 Era III: Real-World Problems (1975–1981)

As Adams took on different responsibilities at Stanford, the course transitioned to other faculty, including Professor Philip Barkan, over the next seven years. The third era of ME310 focused even more on real-world problems, and the course language reflected an emphasis on the design considerations in manufacturing.

A co-instructor said, "The projects all came out of the corporate world. It was very much oriented to real design. We had clients come in from industry to critique [students'] designs. That was a very positive part of the program." In 1979, Barkan began the tradition of submitting final project reports to the James F. Lincoln Arc Welding Foundation, which sponsors an annual competition to recognize and reward achievement by engineering and technology students in solving design, engineering, or fabricating problems. For many subsequent years, Stanford University dominated Lincoln's college graduate division [22].

5.5 Era IV: Mechatronics (1981–1990)

By the early 1980s, the course shifted again to combine knowledge of mechanical engineering with electrical engineering and computer programming. With the growth in mechatronics and smart products – a class of products that rely on computer processing technologies and embedded systems – design for manufacturability had become a main concern. A project advisor then explained that the objective for students was to "learn systematic tools during design to evaluate manufacturing". One student noted his graduate degree concentration as "mechatronics" in the survey, and another student explained that he took the course because he "wanted to use a CAE (computer-aided engineering) package for a real industry project", reinforcing the growing importance of engineering software then.

By 1988, Professor Larry Leifer was the lead instructor for ME310. He had taken ME310 from Adams as a graduate student in the 1970s and then been involved as a project coach for several years. (Leifer also remembers the 'Philosophy of Design' course he took with John Arnold in the early 60s, which ingrained in him the importance of asking questions, a lesson that Leifer repeats to his students today.) As director of Stanford's Smart Product Design Laboratory, Leifer had earlier expanded the graduate course in mechatronics into a three-quarter series with industry-sponsored projects, in hopes to mirror the success of ME310. He explained, "Mechatronics is a particularly good medium for introducing PBL (product-based learning) because of its dependence on interdisciplinary collaboration" [13].

Working with other Design faculty, Leifer began to formalize elements of the emerging model of design thinking that had become to exemplify the department's teaching, building the foundations for what would become the product design firm IDEO and the Hasso Plattner Institute of Design at Stanford. ME310 became a gradual blend of design research and practice. Leifer also revised the teaching model; instead of assigning a faculty member per student team, he engaged industry professionals, experienced students, and other volunteers as project advisors. These advisors were soon referred to as industrial coaches, recognizing the value of hands-on guidance and mentoring on the student teams.

5.6 Era V: Redesign (1990–1995)

The next era of ME310 gradually moved away from an emphasis on mechatronics to a growing emphasis on rapid prototyping. Student assignments in the first quarter taught them about the journey of product realization, starting with raw product concepts. Students were pushed to iterate and rework all mockups and prototypes, and they were encouraged to fail early and to fail often to

Era	Years	Faculty	Engineering Design Pedagogy	First Mention of Key Phrases from ME310 Course Descriptions
I	1967 - 1974	Fuchs, Adams, Staff	Synthesis	"examination of artifacts and records", "interviews with engineers", "prepare written case histories"
II	1972 - 1974	Staff	Immersive process	"project work accompanied by investigations of the design process", "fabrication", "testing", "team-taught"
III	1974 - 1981	Chilton, Piziali, Liu, Barkan, Staff	Real world problems	"Real engineering projects presented by local industry", "Designs will be developed by small groups of students", "Industrial sponsor", "prototype", "methodology", "patents"
IV	1981 - 1990	Barkan, Chilton, Leifer, Staff	Mechatronics	"Provides experience in technical presentations", "Students unfamiliar with manufacturing process and drafting", "Smart Product Design", "Designs will be developed through hardware phase", "design for manufacturability", "exposure to machine design and design methodology", "industrial 'coaches'", "automation technology"
V	1990 - 1995	Leifer, Staff	Redesign	"Project-centered", "Rapid Prototyping", "design alternatives", "industrial team focuses on methodology", "teaching team focuses on methodology", "design exercises", "incremental test/assessment development cycles", "full-scale functional product prototypes", "projects are formally presented to an industrial audience", "Design Affiliates Conference"
VI	1995 - 1998	Leifer, Cutkosky	(Distributed) teamwork	"Cross-Functional Systems Design", "communication", "Experiences in Team-Based Design", "Team-Based Design-Development with Corporate Partners", "design by immersion", "interdisciplinary, distributed, engineering design-teams", "Series of four design-development cycles", "Work guided by case readings", "socio-technical infrastructure for self-management", "professional coach"
VII	1998 - 2004	Leifer, Cutkosky	Entrepreneurship	"Tools for Team-Based Design", "limited SITN/global enrollment", "entrepreneurial design", "effective engineering design team in a business environment", "benchmarking", "deliverable is a detailed document with specifications", "part of the student's portfolio", "Each team functions like a small start-up company"
VIII	2004 - 2009	Leifer, Cutkosky	Global innovation	"Team-Based Design Global Teaming Lab", "global design team with students in Sweden or Japan", "Project-Based Engineering Design, Innovation, and Development"
IX	2009 -	Leifer, Cockayne	Foresight	"The art, science, and practice of design innovation", "global foresight research team", "anticipatory research"

Table 1. Nine eras in ME310 history.

improve their thinking. One of Leifer's fundamental design axioms became "All design is re-design." He gradually added, "All learning is re-learning. All coaching is re-coaching."

A visiting lecturer, who co-taught ME310 one year, noted: "The course somehow embodied the Design Division. You get physical, you mock things up, you test your ideas in a disciplined and creative way." A student, who later became a project coach, took ME310 because he had heard about the course's reputation: "It was a straight jump into Stanford's design philosophy". Another student echoed this comment, "I thought I would get indoctrinated in the Stanford way of thinking."

During this era, benchmarking and instrumenting the design process became critical, allowing ongoing design activity and knowledge sharing to be recorded by teams. By 1993, all project documentation and team communication tools had moved online. Leifer explained, "The focus is on capturing and re-using informal and formal design knowledge in support of 'design for re-design'" [23]. In 1994, the course was offered remotely to professional students through the SCPD (then called SITN) program, which provided class lectures live via television broadcasts and also on videotapes as a variant of distance education. Although SCPD students missed experiencing lectures in person, most lived locally, so they often joined their respective project teams outside work hours.

5.7 Era VI: (Distributed) Teamwork (1995–1998)

Over the next four years, Leifer increased the emphasis on teamwork, experimenting with different ways to enhance team culture and cohesion. Leifer realized that students in mechanical engineering could not become students overnight in electrical engineering or computer science, and it was more effective if different types of students collaborated and shared skill sets. Leifer built on another axiom that design was a social process. For example, multiple assignments in the first quarter allowed teams to mix up members repeatedly, so students could learn each other's working styles and skills before choosing a final project team. Team formation was directed to achieve optimal balance and diversity by using modified profiles of Myers-Briggs and Jung attributes, which many felt positively influenced project success [22]. A student alumni from this era felt that, of all course activities, participating in group discussions had the strongest value and that providing peer reviews on other projects had lasting value – both which rank highly in team interaction and collaboration.

Other course traditions had become fully indoctrinated, including a weekly beer bash called SUDS (soon translated as a Slightly Unorganized Design Session), which helped establish a sense of community among students. Leifer joked, "I lived off the donut cart at Hewlett Packard, so that was in there as a notion. I learned one can do that; one should do that." In 1996, ME310 was opened to select global team members to further increase team diversity. Professor Mark Cutkosky became a co-instructor in 1997, quickly immersing himself in the ME310 culture and allowing Leifer to step away to establish and oversee the Stanford Learning Lab, now rebranded as the Stanford Center for Innovations in Learning (SCIL).

5.8 Era VII: Entrepreneurship (1998–2004)

Cutkosky led ME310 for the next several years, and the character of the course sharpened even more. The definition of design engineers was broadened in scope to emphasize skills in entrepreneurship and leadership, reflecting the Silicon Valley zeitgeist and growing startup fervor. Stanford engineering students responded positively. The course was an opportunity to learn about "a business environment", develop a corporate-sponsored project that was "part of the student's portfolio", and function "like a small start-up company" [24]. The final report was recast as a "deliverable", adopting business jargon, and the digital collaboration tools were further improved. Cutkosky joked that the course itself is "like a company that has 100% turnover every two years," and the instructors and coaches provided the thread of continuity.

In the spirit of redesign, Cutkosky tweaked several assignments and added several new design methods to the course curriculum. He wanted students to continually challenge their assumptions throughout the design process. He explained, "It grew out of my frustration that students were reaching premature closure" and shrinking the design solution space unnecessarily. For example, the Critical Function Prototype asked students to build a mockup that focused on the one most vital feature of their product concept, which allowed them to refocus and prioritize their efforts, ideally from a user perspective. In addition, the Dark Horse Prototype required students to build a mockup that was potentially promising, but rejected earlier for a preferred approach, in order to revisit first hunches and further push the limits of team creativity. These two methods have since become embedded in Stanford's design ethos.

Leifer returned from his term at the Stanford Learning Lab with new ideas about active team learning and communication. Leifer and Cutkosky decreased the emphasis on global collaboration and instead focused on student interaction. Cutkosky explained, "The challenge is to create a 'community' atmosphere that promotes learning between teams as well as within each team" [25].

Local team bonding increased even more. One student dropped a competing course, which combined mechanical engineering with business skills, because ME310 "seemed more fun, like a community." Another student said, "We had at least one other class party at some point where we did DDR (Nintendo's Dance Dance Revolution) and we regularly did dinner together, took other classes together, did karaoke, went skiing, etc. The teaching assistants were also instrumental in the class bonding, in addition to being good sources of help during the course. I believe that the depth and extent of our class community was more significant than any other class I've seen since." Reflecting on lasting lessons for career and life, a third student from that era reported that, "Personalities affect design just as much or more so than design skills."

5.9 Era VIII: Global Innovation (2004–2009)

Building on what they learned about team collaboration, Leifer and Cutkosky expanded the influence of engineering design in the most recent era of ME310. By 2004, engineering design was truly multidisciplinary, multicultural, and even multi-purpose. Since the mid 2000s, the rhetoric of design thinking had risen, showing the world of business how design provides a viable strategy to convert user needs into market demand. More than entrepreneurship, engineering design was now an essential element of innovation, both in terms of process and outcome. Design was also enmeshed in a global business context, and Leifer was particularly interested in exposing Stanford students to more of the world outside Silicon Valley. By 2005, nearly half of the Stanford student projects were paired with global academic partners, and by 2007, all projects had a sister global team. All global partnerships were organically structured, requiring each student team to actively decide and negotiate their own relationships. Several student alumni commented strongly about learning global team

management, both positively and negatively, as a lesson for their careers and lives.

Students who took ME310 during this era were also more business-savvy, with 30% bringing at least two years of previous industry experience into class. The reasons students gave for enrolling in the course also ranged widely, and one said that he desired the "practical application of design thinking to business proposals." In addition, unlike all previous eras, the students surveyed from this era ranked traditional "soft" process skills – such as project coordination, team management, presentation skills, and startup mentality – as having lasting value, compared to discipline-specific content skills. ME310 was an opportunity to connect with future employers, and 21% of the alumni surveyed said that they received a job offer from one or more ME 310 industry partners. Others used ME310 to build a personal network, and over a third of student alumni were in touch with 10 or more other participants.

5.10 Era IX: Foresight (2009–)

A ninth era has emerged this academic year, focused on foresight. Analysis of the data shows that, from 1967 to 2004, all proposals from industry partners asked students to address an immediate problem, and the corresponding solutions were to be built in the next product cycle. By 2004, industry partners began to extend the project time horizon, requiring students to contemplate solutions in the far future. Sample project proposals described "future elderly environments" and the "technician of the future". Instead of short-term design solutions, a growing number of industry partners wanted students to explore possible opportunities and future users 15 years or more in the future. Figure 3 depicts the steady rise in long-term industry proposals.

Responding to the recent trend, Leifer engaged Professor William Cockayne to develop a sister course, ME410, which was piloted in 2008-09 at Stanford. Built on an existing foresight program underway since 2002, ME410 has taught students complementary methods in foresight strategy and long-range innovation, so that they could develop a broader context for their subsequent efforts in engineering design [26]. Time will tell about the exact nature of this shift in pedagogy and in industry partner interests. ME310 has continued to emphasize design thinking and innovation.

6 INFLUENCE ON OTHER ACADEMIC PROGRAMS

At Stanford University, ME310 has positively influenced the development of other courses, such as the three-quarter course series about smart product design. The
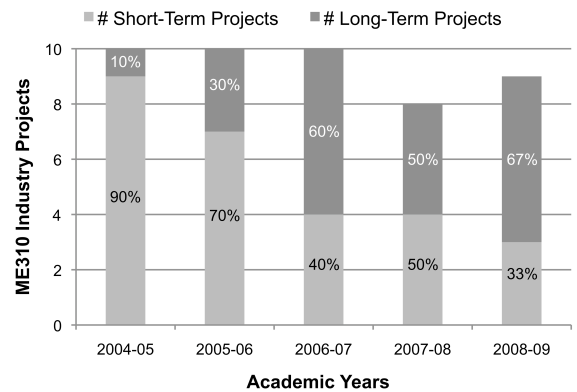

Figure 3. Trend of long-term ME310 industry projects.

broader impact of ME310 has occurred in two primary areas: other American universities and global academic institutions. Table 2 summarizes several example programs directly inspired by the ME310 course model. Please note that this table does not represent an exhaustive list; instead, it is intended to demonstrate a representative diversity of courses. Several ME310 student alumni, who have later become course instructors or faculty, have adapted ME310 entirely or integrated key aspects of the pedagogy to enhance their respective curricula. For example, Professor Natalie Jeremijenko explained, "ME310 has been enormously influential on me, and influenced a whole program I developed as faculty in Yale Engineering, which influenced the ABET accreditors. It has influenced the capstone projects of the environmental studies program at NYU, and at UCSD, and now I am modeling my new systems design masters' degree on the 310 model" [27].

7 CONCLUSION

It is remarkable to witness how one course has had an unusually large effect on the lives of multiple participants, including roughly 3223 students over the years – many of whom have returned to the course as project coaches or teaching assistants – at Stanford University. One student alumna acknowledged the hands-on experience she gained in ME310 and reflected that, "In retrospect, now that I've been out in the workforce, I see what a rare environment and opportunity we had to work in at the [ME310] loft."

University	Location	Year	Course Name
Aalto University	Finland	2007 – current	• Kon-41.4002 – Product Development Project
Loyola Marymount University	U.S.	2006 – current	• MECH/SELP/MBAH 673 – New Product Design and Development
Luleå University of Technology	Sweden	2001 – current	• M7017T – SIRIUS: Creative Product Development
Massachusetts Institute of Technology	U.S.	1980 – 1987	• 2.731 – Advanced Engineering Design • 2.732 – Advanced Design Projects
New York University	U.S.	2006 – current	• Systems Design Masters • VIS149 / ICAM130 – Feral Robotics
Reykjavik School of Art & Design	Iceland	2008 – current	• HFR0122H – HowStuffIsMade
Santa Clara University	U.S.	1986 – current	• ME194, ME195, ME196 – Advanced Design I-III
Univ. of California at San Diego	U.S.	2005 – 2006	• Vis 147B – Feral Robotics
University of Maryland	U.S.	2007	• ENME 472 – Integrated Product & Process Dev.
University of St. Gallen (HSG)	Switzerland	2005 – current	• 7,004-2 – Design Thinking & Business Innovation
Yale University	U.S.	2003 – 2004	• E&AS 996 – SynThesis • ME 386 – Feral Robotics: IT in the Wild

Table 2. Sample academic programs inspired by Stanford's ME310 course

7.1 Research Limitations

While this study's analysis may be illuminating, several limitations in the data are important to recognize. All survey and interview responses are self-reported, and older memories are subject to the vagaries of time. Moreover, the survey sample is not statistically significant, nor does it accurately represent the entire population of ME310. Lastly, the course bulletins were used as a proxy to faculty beliefs about pedagogy and may not necessarily reflect their true intentions, or what actually occurred during the early years of the course.

7.2 Future Directions

This study offers just a start to understanding the complete body of knowledge in ME310. It would be interesting to compare the various eras described here with broader engineering educational trends or economic activity to see if any close linkages exist. In particular, one lens is to examine the pattern of external drivers, such as the changes in the course's industry partners, on the development of ME310. Another question is raised about the changing nature of student development. Has the type of engineering design student changed considerably, and are there any corresponding shifts in student expectations, skills, and backgrounds over the years? Furthermore, extensive ME310 course archives, including student reports and multimedia, provides another source of considerable data that has yet been fully mined. ME310 has an amazing legacy built on 42 years at Stanford University, helping to redefine the frontiers of engineering design. My hope is that this Stanford course has additional decades ahead to pioneer.

8 ACKNOWLEDGMENTS

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