Biochemical Engineering Education in Pakistan

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The understanding of biological systems has been developed to the point that they can be manufactured. The application of core skills of chemical engineering is being increasingly recognized as of valuable in further advancement of biological systems. To sustain the leading role in the industry, chemical engineers must be familiar with the methods available to create, analyze and manipulate biological molecules and systems, so that the engineering tool kit keeps as complete and up-to-date as possible. Chemical engineers also must be familiar with the biological term, and be comfortable in operating in the biology culture, so that they can effectively translate breakthroughs in fundamental biological research to engineering applications in society. Attempt has been made to put some light on the potential of linkage of biological sciences and chemical engineering and challenges and opportunities for chemical engineers in biological sciences in Pakistan. In order to cope with technological developments and globalization it is suggested to bring innovations into the existing curriculum of chemical engineering programs to develop the human resource in chemical and molecular engineering capable of both biological discovery and product development.

Introduction

The abilities to analyze physical, chemical, and biological processes at a molecular level and to use this information to design new products and processes are recognized as hallmarks of modern chemical engineers. Chemical Engineering is concerned with the design, development, operation and management of industrial processes to transform raw materials into valuable and desirable products that we use every day through series of chemical, biochemical and physical processes. Chemical engineers bring a molecular viewpoint to the engineering challenges in all these arenas.

Chemical engineering education has long been built on the physical and chemical processes of chemical transformations. The resulting skill set is developed from fundamental understandings of engineering principles and processes built on a physical and chemical foundation that has been recognized as valuable by a large range of corporate sectors. Chemical engineers are active in various areas ranging from petrochemicals to microelectronics and biotechnology to the environment.

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Chemical engineers have defined and used the terms ‘biochemical engineering’ and ‘biotechnology and bioengineering’ long before they became fashionable. Chemical engineers have long been involved in the engineering of the processes for the production of chemicals, biological materials and pharmaceuticals.

From the manufacturing of penicillin during World War II and the first artificial kidney in the 1960s to the current production of pharmaceuticals and fabrication of living tissue equivalents, chemical engineers have been instrumental in the development of biological products that have touched lives on a global scale and revolutionized the health-care industry. In the past chemical engineering used to focus on making large quantities of small, relatively simple molecules. It is anticipated that in the future they will have to make smaller quantities of more complex, possibly biologically active, molecules and nanostructure materials with increasing frequency.

1. Biological Frontiers in Chemical Engineering

In the past, cheap raw materials based on fossil fuels underpinned the rapid growth of petrochemical alternatives, but environmental considerations are directing renewed attention to bio-resources. Thus, while chemists have long worked to duplicate plant materials, it may now be advantageous from a global environmental perspective to return to starches, cellulose, vegetable oils and proteins as potential alternative raw materials for industrial production. It is no longer necessary to start with a barrel of crude oil to produce chemicals. Developments in biological frontiers has made possible to biologically produce equivalents to petroleum distillate, such as bio-diesel, bioethanol, methane, and molecular hydrogen, greatly reducing the greenhouse gases emission. As new technologies and more efficient separation techniques are being developed, bio-fuel is expected to compete on cost with fuel derived from crude oil in the near future.

Pharmaceutical use of biotechnology is virtually assured; even though issues related to biomaterials, textiles and similar products have yet to be addressed, these areas seem to be on a reasonably firm base. As biotechnology becomes increasingly industrial in scope, the plants producing and refining tomorrow's fuels, textiles, plastics, and other commodities are likely to be plants in the vegetable sense. Cane-sugar, cotton, coconut, corn and soybeans will grow the materials we need. More and more commodities we need are likely to be produced biologically.

Future economic and industrial growth will be increasingly depending on effective utilization of biological resources and efficient biotechnology-based processing. Recently, several of the world's largest chemical companies have announced major new business based on the life science instead of traditional petrochemical processing. Recent mapping of the human genome is anticipated to open new opportunities for life-science-minded engineers.

The ongoing revolution in the biological sciences is creating new challenges for chemical engineers in the field of biotechnology, healthcare and the environment (Chen *et al*., 2005). Wide ranges of chemicals and structural materials can be made from biological raw materials (biomass), including bio-fuel, biodegradable plastics, biopolymers, bio-pesticides, and novel fibers. In the United States (US), commodity chemicals currently derived from plant matter include ethanol (3.8 million tonnes a year), cellulose esters and ethers (0.5 million tons a year), sorbitol (0.19 million tonnes a year) and citric acid (0.16 million tons a year). New processes and renewable resources for other commodity chemicals such as succinic acid and ethylene glycol are in the pilot stage (Canada's Business and Consumer Site).

2. Biological Frontiers in Chemical Engineering in Pakistan

Pakistan's manufacturing industry is heavily dominated by food, textiles and apparel, and leather industries to the extent of over 50% (GOP, 2005).

The leather industry is mainly export-oriented and has a potential to grow rapidly. Environmental pollution in the leather industry is a major issue and noncompliance with environmental standards could hamper Pakistan's exports to the US, Japan and the European Union (EU) in future.

The country has installed an alcohol production capacity of 506.33 million liters and is the second largest exporter of alcohol to EU. Enzymatically enhanced alcohol is produced from the fermentation of molasses, a byproduct of sugar industry, by yeast. Efforts are also being made to produce ethanol from cellulose biomass (Bhutto *et al*., 2007).

In the environmental sector biological treatment systems have been employed in almost all petroleum and pharmaceutical industries while leather industry are still in the process of establishing these facilities. Government is encouraging industries to install biological treatment systems to reduce waste to acceptable level before its final disposal.

The country has attained a high degree of selfsufficiency in the formulation and packaging of finished pharmaceutical products; however, the manufacturing of active ingredients is very small. About 90% of active ingredients are imported (Atta-ur-Rahman *et al*., 2007). The involving chemical engineer specialize in biochemical engineering is expected to bring the pharmaceutical industry on the focus. Pharmaceutical industry is capable of playing a pivotal role in the economic development of the country by ensuring better health to the people through supplying cheaper and quality drugs.

In future, besides pharmaceutical industry, chemical engineers specialize in biochemical engineering are expected to occupy vital roles in production of industrial commodities like citric acid, cellulose esters, ethylene glycol, production of bio-fuel, synthesis and separation of cell in bioreactor and in the fields like food processing and preservation, design of biological waste treatment systems and solid waste treatment.

3. Synthetic Chemicals from Biological Feedstock's

Since the advent of genetic engineering it has been feasible to harness the sophistication of biological systems to create molecules that are difficult to synthesize by traditional chemical methods. For example, compared with traditional polyester (polydimethyl terephthalate; 2GT), polytrimethylene terephthalate (3GT) has been improved in properties. However, the commercialization of 3GT has been slow because of the high manufacturing cost of trimethylene glycol (3G), one of 3GT's monomers. Now the secret to produce 3G has been found in the cellular machinery of certain unrelated microorganisms. Some naturally occurring yeast converts sugar to glycerol, while a few bacteria can change glycerol to 3G. The problem was that no single natural organism has been able to do both. Through recombinant DNA technology, by working together scientists have created a single microorganism with all the enzymes required to turn sugar into 3G. This breakthrough is opening the door to low-cost, environmentally sound, large-scale production of 3G. The eventual cost of 3G by this process is expected to approach that of ethylene glycol (2G). The 3G fermentation process requires no heavy metals, petroleum or toxic chemicals. In fact, the primary material comes from agriculture i.e., glucose from cornstarch. Rather than releasing carbon dioxide to the atmosphere, the process actually captures it because, although microbes do produce CO_2 during fermentation, corn captures the CO_2 as it grows. The liquid effluent is easily and harmlessly biodegradable. More important, 3GT can readily undergo methanolysis, a process that reduces polyesters to their original monomers. Post-consumer polyesters can thus be repolymerized and recycled (Canada's Business and Consumer site).

4. Biocatalyst: A Promising Source of Improved Processes

Developments in biotechnology enable the rapid and controlled production of biological catalysts specifically living organisms and their catalytically active constituents, particularly enzymes. Because they are more specific and more selective than their nonbiological counterparts, biological catalysts yield fewer by-products (specificity) and start with less purified raw materials (selectivity). They are also amenable to continuous improvement. Despite their advantages, they still present problems for industrial applications, as they may be fragile, require large amounts of water, and are costly. Many of these problems are being addressed by chemical engineers in collaboration with biological scientist, using new bioreactor designs and improved catalysts. Enzyme-based processes operate at lower temperatures and produce fewer and less toxic byproducts and emissions than conventional chemical processes. Use of biotechnology has already succeeded in reducing energy use in certain industrial processes. The world over, greater attention is being focused on modern biotechnology to ensure clear production processes.

5. Biological Frontiers in Chemical Engineering Education

Chemical engineering education has long been built on the physical and chemical processes of chemical transformations. In the past 20 years, understanding of biological systems has developed to the point that biological systems can now be engineered (Zukoski *et al.*, 2002). The ongoing revolution in the biological sciences is creating new challenges for chemical engineers in biotechnology, healthcare and the environmental technology. Both the similarly of molecular level biological and chemical reactions used for designing new products and processes, and the growth of biotechnological industries where many chemical engineers are employed all suggest that biology will soon reach almost equal status with chemistry as basic science in defining chemical engineering (Varma, 2003).

The result has been a transformation in problems that can be addressed and products that can be made. The revolution in understanding biological systems has occurred at the molecular level, i.e., where key processes involve physical processes and coupled reaction pathways that are subject to feedback and control. These integrated networks are being engineered to transform materials into useful products at an increasing level. Understanding of biological processes is of importance not only for those sectors involving human healthcare (e.g., the pharmaceutical and biotechnology industries) but increasing the importance for the traditional employers of the chemical engineering field (i.e., corporate sectors including the materials, chemicals, food, personal care, energy, fuels, and semiconductor processing industries).

To cope with the emerging challenges in the field of biology, it is essential for chemical engineers to combine an intimate understanding of basic biological principles with the quintessential problem-solving skills of an engineer to make large impacts in these arenas. To do this, chemical engineers must understand biological concepts that are relevant to, and can be harnessed for, engineering endeavors. Some of these concepts include: (1) Specificity. How do the specific interactions in biological systems give rise to properties seen notably in living systems, e.g., catalysis at low temperatures and pressures, active transport, and cooperativity? (2) Regulation. How do biological systems regulate chemical and physical processes, and how can this knowledge be used to control engineered biological systems? (3) Evolution and information transfer. How do biological systems evolve, and how can these mechanisms be harnessed to develop new biological systems with desirable properties? (4) Sensing and signal transduction. How do biological systems sense and transmit molecular signals, and how can this information be harnessed to develop sensitive and specific detectors? (5) Energy generation and transduction. How do biological systems generate and convert different forms of energy so efficiently (chemical, electrical, mechanical), and how can this knowledge be used for energy production and conservation efforts? (Frontiers in Chemical Engineering Education, MIT site).

In addition, chemical engineers must be familiar with the methods available to create, analyze, and manipulate biological molecules and systems, so that their engineering toolkit becomes as complete and up-to-date as possible. Chemical engineers also must be familiar with the language used by biologists, and be comfortable in working in the biology culture, so that they can effectively translate breakthroughs in fundamental biological research to engineering applications in society. These educational objectives will be the guiding principles for the supporting biology courses of the new curriculum. For that reason it is imperative to incorporate formal courses of biology and biotechnology in the undergraduate curriculum.

6. Problems to Which Chemical Engineers Are Likely to Contribute

The following list enumerates some of the problems to which chemical engineers are likely to contribute (Frontiers in Chemical Engineering Education, MIT site)

- Bioprocess (biochemical reaction engineering, bioreactors with resulting bio-separations): Important in production of pharmaceuticals or commodity and energy products and are an integral part of waste treatment.
- Bio-separations: Supports bioprocesses, but is also of importance in medical applications such as cell separations (e.g., stem cell recovery) and proteomics (e.g., total analysis of protein content in a cell)
- Bio-catalysis: Generation of protein catalysts with novel or enhanced activities, often in unusual environments.
- Metabolic engineering.
- Gene therapy–metabolic engineering combined with drug delivery: Quantitative problem requiring systems analysis.
- Biomaterials: Controlled release of bioactive compounds or surface modifications
- Tissue replacement
- Cell and tissue engineering combines biomaterials and broad concepts from metabolic engineering and analysis of chemical signaling. Manufacturing processes are similar to bio-processing
- Drug delivery
- Drug/chemical metabolism predictions with physiologically based pharmacokinetic models
- Drug design and discovery (computational tools developed by chemical engineers for understanding protein-ligand interactions and chemical signaling in cells). Many other disciplines play here as well.
- Functional genomics or relating molecular or genomic information of cell function.
- Nano (micro) biotechnology, e.g., lab-on-a-chip devices.

7. Incorporating Molecular and Cellular Biology into ChE Degree Program

With the current developments in molecular frontiers application of core skills of chemical engineering is being increasingly recognized as valuable in further advancement of the understanding of biological systems and in the application of biological processes to solve societal problems. Reflecting this change, a number of departments have altering their curricula to make molecular viewpoints of physics, chemistry, and biology as fundamental and ubiquitous in the new curriculum.

With its historical roots in chemistry, chemical engineering has retained its ties to the molecular sciences, and as a result, kinetics, transport phenomena, and other core concepts in the chemical engineering curriculum can be readily adapted to the molecularbased advances that are prevalent in the biological sciences today. Moreover, the quantitative-systems view to problem solving that is a hallmark of an engineering education is particularly relevant to emerging biological disciplines that require analysis of large data sets or complex reaction pathways, with metabolic engineering as a prominent example (O’Connor, 2005).

8. Undergraduate Chemical and Biological Engineering programs

Biology today occupies the centre stage on the research agendas of an increasing number of institutions, national and international, public and private. In fact, several chemical engineering departments in the US have changed their names to ‘chemical and biological engineering’, ‘chemical and biomolecular engineering’, etc. The name reflects the department’s strategic mission and certainly helps to attract the best faculty candidates, graduate students, and undergraduates. The proposed name aligns the department with the rapidly evolving field. These name changes enhance the visibility of the educational and research programs that already contain strong elements of molecular and cellular biology, and establish that these departments embrace biology as a core fundamental science.

9. Chemical Engineering Education in Pakistan

The facilities to educate chemical engineers in Pakistan were adequate from the beginning. Initially a two-year course, leading to the B.Sc. degree in Technical Chemistry by the Punjab University was started in 1917 at the F.C. College Lahore; this was replaced by a three-year B.Sc. (Hon.) in 1925. Department of

Chemical Engineering, the University of Engineering and Technology (UET), Lahore was established in 1962. Dawood College of Engineering and Technology (DCET) Karachi, established in 1964, was first to offer programs on chemical engineering in the industrial city of Karachi. At present four-year B.Sc. chemical engineering program is offered at the following seven institutions in Pakistan (Bhutto, 2005). (i) Punjab University (Institute of Chemical Engineering and Technology.); (ii) University of Engineering and Technology, Lahore; (iii) Dawood College of Engineering & Technology, Karachi; (iv) Mehran University of Engineering and Technology, Jamshoro; (v) NWFP University of Engineering and Technology, Peshawar; (vi) NFC Institute of Engineering and Technological Training, Multan; (vii) NFC, Institute of Engineering and Fertilizer Research, Faisalabad.

In addition four new departments at NED University, Karachi; COMSATS Institute of Information Technology, Lahore; Baluchistan University of Information Technology, Quetta and Karachi University are being established.

In the earlier years, the chemical engineering curriculum in Pakistan was dominated by chemistry courses with only a few chemical engineering courses. With passage of time, courses were added that were based more on general principals rather than description of various chemical processes. To look after the curriculum revision at the bachelor level, the Federal Government of Pakistan appointed a Higher Education Commission (HEC) as the competent authority. In reviewing the chemical engineering curriculum, HEC constituted a national level committee that is comprised of senior faculty members nominated by the every institution and selected from national organizations. The National Curriculum Committee on chemical engineering set by HEC finalized the curriculum in March 2003. Courses determined by HEC are divided into four subject groups: basic subjects (27 credits hours), core subjects (76 credits hours), allied subjects (18 credits hours) and specialized subjects (3 credit hours). The comparison of the curriculum of DCET for academic session 2004–2005 and the HEC curriculum on the basis of basic, core, allied and specialized courses is given in **Table 1** (GOP, 2003; Bhutto, 2005).

10. Chemical and Biological Engineering Program in Pakistan

In Pakistan chemical engineers concern themselves with the chemical processes that turn raw materials into valuable products. Our current education curriculum is centered on developing skills such as design, scale-up, optimization and upon understanding scientific principles such as mass, heat and momentum transport, chemical kinetics and thermodynamics involved in traditional chemical industries such as petrochemicals and commodity chemicals. HEC has defined the objectives for B.Sc./B.E. Chemical engineering curricula in Pakistan as "The chemical engineering curriculum is designed so that its graduates are familiar with the techniques used in analyzing and solving engineering problems associated with the chemical and related industries (petroleum, pharmaceutical, metallurgical, plastics, pollution control, etc.). The goal of this curriculum is to educate men and women who, as graduates of the program, are able to analyze industrial chemical engineering problems and synthesize solutions to those problems, compare favorably in their knowledge of chemical engineering with students completing similar program nationally, and use their training as a springboard to further professional and career development. In addition to preparing students for rewarding jobs in the chemical process industries, the program provides an excellent background for graduate study in engineering, science, business administration" (GOP, 2003).

Interestingly National Curriculum Committee on chemical engineering has completely overlooked the developments in biological frontiers during finalizing the draft curriculum in March 2003. In our opinion it is the most appropriate time to incorporate appropriate biological courses into the chemical engineering curriculum. The new courses that are likely to find place in the chemical engineering curriculum include biochemistry, bio separation technology, bio-product and bioprocess design, and food technology while courses that require modification to accommodate topic related to biology include molecular basis of thermodynamics, introduction to chemical engineering, chemical engineering thermodynamics, chemical kinetics, transport phenomena, Ch. Process Principles heat transfer, mass transfer and environmental engineering. Table 1 shows the curriculum suggested by the authors for chemical engineering and chemical and biological engineering programs in Pakistan.

Chemical engineers have been taught important skills in process development and modeling of chemical reactions. The addition of courses for better understanding of microorganisms and enzymatic processes will allow engineers to apply their basic skills and knowledge to the design and control of bioreactors and bioprocesses. Chemical engineers are already getting comprehensive knowledge in mathematical techniques that allow them to model bioprocesses and to design controllers for its operation. Biotechnology companies will often seek to hire engineering graduates with a background in biochemical engineering.

The contributions of chemical engineering community in Pakistan to research are relatively small. In the future chemical engineers can bring major progress in the health sector of Pakistan through research in

Table 1 ChE curriculum in Pakistan

Curriculum Proposed by the HEC for ChE. Subjects (credit hours)	Curriculum suggested by the authors for ChE. Subjects (credit hours)	Curriculum suggested by the authors for Ch. and Bio. Eng. Subjects (credit hours)
Basic courses (27 credit hours)	**Basic courses (52 credit hours)**	**Basic courses (52 credit hours)**
Eng. Mathematics-I (3)	Applied Calculus and Differential Eq. (4)	Applied Calculus and Differential Eq. (4)
Eng. Math.-II (3)	Linear Algebra and Analytical Geometry (4)	Linear Algebra and Analytical Geometry (4)
ChE. Math. (Numerical Analysis) (3)	ChE. Mathematics (Numerical Analysis) (4)	Eng. Math. (Numerical Analysis) (4)
Chemistry-I (3)	Application of Computer in ChE. (5)	Application of Computer in Molecular Eng. (5)
Chemistry-II (3)	Chemistry-I (5)	Chemistry-I (5)
Eng. Mechanics (3)	Chemistry-II (5)	Chemistry-II (5)
Physics (3)	Biochemistry (5)	Biochemistry (5)
Computer Programming (3)	Physics (5)	Physics (5)
Pakistan Studies and Islamic Studies (3)	Eng. Mechanics (5)	Eng. Mechanics (5)
	Pak. Studies/Islamic Studies (4)	Pak. Studies/Islamic Studies (4)
	Workshop Practice (2)	Workshop Practice (2)
	Personnel and Communication Skills (English) (4)	Personnel and Communication Skills (English) (4)
Allied courses (18 credit hours)	**Allied courses (22 credit hours)**	**Allied courses (18 credit hours)**
Eng. Drawing and Graphics (3)	Eng. Drawing and Graphics (5)	Eng. Drawing and Graphics (5)
Material Eng. (3)	Quality Control (4)	Quality Control (4)
Communication Skills (3)	Elect./Mech. Tech. (5)	Elect./Mech. Tech. (5)
Ind. Management (3)	Ind. Management and Safety Eng. (4)	Ind. Management and Safety Eng. (4)
Elect./Mech. Tech. (3)	Material Eng. (4)	
Maintenance Eng. (3)		
Core courses (76 credit hours)	**Core courses (103 credit hours)**	**Core courses (100 credit hours)**
Ch. Process Tech.-I (4)	Int. to ChE. (5)	Int. to Ch. and Bio. Eng. (5)
Ch. Process Tech.-II (4)	Ch. Process Principles (4)	Molecular Basis of Process Calculations-I (4)
Ch. Process Principles (4)	Ch. Process Principles-II (4)	Molecular Basis of Process Calculations-II (4)
Ch Process Principles-II (4)	ChE Thermodynamics (5)	Molecular Basis of Thermodynamics (5)
ChE. Thermodynamics (4)	Unit Operation-I (Particulate Tech.) (5)	Unit Operation-I (Particulate Tech.) (5)
Ch. Reaction Eng. (4)	Unit Operation-II (Fluid Flow) (5)	Unit Operation-II (Fluid Flow) (5)
Fuel and Combustion (4)	Unit Operation-III (Heat Transfer) (5)	Unit Operation-III (Heat Transfer) (5)
Transport phenomenon (4)	Unit Operation-IV (Mass Transfer) (5)	Unit Operation-IV (Mass transfer) (5)
Particulate Tech. (4)	Unit Operation-V (Separation Process) (5)	Unit Operation-V (separation Process) (5)
Fluid Flow (4)	Unit Process (5)	Bio Separation Tech. (5)
Heat Transfer (5)	Transport Phenomena (4)	Transport Phenomena (4)
Mass Transfer (5)	Chemical Process Tech.–I (5)	Ch. Process Tech. (5)
Simultaneous Heat and Mass Transfer (4)	Chemical Process Tech.–II (5)	Bio-product and Bioprocess Design (4)
Ch. Plant Design (5)	Ch. Reaction Eng. (4)	Environmental Eng. (5)

Process Engineering Economics (4) Process Instrumental and Control (4) Environmental Eng. (4) Ch. Plant Design Project (5)	Environmental Eng. (5) Process Eng. Economics (2) ChE Plant Design (2) Developments in Ch. and Biological Eng. (2) Petroleum Refinery Tech. (5) Process Dynamics and Control (5) Biochemical Eng. (5) Fuel and Combustion (5) Thesis Project (6)	Process Eng. Economics (2) ChE. Plant Design (2) Food Tech. (5) Process Dynamics and Control (5) Energy Management (4) Biochemical Eng. (5) Petroleum Refinery Tech. (5) Thesis Project (6)
Specialized Courses (3 credit hours) *(At least one subject (3 hours) should be selected from the following)* Petroleum Refinery Eng. Petrochemicals Nuclear Eng. Biochemical Eng. Polymer Eng. Minerals Processing Tech. Computer Aided Design Process Analysis and Optimization	**Specialized Courses (15 credit hours)** *(At least three courses should be selected from the following)* Energy Management (4) Sustainable Energy Development (4) Sustainable Development and appropriate Tech. (4) Petrochemical Eng. (5) Polymer Eng. Int. to ChE Research (4) Coal Tech. (5) Computer Aided Design Process Analysis and Optimization	**Specialized Courses (15 credit hours)** *(At least three courses should be selected from the following)* Fuel and Combustion (5) Coal Tech. (5) Sustainable Development and appropriate Tech. (4) Sustainable Energy Development (4) Petrochemical Eng. (5) Polymer Eng. Introduction to Eng. Research (4) Computer Aided Design Process Analysis and Optimization

collaboration with medical science. Other areas for research in the area of biotechnology and bioresources for chemical engineers in Pakistan includes bio-processing, environmental biotechnology, fiber substitutes, bio-catalysis, bio-sensors, pharmaceuticals, and biomedical applications including advanced drug delivery systems.

Conclusion

Globally the field of chemical engineering has now expanded into new frontier in molecular science. The development in these fields in Pakistan will naturally take time. In order to cope with technological developments and globalization, it is appropriate to bring drastic changes in the existing curriculum of chemical engineering programs in order to provide chemical engineers with a strong foundation in biology to produce a workforce capable of both biological discovery and product development. This will also help to foster interdisciplinary collaboration and accelerate productivity.

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