REPORT OF THE 2025 COMMITTEE

ON UNDERGRADUATE ENGINEERING EDUCATION

1. Introduction

The science of learning may not be well understood, **but as the saying goes: "Tell me and I forget, show me and I remember, involve me and I understand".** There is evidence that this statement is correct. The question is how can we transform our education from the current "tell-me" mode to the "involvement" mode? Several approaches have been developed, variously referred to as "inquiry-based", "project-based", and "engaged" learning. The central element of all these approaches is the involvement of students in their own learning experience. This inculcates in them a desire for acquiring new knowledge, and lifelong learning is a positive outcome.

The delivery of education is local, but the competition that our students face is global. Technical challenges that they will encounter will be constantly changing, requiring conceptual understanding and mental agility, excellence in oral and written communication and knowledge of the outside world. If we are successful in producing such students, they will be able to compete effectively with the outside world and may have an edge over the competition as well.

To address the two challenges outlined above, Dr. Enrique Lavernia, Dean of Engineering, constituted a committee that is referred to as the 2025 Committee. Its members in alphabetical order are: Diran Apelian; Kyriacos Athanasiou; Chen-Nee Chuah; Bruce Gates; Michael Hardwick (Sandia); Subhash Mahajan (Chair); Prasant Mohapatra; Dan Sperling; George Tchobanoglous; and Jean VanderGheynst. The committee deliberated on various challenges over a period of six months. Its report is given below.

It is divided into the following sections: trends in student enrollment and persistence in engineering; characteristics of students entering as freshmen in engineering; desirable traits of future engineering students; implementation; and summary.

2. Trends in Student Enrollment and Persistence in Engineering

It is important to consider the current demographics, preparation and interests of our engineering student population and how these might influence training of future engineers. The College of Engineering currently offers fifteen different majors with training in a variety of fields. Enrollment data for all majors are provided in Table 1. Historically, our largest majors have been Civil Engineering and Mechanical Engineering. Biomedical Engineering began accepting students in 2002, which has grown rapidly with a 2010 enrollment of 332 students.

Table 1. Enrollments in Engineering Majors at UC Davis

Major	2006	2007	2008	2009	2010
Optical Science & Engineering	44.5	29	19	18	14
Biological Systems Engineering	166.5	166.5	136.5	145.5	136
Biomedical Engineering	202	268.5	268.5	291.5	332.5
Civil Engineering	576.5	590.5	604	633	678
Chemical Engineering	233	234.5	241.5	244.5	256.5
Materials Science & Engineering	28.5	25	26	34	34.5
Biochemical Engineering	77	90	92	100	84
Chemical Engineering/Materials & Engineering	25	22	28	34.5	40
Electrical Engineering/Materials Science & Engineering	11	10	19	16	8
Electronic Materials Engineering	N/A	N/A	N/A	4	14

Computer Science & Engineering	273	263	262	245	261
Computer Engineering	235.5	208.5	182	181.5	179.5
Electrical Engineering	306.5	291	306	289.5	277.5
Aeronautical Science & Engineering	190.5	179	173	183	104.5
Aerospace Science & Engineering	N/A	N/A	N/A	4	103
Mechanical Engineering	386.5	373.5	363	409	447
Mechanical Engineering/Materials Science & Engineering	32	32	29	26	33
TOTAL	2788	2783	2749.5	2859	3003

An increasing number of students are interested in pursuing engineering, see Figure 1.

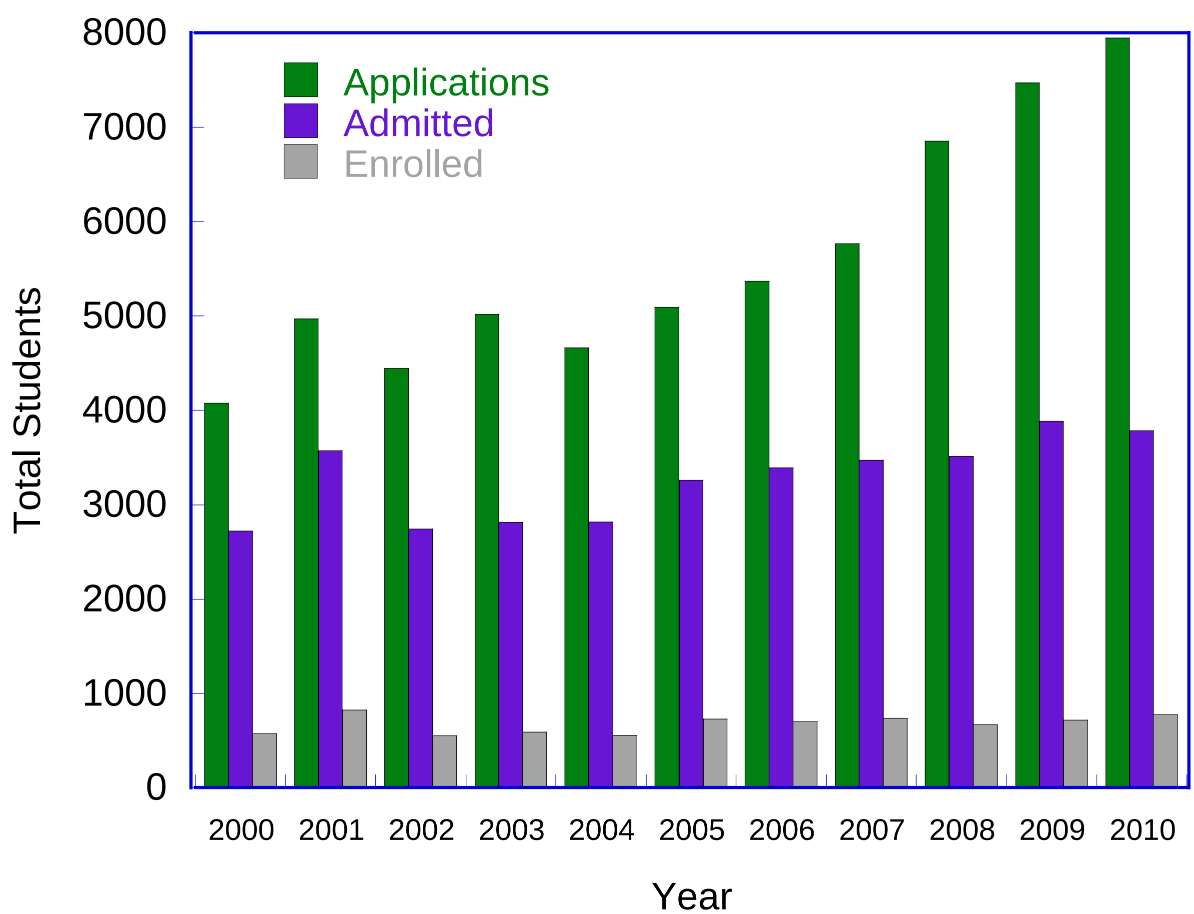

Figure 1. Application, Admission and Enrollments of Engineering Freshmen

Our applications at the freshman level have increased steadily since 2005, going from 5,100 to 7,900 in 2010. Despite this increase, our freshmen enrollment has increased only slightly from 733 to 777 in this same time period. This is due to the CA resident enrollment target for the College that is set by the campus. **The data suggest that there may be an unmet demand for training in engineering in the State.**

We attract a relatively diverse pool of students to our majors. Our total enrollment in 2010 consisted of 23% women and 17% from groups historically underrepresented in engineering (URMs). Currently, our non-resident international population is only 1.75% of our total undergraduate enrollment. This is expected to increase as major efforts are underway by the campus to increase the number of non-resident students at UC Davis. This change in demographics and increasing enrollment (there is no enrollment cap for non-residents) may result in some short-term challenges related to resources, but offers enormous opportunities for broadening the awareness of our native CA student population to other cultures and societal needs outside the US.

The quality of our incoming students has also improved substantially based on standard measures such as high school GPA and SAT scores. Table 2 shows that we are attracting high caliber students to our programs. These students should have the technical abilities to do well in engineering. However, we experience a significant loss of students to other majors or institutions. Of the freshmen who entered the College of Engineering in fall 2004, only 47% completed degrees in engineering. However, more than 85% of transfer students complete their degree in engineering**. Transfer students must complete all lower division coursework prior to joining Davis and may be more committed to succeed in engineering**. This may also imply that we may need to manage better deficiencies of our incoming students who are admitted directly to the University.

Table 2. Average GPA and SAT Scores of Enrolled Engineering Freshmen

Year	HS GPA	Math SAT	Writing SAT
2006	3.78	636	549
2007	3.79	627	555
2008	3.86	638	557
2009	3.89	649	570
2010	3.90	649	582

There are many reasons why a student entering as an engineering freshman might not complete his/her degree in engineering. These could include a lack of interest in engineering and poor preparation in the fundamentals needed for success in engineering coursework (math, physics and chemistry). In 2009-10 244 students changed majors out of the College of Engineering and 188 changed majors within the College. This is a very strong indication that when many students apply to UC Davis they are uncertain about the major that best fits their interests. The average GPA of students changing majors out of the College was 2.83. This is well above good academic standing (GPA = 2.0), **indicating that some students leave engineering for reasons other than poor performance.** Furthermore, of the students who left engineering, 32% were women and 18% were URMs**. Novel teaching approaches are needed that address the disproportionate loss of women from engineering.**

There is a tremendous variation in the rigor and quality of high schools in California and advanced courses may not be available at every institution. As a result, the students admitted to Davis arrive with a broad spectrum of preparation. For instance, some students entering as freshmen have completed sufficient AP course work to advance two courses in the calculus series, while others might need to begin in pre-calculus courses. We certainly have had very successful students graduate with degrees in engineering that began in pre-calculus as freshmen (one that comes to mind works at NASA and is starting graduate school at Stanford), but their experience is very different from that of a student who comes to Davis with significantly more preparation. Also, weak preparation is often associated with schools that serve high populations of URM students**. If we are to continue to improve the diversity of the student population in engineering, the variability in educational experiences of incoming students will need to be addressed.**

3. Characteristics of Students Entering as Engineering Freshmen

The students entering UC Davis as freshmen arrive with distinct personal, social, and academic experiences. These experiences also color their outlook on the world, and define their identities. These in turn affect the meaning they ascribe to attending college. By better understanding these perceptions, we gain insights into how students see the world around them. From such anecdotal observations, coupled with other rigorous evaluations, our programs might be able to deliver instructional material more effectively. One source of these perceptions can be gleaned from student-authored reflection papers (journals), submitted as part of introduction to engineering seminar held in fall of 2010. The following briefly highlights a few of these perceptions and qualities that most frequently appeared in these reflections.

3.1. Personal accountability

"For high school the midterm I would take I would not study for them and I still got an A or a B but in college I study for hours and I still find myself not doing the best in the test." – Glenn

Many students like Glenn expressed frustration with the change in their performance. The common belief is that because success came so easily in high school, the same effort will again result in success at Davis. Students like Glenn are accustomed to meeting high school standards and earning strong grades. When the pattern changes at a university, it can be a real struggle for some to adapt and accept. **Time management becomes a major issue**. For some students in the course, poor grades were an early warning that the level of expectation had changed and, therefore, study habits would need to be modified. In other instances, however, some went on to assign blame elsewhere – problems understanding the instructor, an uncooperative teaching assistant, a roommate, or familial concerns at home tended toward the more plentiful reasons**. The imperative here for educators is not a new one: assist students, particularly freshmen, in realizing that the transition to college includes increased demands and productivity..**

3.2. Learning outcomes

"The problem is, [the instructor] expects us to do hours upon hours of projects for this class. We are required to report how many hours go into each assignment, and the last one alone took 19 hours of work. Yes, we had several weeks to complete this, but it was not an easy task…." – Ronald

It can be difficult for some students to see the "point" of precise, sometimes tedious assignments. Rather than seeing these as opportunities to develop patience and attention to detail, the workload is deemed to be a "problem." Again, we see the student retreating to his high school experience work habits and believing that assignments are constrained to short, discrete intervals. Such behaviors highlight the disparity between secondary and post-secondary expectations and methods. At the same time**, this also presents an opportunity to articulate with high schools a more comprehensive and realistic "college prep" curriculum that accurately reflects the variety and quality of work performed at a college level.**

3.3. Asking for help

"I want to go to office hours of all my classes, but I can never think of any questions to ask. I do not have any specific areas which I have trouble with, the only time I have trouble is when I am taking a quiz or a test." – Rachelle

Rachelle shares a common refrain often told to advisers. Many students resist asking questions during office hours, either because of feeling embarrassed or simply because they are unaccustomed to asking for help (pride), or both. This further enhances the anxiety and can manifest during an exam and often leads to continued poor performance. This comment also underscores how disjointed some students feel from their education. Rather than seeing oneself as an active participant capable of effecting change, some will resign themselves to a passive observer role. **The challenge here, perhaps, is to use a different method of instruction that requires students to interact with others in the course. By working in teams, those students who may shy away from speaking up may feel more inclined to so do in a smaller group setting.**

4. Industry Perspectives of Engineering Graduates

UC Davis engineering graduates, with generally strong analytical skills and some level of design experience, are well equipped to contribute to their employers' missions as entry level engineers. While the graduates' education enables them to successfully begin their engineering careers, **it typically has less impact as they encounter more complex engineering problems, ones that are difficult to structure and that present challenging constraints. A curriculum that better prepares graduates to address these real world issues would set the UC Davis College of Engineering apart from others.**

Because the current curriculum focuses on basic skill development, most problems posed in the academic context are well formulated, but do not represent complex real-world engineering problems. The engineering development process is iterative and includes problem formulation, scope definition, requirements negotiation, constraints identification, conceptual design and engineering trade-offs, cost and schedule estimation, full scale development, and qualification or verification. The process is punctuated with a variety of formal reviews. More often than not, these problems span multiple engineering and science disciplines through which the responsible engineers must navigate. Rigorous engineering processes carefully document and version-control all project definition information. **Throughout the development process, engineers must struggle to make trade-off decisions with less than optimum information and within bounds presented by practical constraints. A curriculum that requires engineering students to understand and practice these skills through thoughtfully considered projects would produce graduates more able to address complex engineering problems**. Soliciting input from industry sponsors would facilitate the development of engineering design problems suitable for an academic context, but that contain real-world engineering challenges.

If the College of Engineering aspires for its graduates to address the most challenging and important national and global problems, it must create a multi-disciplinary environment that fosters creativity and innovation early in their career. Unfortunately, the traditional academic institution is organized, perhaps stove-piped, by discipline. Often, different disciplines do not share common space and opportunities to interact, both for students and faculty, are limited. Interdisciplinary interactions among faculty members are an exception, not the rule. **The college should consider alternative organizational or space utilization constructs that promote more interaction between engineering disciplines. Taking this thought a step further, the College should expose its students to non-engineering disciplines with whom they will interact after graduation, such as business, economics and policy.**

An important skill for any engineer is to clearly and concisely present information to both technical and non-technical colleagues and customers. Important considerations include what to say to a specific audience and how to most effectively convey that message. These skills are developed principally through practice. **Unfortunately, most engineering students are uncomfortable orally presenting**

information and they shy away from practice opportunities. Typical engineering curricula under utilize instruction and practice in this area. Creating a venue through which students can present information to industry partners and receive constructive feedback is a good first step that the College can take. **Building such a mechanism into the full curriculum so that the students' skills can develop throughout their academic career is a worthy goal.**

Finally, engineering students rarely graduate having spent much effort considering how they might impact the world's most important and challenging problems – Grand Challenge problems. Here, technical issues are intertwined with policy issues and understanding how they interact is critical. Seminars that help students develop an understanding of these interactions can greatly enrich the academic experience and set a student on a path for a personally rewarding career with great impact.

5. Desirable Traits for Engineering Students

The engineering training students received in the past has generally served them well. However, given the rapidity with which change is occurring in the 21st century and global competition, it is clear that the engineers of the future will need new skills and traits to be productive and competitive in an ever changing world. Some of the key traits that will be needed are identified below.

Critical thinking based on conceptual understanding of core knowledge

Faculty members strive to develop a conceptual framework of core knowledge for students so that they can reason with them. This goal must always remain central to teaching objectives, even as students become more and more proficient in the rapid acquisition of facts and software for making predictions and doing designs. There is a need to make the understanding of fundamentals more central to our teaching. It is also essential to understand how the knowledge can be built further on the foundations of fundamental knowledge base. **Critical thinking to assess the veracity of information that emerges from various sources, including the Internet, will be essential in the future.**

5.1. Ability to write and speak well

Engineering students have long had the reputation of not being able to write proficiently and clearly. Many faculty members believe that the lack of motivation to master the written word in English may be reflected in the lack of the mastery of technology. Also, more foreign students are joining the university and are learning in a language that is not their first language. There needs to be a realization that written English is a necessity for today's engineers and that English is rapidly becoming the language of science and technology worldwide. **Improved approaches are needed to help students improve their skills in English.**

5.2. Ability to design in a multi-dimensional space

A capstone design class that may last more than half an academic year is a critical element in engineering curricula. Students take technical courses early in their studies, but these courses are mostly theoretical, with their practical ramifications often not understood or lost**. New strategies are needed for a pilot program that will allow a group of selected students to enrich their core studies with projects that engage them in design. Such programs and or projects could begin as soon as the first year.** This project-based learning would encourage students to acquire on their own interdisciplinary knowledge in fundamentals. This recommendation is not novel, as there are already other institutions that are practicing or considering continuous design. Aspects of the design process not emphasized currently can play a more important role early in the curriculum. **Design criteria should include economics and environmental issues, policy and political constraints, entrepreneurship, and leadership.**

5.3. Recognition and understanding importance of economic realities

In some developing countries, the principal criterion in designing medical instruments or devices is cost. Amazingly, it is well known that there are artificial joints whose retail costs are at least one order of magnitude (if not two) lower than equivalent designs in the US or other developed countries. Although an attempt is made to introduce economic considerations in engineering programs, they do not enter the design domain as robustly as they might. Simply put, the faculty does not view economic issues as important as other engineering considerations. Engineers are uniquely capable of embarking on designs that are based on constrained optimization, whereby a main optimization parameter is cost. **Knowledge of economics can be central when it comes to design. In future course offerings, efforts should be made to incorporate economics as an important element of engineering design**

5.4. Understanding elements of entrepreneurship and innovation

In June of this year, the inaugural Biomedical Engineering Entrepreneurship Academy was held at UC Davis. Its objective was to provide the participants with a solid understanding on how research moves from laboratory to commercialization and application. As was reported in the proceedings "while…capstone design courses are a core of most academic programs, and there are national design competitions…, there are far fewer training programs that demonstrate how to commercialize inventions or design innovations." **Although it is not envisioned that all students will participate in entrepreneurship academies, the elements of entrepreneurship can be taught and promoted in engineering design courses, along with economic considerations discussed above.**

5.5. Engineers as captains of industry

In the past, it was common for engineers to be Chief Executive Officers or Presidents of successful companies. Unfortunately, it now appears (anecdotally) that fewer and fewer engineers run companies. Clearly, it appears that managing a company does not seem to be part of an engineer's life or career trajectory at the current time. Since not all engineers will receive MBA degrees, elements of business administration and leadership should enter the design or didactic aspects of educating future engineers. **Exposure to elements of business administration and leadership would offer insight to future decisions engineers make as the move up within an organization.**

5.6. Political astuteness

On August 8, 2011, the New York Times published an article titled "Groups call for scientists to engage in the body politic" which highlighted the absence of the "technically trained" in politics, as well as popular culture. As an example, it was noted that "according to the Congressional Research Service, the technically trained among the 435 members of the House include one physicist, 22 people with medical training (including 2 psychologists and a veterinarian), a chemist, a microbiologist and 6 engineers." The paper cited the well-known aphorism that technical people tend to avoid the "irrational hurly-burly of politics." Consequently, the politicians, who make decisions about energy, healthcare reform, space exploration, climate change, transportation, and so many aspects of everyday life that are solidly based on science and engineering, may not be well-equipped to make well-informed, scientifically based decisions. Engineers increasingly should be in leadership positions in government or policy-making. Educators must change their tendency to ignore politics, as many aspects of our profession—and our lives—are affected by political decisions. **The faculty should identify opportunities for engineers to engage in politics by serving in positions such as governmental internships whereby they can learn how the political system works.**

5.7. Internships abroad

Currently, many universities offer study abroad programs. These programs have many positive features and allow students to spend one to two semesters abroad. The students take courses at foreign institutions that are generally credited towards their curricula requirements at their home institutions. Over the years, a large number of students have benefited from such programs. However, we feel that an internship abroad program may be more beneficial for our engineering students. It has basically two advantages. First, students complete course work at home institutions. Second, their interactions with foreign hosts are much more intense in the working environment**. We suggest that we initiate an "Internship Abroad" program in engineering.**

6. Implementation

This section discusses how we can transform our undergraduate engineering education to prepare our students to tackle pressing global grand-challenges, and to achieve the desired traits that we identified in the previous section. In particular, our engineering curriculum should build in experiences for students to develop skill sets that are traditionally not taught in our classrooms, including better communication (both presentation and technical writing) skills and entrepreneurship, and exposure to the design and innovation process that takes into account real-life constraints from economic, social, and political perspectives.

6.1. Pilot program: overview

We propose to start with a small-scale pilot program, consisting of 25 students, to determine the feasibility of a *design-centric* undergraduate curriculum. The learning outcomes should be clearly defined for this pilot program. We expect the performance metrics to be derived from the list of desired traits (e.g., better communication skills, performance in design projects or internships, appreciation of economics, etc.). **An evaluation strategy needs to be crafted to validate the outcomes.**

To allow time for faculty recruitment and curriculum development, we envision that the pilot program will be launched in 2013, with proper advertisement to promote the awareness of this opportunity to prospective students. The pilot program will be inter-disciplinary in nature, and will accept applications from students across all majors within the College of Engineering. **To ensure that the students in the pilot program exhibit a similar diversity (in terms of aptitude, high school preparation, demographics, etc.) seen in the incoming freshmen class for the College, we propose to randomly select the 25 participants from the pool of applicants.**

To make a fair comparison of the outcomes between the pilot program and the traditional curriculum, we should consider three cohorts of students: (i) student participants in the pilot program, (ii) students who apply to the pilot program but are not selected, and (iii) students in the traditional program who do not apply to the pilot program. We hope that this will minimize any bias introduced by the inherent personal traits of the students, e.g., highly motivated students are more likely to apply to the pilot program, and hence if the selection is based on academic performance, it will be difficult to gauge whether students in cohort (i) do well because of the features of the pilot program or because the students are better to start with.

The students participating in the pilot program will take a combination of rigorous science & engineering courses (as required by the different majors) and a set of new courses that cover entrepreneurship, technical writing, economics, and design/innovation process. Since additional courses will be introduced to the curriculum, we need to ensure that the pilot program does not increase time-to-degree for the participants. In addition, there should be no penalty for the participants to opt out of the program at any point in time.

6.2. Key features of the pilot program

A critical feature of the program will be courses that engage engineering students in learning leadership, social, entrepreneurship and global skills and how these skills are applied in solving grand challenges. New courses will be developed to support these goals and designed to satisfy general education and engineering elective requirements for our majors. Note that the key challenge here may not always be in generating new course content, but in identifying a set of important topics that form a coherent theme (e.g. sustainable design process) and coordinating a series of lectures that can potentially involve instructors from a wide variety of disciplines. The pilot program should also leverage and engage in existing and new programs/initiatives on campus. All participants in the program should be required to take at least one course in a campus initiative area. Current areas include sustainability, energy and foods for health**. Project-based, design-centric learning in a sequential set of courses will be used to facilitate student learning in leadership, social and global skills, while allowing students to address a**

current problem facing society. Courses will complement the course sequence for math and science in the engineering curriculum and requirements for program accreditation.

To retain a cohort of students and ensure continuity in participation, required courses will be offered every quarter. Each course will be 1-2 units and collectively designed to satisfy communication (oral and writing) requirements. In addition students will be allowed to elect to have courses satisfy general education requirements under the social sciences designation and topical breadth areas of American and World Cultures. Courses will be designed and offered by new faculty hired under the 2020 Initiative of the University.

In addition to coursework the program will be designed to facilitate the participation of students in enrichment opportunities identified under the 2025 grand challenges. Students in the program will be required to complete an undergraduate research experience or internship or education abroad experience as discussed above. Research and internship experiences could be with industry partners, UC Davis faculty, and national laboratories.

Upon completing the program students will have an ability to communicate technical material to a broader audience, lead teams of interdisciplinary students and appreciate the broader impact of their work in a global context. In addition to a degree in their selected engineering major students will earn a certificate upon completing all requirements of the program at graduation.

6.3. Issues to be considered

Several issues need to be carefully considered for a meaningful pilot study of the proposed plans. These issues include the selection of students, faculty recruitment, faculty load, incentives, and metrics for outcome assessment.

The process of selection of students should be done carefully to reflect a broad spectrum in terms of capabilities, diversity, preparedness, economic background, and interests. We need to also make

contingency plans such that opting out of the experiment anytime should not have any impact on a student's graduation schedule.

The pilot program will require substantial commitment of faculty time and effort. Undoubtedly a few additional faculty lines (2 to 3) may be needed during the pilot program. A combination of new faculty and release time for existing faculty could be used. Another approach would be to include incentives such as credits for merits and promotion. Additional teaching assistants and IT resources will be required. Involvement and interactions with industrial partners would be highly desirable and should be facilitated.

One of the most critical aspects of the pilot program would be outcome assessment. Metrics should be carefully chosen to quantify the outcome of the pilot program. The metrics should be easily quantifiable and must reflect the goals of the program. We may want to observe short-term metrics for quantifying immediate impacts, and then must track longer term impacts and quantify those metrics too (in future). **During the pilot program, we will certainly learn from our successes as well as from mistakes and must have a mechanism to record the best practices and make implementation changes as needed.**

7.Summary

The 2025 Committee has put together a design-centric educational plan for our engineering undergraduates. Its salient features are as follows.

1. Critical thinking based on conceptual understanding of core knowledge,
2. Ability to write and speak well,
3. Ability to design in a multi-dimensional space,
4. Recognition and understanding of economic realities,
5. Understanding entrepreneurship,

6. Political astuteness, and

7. Internships Abroad.

We envisage that the changes suggested in the above plan will prepare our engineering well to face future challenges and compete effectively in the global arena.