From Dream to Reality: Forty Years of Operation of an Industry-oriented Design Program

M. M. Gilkeson
Harvey Mudd College

Abstract: Post World War Two decades provided substantial change in American engineering education. The immediate trend was toward engineering science, often at the expense of design. Beginning in the mid-1960s, and building on the successes of cooperative engineering programs, practice schools and internships, a new form of practice-oriented design was introduced at Harvey Mudd College. The development and operation of an Engineering Clinic at Harvey Mudd College is described. The paper concludes with a description of efforts to build similar ventures to replicate the Clinic form at other institutions around the world.

Introduction

After WW2, significant changes transpired in American engineering education, especially a trend toward engineering science, often at the expense of design. At Harvey Mudd College [HMC], then a brand new college, we were faced with erecting an engineering curriculum suitable to the post-war world. Beginning in 1961, and building on the successes of cooperative engineering programs, practice schools and internships, we created a new form of practice-oriented design. My quest today is to describe the result: an experiential learning program which now has been an established program for four decades at HMC.

The Initial Task

The emphasis on science in the 1950s engineering education resulted directly from the successes of scientists during WW2 in solving the military's engineering problems, from radar on to the atomic bomb. Departments of engineering science were springing up, often at the expense of the design stem. This swing to the far end of the engineering-science spectrum was widely applauded at the time.

Stimulated by the influential Grinter Report in 1955, many U.S. universities were modifying the titles of their engineering departments to include the word "science." As later summarized by Harris, "The Grinter Committee viewed appropriate partnerships between academe and industry as more or less confined to consulting as a faculty activity . . .."[1]

Into this mix, sprang Harvey Mudd, a new college of engineering and science. The story that I will relate describes our faculty's response to our perceived need for a curriculum which would bridge effectively between practice at the core of professional engineering and the engineering science plus systems courses.

Development of the Program

In 1962, my fellow associate professor, Jack Alford, and I were assigned the task of organizing the design stem of the HMC engineering curriculum. The job was made easier by the fact that the HMC curriculum had been structured as a general engineering program without division into separate departments. However, the task was made substantially more difficult politically, for the handful of engineers were a faculty minority of twenty percent, surrounded by scientists, mathematicians, and humanities professors. Interestingly, the humanists initially became the most supportive of our efforts to build a practice-oriented program.

My partner and I proceeded to do the requisite research. We studied existing programs such as the successful Cooperative education, the Practice School, and Internships. Each mode served quite successful in its setting -- but we noted that the operations took place mainly off-campus. We visited a number of schools and read about others.

We studied professional education in the fields of medicine, law, and education, particularly W.J. McGlothlin's "Patterns of Professional Education."[2] We were inspired by the work and writings of landmark educators such as Lawrence Kubie[3] and especially Abraham Flexner[4], whose work had revolutionized medical education at the beginning of the last century. Flexner's slogan, "we learn by going about" became my own byword.

I should also mention the stimulation provided by the amusing "The Saber-Tooth Curriculum,"[5] by Harold Benjamin (aka J. Abner Peddiwell) --a series of (imaginary) discourses on professional education that take place between a professor and his former student. These informal 'lectures' happen while the two are sipping many tequila daisies in "the longest bar in the world," located in Tijuana, Mexico. [See End Note 1 and Reference 6.]

To quote Time Magazine's 1939 synopsis,[7] "When . . . tigers disappeared, schools nevertheless went on teaching the old fundamentals for their cultural value." New-school educators ". . . found two surviving old tigers, . . . [and] started a Real-Tiger School." Needless to say, the saber-tooth curriculum survived well beyond the extinction of that species of tiger. This may sound familiar to some educators.

A Personal Note

My first in-depth exposure to experiential learning came in the 1950s at Tulane University. I was assigned to develop a Practice School, which would take chemical engineering seniors four days per week to a petroleum refinery for their final semester. A decade of experience in the practice school setting convinced us that, while the lecture mode was "efficient," the experiential mode was more "effective." Moreover, the two teaching-learning modes were complementary. We also found that interfacing experiential programs with industry could be operated without adversely affecting quality of education. And, we learned a lot about selecting viable projects and about the details of managing a non-traditional design program.

In parallel with my experiences, my co-conspirator at HMC, Jack Alford, had spent a decade in industry and a part of 1959-60 at Stanford University, a stimulating experience. But he had come away with the perception that design course outcomes often depended strongly on instructor's background and personality. Some very imaginative design courses simply disappear when that particular professor retires.

My own most interesting work in the 1950s had come via extra-curricular consulting. In addition to the requisite research at Tulane and forensic engineering consulting, I had worked on development of a photocopying process in New Orleans and the design of a paper-coating manufacturing plant in Mexico City. These endeavors were exciting and enjoyable. But, from time to time, I reflected uncomfortably, that such excitement would have been more useful to my students had it taken place on campus in their full view and for them to share.

The Challenge

By 1963, Jack Alford, the Engineering Department Chair Warren Wilson, and I were clear on one point, we wanted to go beyond the lecture format for teaching of design. Especially, we wanted to capture some of the high energy that we could see students were putting into extracurricular activities. For example, in spring 1962 after our noon swim, Alford and I were standing watching Harvey Mudd students who had been working all night building floats for Homecoming. We looked at each other and thought simultaneously that it be would great if we could capture that same enthusiasm inside our design courses. I had expressed similar thoughts about engineers' springtime open houses that I had seen in the Midwest – terrific efforts but extra-curricular. Moreover, Alford and I had come to realize how difficult it was to keep contriving new problems year after year. We wondered: why not reach to community problems which were all around us?

I shall touch only briefly on the intensive effort required for us to proceed from concept to implementation. With our Department Chair, Warren Wilson, providing strong support, we partially calmed the fears of the College faculty, who allowed a two-year trial period for the Clinic. The HMC administration, including President Joe Platt and our then one Dean, Gene Hotchkiss, gave strong encouragement, obtaining start-up grants and providing moral support.

Of course to begin with, the infrastructure that was needed to handle hardware projects was rudimentary. So was our imperfect capability in advising students on authentic projects. We gained momentum and vital support to the effort with the naming as Dean of the College, Jack Frankel, an engineer who was convinced of the value of the Clinic.

With time, we engineering professors became more adept at project advising. The younger, research-oriented engineers began to see the Clinic as an interesting challenge. Then, finally, and absolutely crucial to the effort, was the hiring as Director of the Clinic of Tom Woodson, who had enjoyed a highly successful career in engineering product development. With "Ted" Woodson as a role model, succeeding Clinic Directors have been able to build on and improve the operation.

Engineering Clinic Operations

As implied by its name, the Engineering Clinic is analogous to the teaching Clinic of a hospital, experienced by medical students and their physician-professors. Within the HMC setting, services are furnished for clients from industry, commerce, or public service agencies, while the students are faced with the responsibilities of professional engineering under restrictions of time, budget, and interpersonal relationships. Students participate in Clinic for academic credit during three of their final four undergraduate semesters. Previous papers by Gilkeson, by Clinic Directors Phillips, Bright, and King, [8,9,10,11] and by Don Remer[12] have described much of the detail presented in the following paragraphs.

Each year the Clinic organizes up to two score projects involving a sponsor, three to five students per project team, and a faculty advisor. The student team works with a client liaison on carefully selected, industry and government-sponsored R&D projects. The client liaison is an essential member of the team.

The composition of the team is matched to the professional requisites for solution of a specific problem that originates with the sponsor. A typical team will include both juniors and seniors. The principal location of the activity is on campus, with field trips as necessary to the sponsor's site and to other industrial and commercial centers. Project sponsors pay for and expect professional-quality engineering solutions to their problems. Sponsors retain intellectual property rights.

The Clinic Director's primary responsibility is to solicit projects. The projects are matched to students' interests. This helps ensure their continued investment in the program. The Director works during the summer to obtain candidate projects for the following school year. Before leaving school the previous spring, each engineering student has been given a questionnaire, listing engineering specialties. On this they state their preferences (more than one selection) for the type of project that they would like to pursue in the next year's Clinic.

The team's professor advises, coaches, monitors, evaluates, and provides feedback. Each engineering faculty member serves as a faculty advisor for two projects each school year. Since this task is an important part of every engineer's teaching load, advising the capstone design experience is viewed as everyone's responsibility. It follows that the Engineering Department would not hire an individual who does not believe in the importance of the Clinic Program.

The student team coordinates its activities with the sponsor's liaison to ensure that the sponsor's goals are achieved and that the design experience corresponds as closely as possible to what engineers encounter in actual practice. Thus, the questions and problems that teams face are typical of those regularly confronted by practicing engineers, and the solutions they devise must work in practice, not just in theory. Teams are required to give polished oral presentations to their peers periodically throughout the duration of the project.

Once the fall project has begun, each Clinic team works with the faculty advisor to develop a problem statement. The problem statement is revised until accepted by advisor, company liaison, and the Clinic Director. Project progress is evaluated throughout the year through design review meetings, a midterm report, and in a final 20-minute oral presentation to the college community.

All Clinic teams give a set of three oral presentations on Projects Day in May, with two hundred persons from outside of the College in attendance. As the final activity, each team drafts and revises a formal written report, which is approved by the advisor and then is presented to the sponsor, together with any hardware or software that has been created.

Further assessment of Clinic is provided by the Clinic Advisory Committee (CAC), composed of a score of persons from a variety of companies and disciplinary backgrounds. Included are middle-management engineers from industry and government laboratories in addition to several college trustees. The CAC meets quarterly to provide industrial guidance for the program. Periodically, CAC members attend the meetings at which the student teams give oral progress reports and then will provide formal feedback to Clinic teams on their work and on the presentation.

The CAC also conducts a year-end formal phone interview-survey with each Clinic liaison to evaluate the success of the individual projects. The results of those interviews, which are structured around a prepared survey form, are analyzed and presented to the faculty and to the CAC each year. Together with Clinic reports, the CAC interviews enable the Director and faculty to evaluate the program both as a whole and with respect to individual projects and companies.

The Engineering Clinic: "An Appropriate Technology"

Through four decades of development, twelve hundred projects have been completed at HMC. We have strived to achieve “an appropriate technology” for teaching-learning. There are pedagogic underpinnings for what we have constructed. Along the way, we have been stimulated and reassured by what we found to read on experiential learning. [In particular, see End notes 2 and 3 and References 13, 14 and 15 for enlightenment.]

In sum, appropriate to engineering education at Harvey Mudd College we have achieved the following:
(1) Students have gained the opportunity to form their own bridges between knowledge and practice -- knowledge derived from lectures/reading/interviewing, which is applied through work on real, unsolved problems generated by industry and public-service institutions.
(2) The HMC program has become institutionalized:
  (a) The Clinic does not depend on the personality and longevity of individual professors for successful operation. The Clinic has flourished through five successive Directors.
  (b) Infrastructure has been built up; the Clinic support personnel have gained the know-how and possess the resources to function at the interface with industry.

(c) Client proficiency in working with the College has improved. Better problems are provided; client expectations are more realistic.
(d) Alumni/ae support, especially in bringing Clinic projects to the College, has multiplied.

(3) The Clinic has been absorbed into the mainstream of the curriculum. Design is not merely a capstone activity provided too late to motivate students to learn engineering principles. The design stem occupies curricular space in all of the undergraduate years. [See End Note 4 for description.]
(4) Peer teaching has become a powerful force in educating of engineering students at HMC.
(5) The Clinic has proven a successful tool for continuing education of faculty members.
(6) Curricular flexibility results; projects mirror current client interests: 15% of the upper-level courses immediately reflect latest technological interests of industry and of academia.
(7) Students have been fully exposed to professional level work. When warranted, students are named on patents. In 2005, Clinic sponsors filed 13 patent disclosures at the end of their projects.

Other advantages at HMC include realistic practice of ethics, development of communications skills, and intensive experience in time management. None the less, teaching in Clinic remains a high risk operation. Here are some of the issues faced by the College:
-- To conserve harmony of the Clinic program with the university objectives and methods.
-- To maintain academic quality of the entire engineering program.
-- To retain Clinic educational control in the face of administrative pressure for funding.
-- To balance student's time between formal courses and open-ended practice labs.
-- To balance faculty time -- among lecture preparation, research and consulting, committee work, and Clinic supervision.
-- To balance Clinic projects between interests of faculty and students in their disciplinary specialties and possibly differing needs of the "market" -- i.e., clients' projects.
-- To reconcile the potentially conflicting goals of providing client satisfaction while providing educational suitability to the student.
-- To balance private versus public sector projects; balancing research and long-range projects against applied and short-range projects.

With the help of the faculty/staff and Clinic sponsors thousands of HMC students have built:
(1) A coherent design stem in the engineering program extending from the frosh projects course, through the sophomore experimental lab, to the junior and senior Clinic courses.
(2) A realistic concept of design that extends from problem inception to end product. This involves not only the creation and execution of the design but the management effort as well.
(3) A work-study climate on Campus in which professionals and preprofessional can engage together in the activities and exchanges characteristic of engineering practice.

Program Assessment

Over the years, we have been able to appraise Clinic performance. We have continued to build on the initial structure, providing the infrastructure and guidance that was missing in the earliest days. Bright and Phillips[10] reviewed these efforts in 1999. These data reinforce our belief that the educational path we have taken is a valid one, at least for Harvey Mudd College.

A survey, in 1997, of some thirty recruiters of HMC engineering graduates, rated them on their preparedness for industry found the following. Based on scoring from 1 to 10, with 10 as high,

► Ratings of 8.5 were given for creativity and for attack on open-ended problems.
► A rating of 8.0 on assuming leadership roles, and
► Ratings in mid-7s on familiarity with engineering practice, on management skills, and on appreciation for non-technical aspects of design.

A Clinic sponsor survey, conducted in 1996, rated the Clinic teams on five criteria. The results:

► About 30% of clients rated the team's communication skills and its creativity as exceptional; on the team's technical knowledge: 30% exceptional, 30% good, and 40% fair/poor.
► On teamwork: 30% exceptional and 60% good, and 10% fair/poor.
► On project management: 10% exceptional, 30% good, and 60% fair/poor.

For this last item, it's not clear whether the client responses measured against performance in industry or rather assessed expectations for an undergraduate experience. Incidentally, a 1990 survey of alumni/ae found approval of Clinic, as an educational experience, to be significantly higher for those more than a decade out of school, as compared to the more recent graduates. Our most recent data, for 2005-06, show the following for twenty-six Engineering Clinic Teams:

On Quality of Work:	Outstanding: 9	Very Good: 13	Average: 3	Poor: 1
On Results have met goals:	Yes: 25	No: 1		
On Benefit/Cost:	Excellent: 12	Good: 13	Low: 1	

A majority of our clients continue to support clinic projects the subsequent year. We are showing sponsors return rates of over 70%, and one 1990s survey of ten sponsors placed the project's value to the client at near one hundred thousand dollars. Planning for future sponsorship was deemed to depend equally on business needs and on corporate citizenship.

Spread of the Clinic Mode of Education

A number of efforts have been made to transplant the HMC Clinic model to other institutions both in the US and abroad. These include the University of St. Thomas in Minnesota, the University of Canterbury in Christchurch, NZ, and Kogakuin University in Japan. New colleges such as Rowan University have embraced the Clinic idea. Smith College, an older college, has started a new engineering program which incorporates an engineering clinic.

In mathematics education, the Clinic idea has spread widely. For college-level math it has become common to label the experiential, academic-industry programs as either "Claremont- type" or Oxford-type." The "Claremont-type" program is that utilized by the HMC Mathematics Department and by the Claremont Graduate University, and hence operates in two-semester-long projects in the manner described for the Harvey Mudd Engineering Clinic.

In contrast to the Claremont type of Clinic, the "Oxford-type" concentrates activity into one week, with industrial representatives posing problems and inviting graduate students to tackle a problem provided by industry. Most European Universities utilize the Oxford-type. The Claremont-type clinic idea has spread to Australia and New Zealand and to many other colleges and universities in the U.S. Sites include Cal Poly, Pomona College, Claremont Graduate School, Pomona College, Salisbury State University MD, San Diego State University, San Jose State University, the University of Colorado at Denver, University of Washington, and Worcester Polytechnic Institute.

A final question for contemplation: Should the clinic form be adapted and introduced to the reader's institution? The answer: most likely it would prove feasible to adopt some features. A more important thought to take away: imagination and entrepreneurship should be part of the make-up of all engineering faculties – perhaps not leading to a clinic operation – but why not something else that will stimulate the students in our changing world?

End Notes

(1) The Saber Tooth Curriculum is available at an online site for 44 cents and up – a real bargain! And, the four reviewers at that site each rated the book as five stars. The UNL site[6] gives the flavor of the book. And, quoting Time Magazine,[7] "The Saber-Tooth Curriculum, a satire on educators, consists of a series of lectures on the history of paleolithic education, delivered by a fictitious Professor J. Abner Peddiwell while he drinks tequila daisies at a Tijuana bar.

Professor Peddiwell reports that the three fundamentals taught to youngsters in this curriculum were: 1) fish-grabbing-with-the-bare-hands, 2) horse-clubbing, 3) saber-tooth-tiger-scaring-with-fire. When fish became too agile to catch with the bare hands and horses and tigers disappeared, schools nevertheless went on teaching the old fundamentals for their cultural value. Eventually progressives, insisting that 'to learn tiger-scaring, it is quite helpful to have a real tiger,' revolted against the traditional curriculum, found two surviving old tigers, put them in a cage, had children wave torches in their faces, started a Real-Tiger School."

(2) As sometimes happens, the program invention came for us in parallel to a search for a theoretical basis. However, during the Nineteen Eighties, we became aware of the confirmatory writings of Karl Smith[13] and especially of Richard Schon on "Reflection in Practice."[14]

(3) Is lecturing in the classroom effective? Michael Kane, a psychologist at the University of North Carolina at Greensboro, sampled students' thoughts 8 random times each day for a week. He found that on average, they were not thinking about what they were doing 30 percent of the time.[15] So, is lecturing in the classroom efficient? As lecturers we set up the 'rules' of engagement, defining the course content, the testing, and the evaluation. Thus, not surprisingly, we may consider ourselves 100% efficient in our lectures. It is, we feel, the students who range themselves from "A" to "F".

And, during these past four decades at Harvey Mudd, we have endeavored to follow this maxim:
"If I hear a thing – I forget If I see -- I remember If I do -- I know (understand)"
[Posted in a classroom at the Punjab Engineering College in Chandighar, India and also viewed earlier in Spanish at the Universidad de Carabobo, Venezuela. The earliest version of the proverb is said to come from Confucius.]

(4) In the Harvey Mudd engineering curriculum, the design and professional practice stem includes five required courses which provide students with the means to work in teams on open-ended, externally-driven design projects that, over the course of the curriculum, encompass the following: conceptual design, preliminary (or embodiment) design, and detailed design with "Hands on" exposure to professional practice. To start with, with students undertake challenging design problems in the first year (E4); continue with two sophomore-level courses, a practicum (E8) on drawing and making objects, then an experimental engineering course (E80, which teaches a large subset of fundamental principles through multiple experiments in a number of engineering disciplines), and, finally, three semesters of junior and senior level Engineering Clinic (E111-113). Clinic operations are described for students in a 46-page Handbook which is provided online.[16]

References

(1) Harris, James G., "Journal of Engineering Education Round Table: Reflections on the Grinter Report," Irene C. Peden comments, Jnl. Engrg. Ed., Vol.83, no.1, p.71, Jan., 1994. Also, Grinter, L.E., "Report of the Committee on Evaluation of Engineering Education," Washington DC: Amer. Soc. for Engrg.Ed., June 15, 1955.

(2) McGlothlin, W.J., "Patterns of Professional Education," New York: G.P.Putnam's and Sons, 1960, p.288.

(3) Kubie, Lawrence S., "Neurotic Distortion of the Creative Process," Univ. of Kansas Press, Lawrence KS, 1958, p.129.

(4) Flexner, Abraham, "An Autobiography," New York: Simon and Schuster, 1940. Also see Flexner, Abraham, "Medical Education - A Comparative Study," New York: The Macmillan Co., 1925, p.334; and Flexner, Abraham, Bulletin No. 4, Carnegie Foundation for the Advancement of Teaching, 1910.

(5) Benjamin, Harold, "The Saber-Tooth Curriculum, New York: "McGraw- Hill Book Co., 1939, pp.55-6 (6)
nerds.unl.edu/pages/preser/sec/articles/sabertooth.html. [University of Nebraska, Lincoln site] (7)
Time Magazine free archives, www.time.com/time/magazine/article/0,9171,760925,00.html, Mar. 13, 1939

(8) Gilkeson, Mack and Sant'Anna, Jose Alex, "Administration of University Programs Involving Joint Action of University and Enterprises, VII Pan American Congress on Engineering Education, Rio De Janeiro, Oct. 1976

(9) Phillips, J. R. and Gilkeson, M. M., "Reflections on a Clinical Approach to Engineering Design, DE-Vol. 31, Design Theory and Methodology, ASME 1991

(10) Bright, Anthony and Phillips, J. R., "The Harvey Mudd College Clinic, Past, Present, Future," Journal of Engineering Education, April, 1999, pp 189-193

(11) King, Joseph, "A Recommendations for the Long-Term Success of Industrial Collaboration in Engineering Training Programs," Proceedings of FEDSM2003, 4th ASME/JSME Joint Fluids Engineering Conference, July 6-11, 2003 Honolulu, HI

(12) Remer, Donald S., "Experiential Education for College Students: The Clinic, What It Is, How It Works, and How to Start One," NLA Monograph Series, 1992, Truxal and Visich, SUNY-Stoney Brook NY.

(13) Smith, Karl A., "The Nature and Development of Engineering Expertise." Proc. 1988 ASEE Ann. Conf., pp.569-78

(14) Schon, Donald A., presentation on "Marrying Applied Science and Artistry in Engineering Education: Recovering from the Last Reform," Paper presented at 1988 ASEE Ann. Conf., Portland OR. See also "Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions," San Francisco: Jossey-Bass Publishers, 1988.

(15) Ritter, Malcolm, The San Diego Union-Tribune, from the Associated Press, March 20, 2007

(16) Clinic Handbook link in http://www.hmc.edu/acad/academicdepts/engin.html