Beyond Study Abroad: Preparing Engineers for the New Global Economy

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Abstract

Rapid change in economic and political conditions in China, India, and other countries has already begun to affect corporate planning for the engineering workforce in the U.S. To remain competitive in the ever-changing global workforce, American engineers must develop broader perspectives and new teamwork and entrepreneurial competencies to supplement preparation in the traditional technical subjects. Although a semester-long study-abroad experience is a valuable part of an educational program aimed at providing these competencies, this paper discusses the value of supplementing such programs with broader and more comprehensive approaches. In particular, a program with distributed and progressive experiences in teamwork, entrepreneurial thinking, and pervasive design and innovation experiences are described.

Background

Several recent studies [1-3] have identified major global forces likely to change the role of engineers in the future. The effects of these forces may already be seen in the recent rise in production of engineering graduates and the demand for engineering services in Asia, India, and elsewhere[1]. The studies make the case that American engineers will need a broader set of competencies to remain competitive in the face of rapidly increasing numbers of engineers in the global workforce that are now willing to work at lower cost. While continued strong technical skills are implicit, the NAE report on Educating the Engineer of 2020 lists "team, communication, ethical reasoning, and societal and global contextual analysis skills as well as understand work strategies" as essential for the American technical workforce of 2020 [5]. In addition, they identify attributes beyond technical competence including "creativity, ingenuity, professionalism, and leadership [6]."

Compared with U.S. graduates in other disciplines, engineers are differentiated primarily by their strong preparation in technical subjects, such as applied mathematics, engineering sciences and design. On American campuses, engineering students generally have less flexibility in their program of study and take subjects that are known to be among the most demanding[2], compared to students in many other fields of study.

On the other hand, when compared to engineering graduates in most other countries, U.S. graduates take programs with considerably more flexibility and breadth and less depth in required technical subjects. In some cases, U.S. engineering graduates have substantially less preparation in technical subjects than their counterparts abroad and instead have more exposure to subjects that correlate with creativity and social context of complex problems. This is a primary differentiator of U.S. engineers versus those who are educated abroad.

Furthermore, the advice given in recent studies is to broaden the preparation of engineers further still, to address the need for increased competency in teamwork, communication, entrepreneurial thinking, creativity and design, and cross-disciplinary thinking in a global context. This breadth in preparation is an important dimension to the preparation of American engineers for the global challenges of the future.

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[1] While there is some debate about the accuracy of the numbers involved in comparisons of graduation rates of engineers in China, India, and the U.S. [4], many knowledgeable observers agree that significant imbalances exist now and trends indicate growing imbalances in the future.

[2] For example, the general education requirements in the physical sciences and mathematics on many U.S. campuses have been weakened over the years, further increasing the relative rigor in the preparation of engineers as compared to those with majors in history, English, psychology, and other non-technical majors.

Study abroad programs provide an important component of the education of engineers for the global challenges ahead. When well conceived and implemented they result in (1) an ability to work productively on teams involving those with very different cultural values, attitudes, and abilities, (2) a sensitivity to the opportunities and challenges presented to engineering endeavors in other regions of the world, and (3) an appreciation of the limitations of the U.S.-centric view of the world, including the international perceptions of U.S. strengths and weaknesses. As a result, it is tempting to consider adequate global preparation of engineers as the combination of a rigorous technical program of study combined with an effective semester-long study abroad program.

This raises the question whether such a combination is, in fact, the best we can do to prepare our engineering graduates for global competition. In response, I propose that significantly better preparation may be provided by a more comprehensive approach in which the study away experience is but one component of a spectrum of teamwork and non-technical experiences integrated over a four-year program.

Preparing Engineers Beyond Technology

The vision for the engineer of 2020 proposed by the NAE includes significantly broadened competencies in areas that extend well beyond technical fields. Fundamentally, these competencies are more about people skills, personal creativity, attitudes and experiences than they are about increased technical knowledge. To some engineering faculty members, this may raise several concerns. First, these new competencies do not seem to be well aligned with the subject matter traditionally included in engineering courses (and therefore the competencies of most current faculty members). Secondly, spending a higher percentage of the limited time available for instruction on these subjects would seem to further weaken the technical preparation of U.S. engineers in comparison with those from other countries. Before undertaking such a non-intuitive approach it is important to address these concerns.

To begin, the assumption underlying most traditional engineering curricula is that math and science are the foundation for success in all engineering endeavors. Building on this assumption, we have developed admission criteria that place an emphasis on academic performance and test scores in these subjects, and we have selected faculty members who are superbly prepared in research in these fields. The traditional engineering curriculum is also strongly focused on technical subjects aligned with this assumption. We then attempt to provide some degree of non-technical education by requiring students to take a limited number of courses outside the technical fields, but this is usually limited to about ¼ of the total program requirements (often less).

However, the correlation of long term career success of engineering graduates with their test scores, grade point average, and number of technical subjects taken is not as high as we might expect. Instead, it is not uncommon to find highly successful engineers in industry and elsewhere whose academic records would have given little indication of this potential.

One possible interpretation of this phenomenon is provided by modern theories of brain function and of education. For example, in 1983 Professor Howard Gardner of Harvard University proposed a theory of multiple intelligences [7]. Gardner proposes that all people have a complementary set of largely independent abilities or “intelligences” that work together in practice to allow them to solve problems and fashion products of value within their culture. According to Gardner these intelligences include (1) linguistic, (2) logical-mathematical, (3) spatial, (4) bodily-kinesthetic, (5) musical, (6) interpersonal, and (7) intrapersonal intelligence. (In a later work [8] Gardner identified an eighth form of intelligence, naturalist intelligence.) According to Gardner, each of these intelligences is present in all humans, and localized to specific areas within the brain in varying degrees, as demonstrated in studies of individuals with brain damage, educational development in individuals with unusual abilities and inabilities, historical investigations of human evolutionary biology [7], etc. Gardner points out that in the 20^{th} century American higher education focused on the first two intelligences as fundamental to intellectual achievement. The next three are often regarded as the basis for artistic achievement, and the last two for success in social settings, including marketing, management, and influence. He reports that such quantitative indicators of overall intelligence as the IQ test and the SAT test are largely correlated with the first two forms of intelligence.

Within engineering education a strong case can be made that we have emphasized the first two forms of intelligence in formal education and given much less emphasis to all the others. Admission criteria to our colleges generally emphasize SAT scores, grades in math, science, and courses that emphasize reading and literature. The process for selection of our faculty members also emphasizes these abilities much more than the others. But it is precisely these other forms of intelligence that are likely to be of primary importance in developing the full set of competencies for the engineer of 2020. This raises the question of whether we are attracting the right people into engineering to achieve our goal.

Other independent work in the cognitive and neuroscience fields lends additional support for this basic conclusion. The Nobel Prize-winning work by Roger Sperry in the 1960s [9] demonstrated that the two hemispheres of the brain operate largely independently. In particular, Sperry concluded that the left brain largely reasons sequentially, is excellent at analysis and processes words. In contrast, the right brain largely reasons holistically, recognizes patterns and interprets facial expressions. Sperry's work forms the basis for more recent work [10] that correlates the dominance of one or the other hemispheres with gender, handedness, and other characteristics. The different intelligences of Gardner are located in one or the other or both hemispheres, and the overall "intelligence" of each person is the combination of these various distinct brain functions and the apparent balance between them.

Robert Sternberg [11] developed a "triarchic" theory of human intelligence that identifies three independent forms of cognition. These include analytical, creative, and practical intelligence. Sternberg, who is now Dean of the School of Arts and Sciences at Tufts University, is exploring the application of this theory in the development of new admission criteria for Tufts intended to render a student body with a better balance between these three forms of intelligence.

While it is possible to extend the implications of these research findings beyond the validity of the data, the general picture that emerges is that to produce the engineer of 2020 we may need to broaden our focus beyond the traditional linguistic and logical-mathematical intelligence that is currently dominant in engineering education. Certainly these will continue to play the central role in engineering, but the other intelligences associated with artistic and social endeavors may need to be elevated significantly within our value system, in everything from the criteria for admission of students, criteria for selection of faculty members, and the relative balance between technical and non-technical content in our academic programs.

General Implications for New Educational Approaches

In 1993, Gardner [12] recognized the implications of multiple intelligences for the design of the educational experience. Quoting him:

> "I want to suggest that along with this one-dimensional view of how to assess people's minds comes a corresponding view of school, which I will call the 'uniform view.' In the uniform view, there is a core curriculum, a set of facts that everybody should know, and very few electives. The better students, perhaps those with higher IQs, are allowed to take courses that call upon critical reading, calculation, and thinking skills. In the 'uniform school,' there are regular assessments, using paper and pencil instruments, of the IQ or SAT variety. They yield reliable rankings of people; the best and brightest get into the better colleges, and perhaps—but only perhaps—they will also get better rankings in life…
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> "But there is an alternative vision that I would like to present—one based on a radically different view of the mind, and one that yields a very different view of school. It is a pluralistic view of mind, recognizing many different and discreet facets of cognition, acknowledging that people have many different cognitive strengths and contrasting cognitive styles. I would also like to introduce the concept of an individual-centered school that takes this multifaceted view of intelligence seriously. This model for a school is based in part on findings from sciences that did not even exist in Binet's time: cognitive science (the study of the mind) and neuroscience (the study of the brain)…"

For the past fifty years or so it seems that engineering education has been very much aligned with what Gardner calls the "uniform school." It has emphasized left-brain activities like sequential reasoning and mathematical analysis. The more artistic and creative dimensions of learning that are associated with design have not been given nearly as much attention. Neither have the more social and personal dimensions of learning associated with teamwork, leadership, and entrepreneurial thinking. Not surprisingly, the result is a workforce that needs improvement in these areas, as concluded in the NAE report on educating the engineer of 2020 [5] and many other similar studies.

An Adaptation to Engineering Education

The first step in adapting this approach to engineering education is to embrace the notion that we need to produce graduates with well developed multiple intelligences and a better balance between left-brain and right-brain abilities. Ideally, this would start by revising the criteria used for engineering school admission to increase the emphasis on evidence among applicants of balance among these multiple intelligences, including "right-brain thinking." The goal should be to supplement—not replace—our current emphasis on math and science ability. Since students with these broad talents and abilities are often interested in many different possible careers, it will likely be necessary to simultaneously adopt a broader definition of engineering in order to attract these applicants. Specifically, we may need to define engineering more as a way of thinking and learning about the world than just a highly specialized career opportunity for the development of new technology. (It is noteworthy that Gardner's definition of intelligence bears a strong resemblance to what might be proposed as a broadened modern definition of engineering: "An intelligence entails the ability to solve problems or fashion products that are of consequence in a particular cultural setting or community" [13].)

These new students are likely to be a bit more interested in the arts, social sciences, and humanities than the average engineering student is today—and perhaps less certain of their ultimate career goal. To attract them, hold their interest, and help them develop in all dimensions simultaneously, some fundamental changes to the engineering curriculum are needed. For example, engaging students immediately in creative design projects requiring social interaction in small teams and with "client groups" is one possibility. Developing a learning culture throughout all four years in which teamwork is pervasive, disciplinary boundaries are blurred or eliminated, independent study leading to a "can do" attitude is nurtured, and students are encouraged to explore careers other than engineering may also prove helpful in developing the multiple intelligences of this new generation. Students with more right-brain dominance are likely to think of engineering as a kind of "performing art," inviting a deliberate effort to borrow from the most successful pedagogies in music and fine arts [14]. Requiring every student to "stand and deliver" in a professional "performance" is one such natural adaptation from the performing arts.

To address these new dimensions to an engineering education within the confines of required technical courses that are already crowded, it may be necessary to focus more on the way the material is presented than on the content alone. In addition, it may be necessary to consider the learning opportunities presented by the entire student life experience in the residence halls, co-curricular activities, and social interactions outside of formal instruction. At first glance an approach based on simply selecting a different set of existing stand-alone courses from non-technical fields would not seem promising. Pedagogy may be much more important than the content of the course syllabus to achieve this type of integration, and the learning culture is likely to be most important.[3] The learning culture is all about relationships and values on campus, and what is widely regarded as "important." For example, two questions that are quite revealing in this regard are (1) what's most important here?, and (2) who's most important here? Answers to these two questions provided by students are likely to provide insight into the prevalent learning culture on any campus.

One way to approach the integration of these broader non-technical dimensions within an engineering education is to imagine several independent axes of learning and a spectrum of learning experiences and associated competencies that transition smoothly from one end of the spectrum to the other. These multiple dimensions of learning are occurring simultaneously within any given course.

For example, one such axis might have mathematical analysis and laboratory science on one end of the spectrum, and creativity and design on the other. The abilities that are best aligned with the analytical subjects are the logical-mathematical and linguistic abilities of Gardner. On the other hand, the abilities that are best aligned with the creativity and design subjects on the other end of the spectrum are the spatial, bodily-kinesthetic, and musical abilities of Gardner. Alternatively, this axis might be interpreted to span from left brain to right brain functions in the context of Sperry's work.

A well balanced educational program would then attempt to provide a trajectory for each student through the curriculum that perhaps begins with more emphasis on the structured analytical subjects in the early years and gradually shifts the emphasis toward more flexible creative and design content in the later years. However, in each year of the program these two aspects of learning are blended and taught simultaneously and in an integrated manner, so students are not easily able to identify whether they are learning analysis or design. It is of fundamental importance in this approach that students perceive approximately equal levels of respect and value for both analysis and design throughout the academic program by all members of the community.

Another axis of learning, possibly independent from the analysis—design axis, might have independent/solo performance as an individual on one end of the spectrum and integrated performance on a diverse team on the other. There are many layers to learning to work effectively in teams. Perhaps the first layer is to learn to work in pairs in a laboratory with other students with the same major, in the same year in the program, in the same university. Another layer might involve learning to work on a team with students majoring in other engineering subjects, in the same year, in the same university. Yet another layer might involve working in teams with students majoring in subjects outside of engineering, in the same year in the program, within the same university. Further layers would then include learning to team with students with different levels of maturity and age, from different universities, or with non-students who are practicing engineers or managers many years older than they are, and possibly from a different ethnic, gender, socio-economic, political and religious background. Learning to work effectively with people of different ages and experiences levels is a particularly important skill which unfortunately is hard to address within the traditional educational environment. It is important to recognize that many sophisticated and subtle skills are required to

[3] Charles Vest, President of the National Academy of Engineering, observed that "Making universities and engineering schools exciting, creative, adventurous, rigorous, demanding, and empowering milieus is more important than specifying curricular details" in remarks at Harvard University, September 20, 2007.

successfully work in this way. These include learning to recognize emotion and develop empathy for others, learning to listen well and to persuade others, to negotiate fairly and establish trust, to set priorities within a group and to establish a professional attitude for completing assignments and delivering what is promised.

Finally, working on a team with partners who are located in another nation, with a different language, a non-American world, and cultural values very different from ours—which might be accomplished through a thoughtfully structured study-abroad program—would occupy an important region on this spectrum. When a study abroad program rests on top of an integrated program involving teamwork in each semester from the freshman year forward—with a steadily increasing level of diversity involved in the teams each year—the final educational result is likely to be significantly different from a program in which the study abroad program is simply appended in a disconnected way to a collection of independent technical courses.

There are many other axes of learning that may be woven into an engineering education designed to produce graduates with broader capabilities. These might include (1) an axis that integrates intellectual property, opportunity assessment, and entrepreneurial thinking into the engineering design process, (2) an axis that spans the spectrum from highly structured subjects learned in courses with instructors, textbooks, and prerequisites on the one hand, to entirely independent individual and group learning activities and research that results in constructing knowledge that is new to the student (and perhaps publishable), and (3) an axis that spans the spectrum from caution, respect for authority, and hesitation to take risk on the one hand, to the development of a realistic and appropriate "can do" attitude resulting from a progression of experiences in project-based learning that each lead to a feeling of accomplishment. Of course there are many other such axes that together provide integration of the traditional technical content with learning experiences intended to develop the other intelligences needed for engineering success in 2020 and beyond.

A natural concern in attempting to fit these new dimensions of learning into the crowded engineering curriculum is how to find semester credit hours devoted to specific courses in these areas, and who should teach the subjects. When approached from the point of view of independent additions to a highly structured existing engineering curriculum, this can be an intimidating problem. Few engineering faculty members feel comfortable in attempting to teach independent subjects in these areas.

However, it may not be necessary to create courses taught by experts with research credentials in related formal disciplines in order to provide the learning experiences that are necessary. In fact, developing independent new courses in these topics that are separate from the technical core subjects in engineering is not likely to provide an effective mechanism of integration. Instead, if the new subjects are not viewed by students (and faculty) as an integral part of learning to become an engineer, they are not likely to be taken as seriously. However, by changing the way the current engineering content is presented—for example, by exploring new pedagogical approaches that emphasize integration of these broader skills into the core subjects in engineering—it may well be possible to nurture both left-brained and right-brained thinking with a minimum of new courses. It is important to note that this is almost certain to require a high degree of interest and commitment on the part of the faculty, and a willingness to experiment with new approaches and to take educational risks along the way.

Another natural concern associated with the proposed new approach is how to design the new educational experiences and how to assess the results. Traditional engineering courses often rely on quantitative assessment techniques involving exams and problem sets intended to evaluate individual student performance. However, assessment tools for learning objectives aimed at creativity, inventiveness, entrepreneurial thinking, teamwork, and interpersonal skills are likely to require a different form. Perhaps methods borrowed from the arts, architecture, or management might be needed. Personally, I believe much could be gained from deliberate efforts to learn best practices from schools of art, music, business, education, medicine, and liberal arts, and to seriously engage our colleagues from these disciplines in our deliberations on how to make the needed changes in our educational programs. Again this will require engineering faculty members willing to learn new approaches and take some risks in experimentation with new educational models.

The Urgent Need for Global Thinking

Among the many new dimensions to non-technical competencies that might be included in a broadened approach to engineering education, special attention should be given to global thinking. Americans will need to become far more knowledgeable of opportunities and challenges in other countries in the future than they have been in the past. Although it is still true today that major changes in the New York Stock Exchange generally precede similar changes in the Asian and European markets the following day, it is likely that this will reverse in the years ahead. When it does, events from abroad will quickly become of central importance to many Americans—and those who are best prepared to understand these trends and use them to advantage are likely to become leaders in the next generation.

The challenges to achieving this goal would seem to be profound. Not only do American students generally know relatively little about the languages, geography, government, and history of other countries, they seem to have less appetite or natural interest for learning in this area than do many students from other countries. For example, experience with student exchange programs with universities from abroad often reveals much greater numbers of international students eager to enroll in American universities than American students willing to go abroad. The reasons cited by American students range from concerns over safety, security, cost, and transferability of credits, to concerns about not speaking the language, not liking the food, and loss of opportunity for on-campus leadership positions, among many others. (International students face essentially the same challenges and yet they seem to be much more eager to travel to the U.S.) Creating an appetite for substantive international experiences would seem to be an important initial step.

In order to foster an authentic global perspective, the goals of an international experience should ideally go beyond the perspective of a single country. To obtain a systems-level understanding of the emerging global dynamic, it is important to develop some understanding of the world view, ethic, and challenges faced by different regions, and the forces that hold them in balance. It is clear from recent events that in this post-Cold-War era civilizations and religious identity are likely to play a larger role in this dynamic than governments and national boundaries. Study abroad programs that provide students exposure to a single country—while this is often the best we can do within the limitations of time and resources—offer limited opportunity to develop a systems-level understanding of globalization.

Recognizing emerging global technological challenges such as climate change, sustainable energy sources, and low-cost technology for third world nations is an important goal of a global perspective. Other important goals include: (1) gaining insight into the global market share and economic trends in use of resources of different regions; (2) understanding the factors that control the establishment of successful technological ventures in other cultures; and (3) understanding different cultural norms for behavior. The special problem of differing business ethics and tolerance for corruption in international partnerships is of particular importance in developing a practical understanding of the successful operation of global engineering systems.

Since about half of the faculty at many American engineering schools are foreign born and educated, they represent a wonderful resource for addressing many of these issues that is rarely utilized well. A great deal could be accomplished in sharing their personal experiences and contacts with students through both informal and formal educational projects. Granted that such experiences here on American soil are not the same as a total immersion experience abroad, nevertheless the personal stories of a foreign-born teacher can be a powerful influence on young minds and should not be underestimated. As previously suggested, it may be most practical to attempt this type of enhancement by integration of global perspectives through the pedagogy used in existing engineering courses rather than by attempting to create new courses outside of engineering that are taught by experts. After all, much of the learning in a study abroad experience arises from random personal contacts with individuals in informal cultural settings rather than solely in structured exercises supervised by a highly qualified instructor.

Olin College

Many schools of engineering around the U.S. are currently involved in important and inspiring educational innovations, some of which are well aligned with the concepts presented in this paper. The list is long and is steadily growing, but limitations of space and limitations in the author's personal knowledge prevent a comprehensive summary here. However, the long-established and exceptional programs in project-based learning and liberal arts at Harvey Mudd College, as well as project-based learning and study abroad experiences at the Worcester Polytechnic Institute provide important examples for those considering curricular change in this direction. Many large public institutions also have exceptional innovations under development, and their absence here is not intended to imply they are any less important or inspiring.

However, I am obviously most familiar with the program at Olin College. The educational approach under development there is aimed at producing graduates who are well prepared with the skills identified in the NAE report on the engineer of 2020. Teamwork, communication, creativity and design, entrepreneurial thinking, self-directed and agile learning skills, as well as technical competence are our goals. Like most other competitive engineering schools, we aim to produce engineers who are competitive in the new global economy. Hence, we are attempting to implement the philosophy outlined in this paper.

An overview of some of the major features of the Olin program is provided here to illustrate the efforts at Olin to develop a comprehensive program aligned with the approach proposed in this paper. Olin currently offers three ABET accredited B.S. degree programs (Electrical and Computer Engineering, Mechanical Engineering, and Engineering) and this overview applies to all three programs.

All students are admitted to Olin only after an extensive interview process in which teamwork, creativity, and interpersonal skills are observed and evaluated in addition to traditional written application materials. The design process forms a central framework throughout all four years of the Olin program, and all students participate in design-build team projects starting in their first semester on campus. Most students are involved in team design projects in at least six semesters, and in the senior year all students must complete a year-long small team design project that is financially sponsored by a corporation (usually at the $50,000 level). This senior design project is similar in many respects to the well known Clinic program at Harvey Mudd College. Since Olin does not have departments, nearly all team design projects involve students with a variety of engineering majors. Several of the design courses now include team members from neighboring Babson College (a business school) or Wellesley College (a women's liberal arts college). At the conclusion of every semester, each student is required to "stand and deliver" either a lecture or poster presentation based on some aspect of their educational program. These presentations (part of our bi-annual "Expo" event) are evaluated by approximately 100 professional corporate and academic visitors from off campus.

The first two years of the Olin program provide a broad foundation in mathematics, natural science, and engineering design. These courses are organized in integrated course blocks involving three courses taught by a team of three faculty members. On occasion all three faculty members are present in the class simultaneously. A deliberate objective is to embed the material in context in order to minimize disciplinary boundaries.

The Olin program also includes a time block in the junior year reserved for a study-away experience. The "study away" program is highly encouraged but is not mandatory. Currently, approximately 20-25% of each graduating class has chosen to participate. There is growing interest among students to use this experience to establish a business off campus as an alternative to study in a university abroad.

Every student at Olin is required to complete a program in fundamentals of business and entrepreneurship. This program includes a requirement that every student participate on a small team to establish and run a business for a semester. More than ten percent of our students continue with entrepreneurial activities and are involved in starting and running their own businesses throughout their undergraduate studies. We have devoted a building dedicated to house their new ventures (Foundry@1795). More than 10% of the Class of 2006 is self-employed in their own new venture.

All Olin students are required to complete a capstone project in Arts, Humanities, or Social Sciences, or in Entrepreneurship. About 25% of Olin's students are cross-enrolled at Wellesley College in each semester, and another 5-10% are enrolled at Babson College.

In addition, all Olin students are required to develop evidence of achievement of nine competencies before graduation. These competencies include: (1) quantitative analysis, (2) qualitative analysis, (3) teamwork, (4) communication, (5) life-long learning, (6) context, (7) design, (8) diagnosis, and (9) opportunity assessment. This evidence is cumulative across all four years of study and distributed across all courses and projects.

Since our program is quite new (we have graduated only two classes of students at this point) it is too early to tell how successful our efforts will be. However, we are committed to a process of continuous improvement and revision. We expect to learn from our mistakes. Each January we schedule a faculty retreat to review the evidence and assess the state of the curriculum. Our curriculum has an expiration date, and must be revised or reinvented periodically by a comprehensive review involving all students and faculty.

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