The Institute of Biological Engineering

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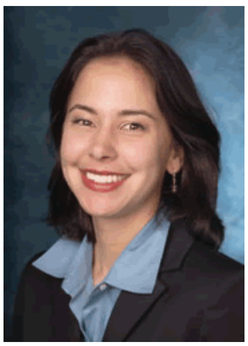
INSIDE

Winter 08-09 Volume 12.3

Message from the President



Christina Smolke

With the end of the year, come many important activities and events within IBE. One of the more important upcoming events is the council and executive council elections, which puts in place the future leadership of IBE. Our leadership is critically important to the energy, growth, and vision of this organization, and therefore, a big thanks to this year's nominees for their willingness to take on this task. Keep in mind that there are plenty of other opportunities for membership to become involved in IBE. For example, committee involvement is a great first step to becoming actively involved with IBE. Our committees span many diverse areas (education, chapters/branches, meetings, membership, public relations, recognition/awards, website and communications, nominations/elections, bylaws and publications), and interested members should contact the committee chairs listed on the IBE website.

We have initiated several new activities in 2008 in order to support IBE's membership. For example, we held our first Regional Student Meeting in October joint between four universities- Mississipi State University, Utah State University, Purdue University, and Cornell University. This regional meeting was largely organized through active IBE student chapters and faculty, and had participation from students, faculty, and industry from local areas at each university. The meeting was organized to incorporate sessions that were webcast to each of the participating universities and to stress student participation. Thank you to all of the organizers and participants that made the regional meeting hugely successful. We look forward to this becoming a reoccurring event rotating between different universities and student chapters. If you are interested in participating in future IBE Regional Student Meetings, please contact us.

IBE is also initiating several efforts to reach out to new and rapidly growing communities within biological engineering. For example, IBE is a sponsor

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Editor, Art Johnson

The Age of the Cowboys

Biological engineering has now entered a new phase. Gone are the wild ideas, the era with few, if any, rules and regulations, and where any imaginative fantasy relating engineering to biology was completely fresh. Here with us today are more mundane products and product improvements, Institutional Review Boards or Animal Care and Use Committees, and empiricism. In other words, the Technocrats have replaced the Cowboys.

The Age of the Cowboys was truly a golden era. Funding was loose, laws were looser, and excitement was in the air. Expectations were at once high and higher, and every success was a big success. Very few ideas had been tried before, so the Cowboys could try almost anything to see if it would work. Opportunities were seemingly limitless. There was some vague notion about what might be able to be done, but no one knew for sure. Technology was in its infancy, and it was like the California gold rush all over again.

The Cowboys were an interesting bunch. They had visions of biological engineering breakthroughs, and the means to try almost anything imaginable. They were explorers, magnates, and tinkerers all rolled together. They believed in them-

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of the 2008 iGEM (internationally Genetically Engineered Machines) competition, an international undergraduate synthetic biology competition held at MIT in November. Tom Richards, our Past President, has taken a lead in organizing the judging for the competition, and IBE is sponsoring an award to the winning teams. We have significant participation from some of our student members in iGEM, as well as participation in judging and team mentoring from our full members, and we are looking forward to further interactions with this growing community. For those of you who are not able to attend iGEM this year, we will have a special session at our annual conference focused on presentations from select iGEM teams. I also participated in Synthetic Biology 4.0, held at the Hong Kong University of Science and Technology. The conference brought together over 600 participants from diverse disciplines, including engineering, science, law, and policy, and the program format was inspired by suggestions from the community and included over 100 oral presentations and 220 poster presentations. There was a session on "Emergence of Professional Organizations" in which IBE participated.

We have also initiated our student membership drive, in which we are offering one year membership free to our student members. This offer is linked to our new resume bank and job board posting for IBE members, such that we ask all student members taking advantage of this offer to post their resume in the bank. We look forward to feedback from you on this new system, and what we can do to further improve it for our members.

The Journal of Biological Engineering (JBE) continues to be a significant success. Several of the articles published in JBE have been referenced in articles appearing in Scientific American and Nature. A big thanks to Mark Riley for all of his efforts in getting this open-access journal off of the ground. Mark Eiteman will be taking over the reins as editor-in-chief at the end of the year.

Finally, we recently held our bi-annual council meeting in Santa Clara, CA – on site for the 2009 IBE annual meeting. Much of the council's efforts were directed to discussing formats and programs for the upcoming annual meeting. We are putting together an exciting program with several new session formats, and we look forward to everyone's participation in making the annual conference a success. If you have ideas regarding session topics and formats that you do not feel are represented in the Call-For-Papers, please contact us.

Leading into next year, we will continue developing activities and strategies that will reach out to new members, while at the same time developing new initiatives and services to support the IBE membership. In addition, our efforts will continue to focus on leading discussions in education in biological engineering and on the foundational advances critical to biotechnology.

From ASEE News Today

Bio-computer allows scientists to program molecules

National Geographic News (10/16, Than) reported, "A newly developed bio-computer allows scientists to 'program' molecules to carry out 'commands' inside cells." These "devices could one day allow humans to manipulate biological systems directly, said the California Institute of Technology's Christina Smolke" who co-authored the study published on Thursday in the journal *Science*. "Bio-computers might eventually serve as brains for producing biofuels from cells, for example." The article noted, "The new bio-computer consists of snippets of engineered RNA assembled inside a yeast cell. ... In engineering terms, the bio-computer's 'inputs' are molecules floating around inside the cell. The 'output' manifests as changes in protein production."

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selves and the technology they thought they knew, but they had little idea about the chances of success. They were optimists, every one, and their collective motto was: "Let's try it!"

I was fortunate to have known some of the early Cowboys. People like Francis Long, Lester Goodman, Allan Kahn, Les Geddes, Pat Horner, Wilson Greatbatch, William Kolff, Michael Debakey, and Dick Gowan. Many of these were biomedical device guys, for that's really where it all started. Soon after, the biological engineering visionaries appeared – people like John Ogilvie, Pat Hassler, Bill Splinter, Bill Fox, and Jan Jofriet. They would probably admit their lack of biological engineering knowledge, but they were true pioneering giants.

On their shoulders stand the Technocrats of today. These men and women know as much about biology as they know about engineering. They compete successfully for funding and they are familiar with NIH rules and regulations. They are adept at getting the most from their creations involving living things, and their improvements are measured in tiny steps rather than in giant strides. They have and use vast amounts of empirical data so that they can overcome secondary limitations of their devices and systems. Just saving a life is not necessarily their goal; adding quality to a long lifetime is their goal.

You can tell that a field has reached maturity when the Cowboys are gone and the Technocrats abound. The field becomes much more specialized and fragmented because the Technocrats generate specialized data and have limited ranges of interest. They are less interested in broad connections than they are in deep progress.

The original vision for biological engineering (and IBE) was that it would remain in the nascent state forever. It would bring biomedical engineers together with ecological engineers, and they would both be able to converse intelligently with metabolic engineers and food engineers. There would be no separation for synthetic biology, wetlands reconstruction, biomaterials, or bioreactor design. We would all appreciate the commonality that we share, and emphasize general laws at the expense of empiricism. We would all share enthusiasm for the system and appreciate its wholeness.

Something happened on the way to the corral. Our own generalist Cowboys have largely been replaced by our specialist Technocrats. Our meetings are dissected along specialty lines, and we hardly ever see a paper that cuts across these lines. We don't talk to each other in the hall as we once did, because we have little in common. We don't understand general connections because we are too interested in narrow research topics. The success of the IBE meeting is based on numbers of papers and attendees, and not on the discussions that we once had.

When did we lose the foundational vision of IBE? Perhaps it was when we had to face the prospect of writing funding proposals that required specialized expertise. No matter – IBE is now as balkanized as any other society.

I would suggest at least one non-concurrent session at each meeting to host papers of a generalized nature that cut across specialties. There needs to be no other theme for this session than its generality. Papers for this session would be selected, perhaps even invited, from the Cowboys among us. They should be selected to bring back the excitement that the discovery of new knowledge can generate. When the session is finished, we should have a party. With Cowboy hats.

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iFAQ

iFAQ is a new column to appear in the IBE Newsletter, and we intend for it to appear regularly. Questions concerning almost any topic related to Biological Engineering, student life, professional interests, career management, or other issues of concern are invited from the readers of this newsletter. Answers will be contributed usually from older and wiser IBE offi cers and Council members, and sometimes from students or others in the field. The intent of this column is to give useful advice on topics that are not always discussed among peers. If you have a burning question that you would like to have answered by our distinguished panel of experts, then send them along to Art Johnson, Editor, artjohns@umd.edu. Include in the email subject line the words "iFAQ Questions".

Q **In one of my classes we were assigned to write a report about a topic of our choice. I spent a lot of time doing mine, and got it in just in time. I recently learned that one of the other students in the course copied his report from material on the web. I don't think it is fair for me to have put in so much work and he just copied his. What can I do about it?**

First let me state that honesty is an essential characteristic of professional educators and the higher education system. Higher education is based on seeking knowledge and truth. It is the responsibility of all members of the education system to promote the integrity of the institutions and to discourage academic dishonesty. --- Now to the specifics of your question. The person you describe has committed plagiarism and should be held accountable for his/her actions. I would recommend that you discuss this with your dean of students to get advice as how to proceed with reporting this action. Different schools have different policies about the reporting of academic dishonesty. At the very least, I would recommend that you ask your instructor to spend some time reviewing what constitutes plagiarism when completing an assignment. Whatever you do, approach it from the standpoint of doing what you know is right. Don't do it because you feel personally cheated. The individual has cheated himself/herself and the education system and if unchallenged may continue with dishonest behavior that may have far greater consequences in the future. – jag.

The Question of What is Biological Engineering?
by Jerry Gilbert

The term "biological engineering" has been and continues to be a phrase that creates a certain amount of ambiguity and uncertainty in people's minds. It was coined in the 1960's and ever since then people have been trying to figure out what it means. As a young biological engineering student running for an office at the annual meeting of the southern regional honors council, I was asked by a rather condescending humanities professor from another university: "What the hell is biological engineering?" It seems like I have been plagued with that question for almost 35 years.

Over the past ten or so years, however, people have become more polite and more curious. Now in response to biological engineering I often hear: "Is that like Biomedical Engineering?" My answer is always something similar to this: "Yes, but it is a broader term. I have an undergraduate degree in biological engineering and a doctorate in biomedical engineering." Just as I go on to explain that I specialized at the graduate level, I explain that biological engineering is a broader, more encompassing field and that you can think of biomedical engineering as biological engineering specialized or focused on humans.

This example of question and answer, as simple as it may seem, provides a good basis to start a discussion of what biological engineering is. Biological engineering is an engineering discipline based on the science of biology. You should stop at this point and think about what biology includes: all things living. The range spans from microscopic single-celled creatures to organisms to ecosystems. Although biological engineering may have initially focused on the organism level (plants and animals), much research is being conducted today at the cellular and the molecular level.

Biological engineering is the application of principles of engineering to study "life" and the components of things that are living. The living items may be in a process such as the production of a biofuel or in an ecosystem such as in a constructed wetland or they may be bacteria as in the subfield of synthetic biology. The study may focus on humans, non-human animals, plants, microbes,

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Report on *Journal of Biological Engineering*
Mark R. Riley, The University of Arizona

JBE launched on October 10, 2007
JBE can be accessed at: www.jbioleng.org

Journal of Biological Engineering (*JBE*) has just had a birthday! We launched on Oct 10, 2007 and have had a very active year. JBE is the flagship peer reviewed publication of the Institute of Biological Engineering.

In *JBE*'s first 12 months, we have published 22 excellent manuscripts. This is above our initial first year goal of 20 manuscripts and is fully in line with start up of other similar journals. The most accessed articles of the past 30 days have been in the area of synthetic biology and biomedical applications. These have been boosted by advertising campaigns by our publisher, BioMed Central. Articles referencing these *JBE* manuscripts have appeared in *Scientific American* and *Nature*. The number of manuscript accesses has increased substantially with the most accessed articles been viewed more than 7700 times. The average number of article views is about 2,500 times per article published. Clearly, *JBE* has a solid audience.

JBE currently has 10 manuscripts in review and the average time to decision has been about 120 days. The rejection rate is about 40%, as we have been highly selective based on content and topical area.

In the few months we have added new members to the editorial board including those listed below. We also have named Ms. Elyssa Tardiff from Purdue University as the *JBE* Copy Editor. Elyssa has been doing outstanding work ensuring that manuscripts meet the high standards of our publication.

Kaustubh Bhalerao	University of Illinois	USA
Sean Brophy	Purdue University	USA
Patrick Cirino	Penn State University	USA
Marko Dolinar	University of Ljubljana	Slovenija
Gaétan Laroche	Université Laval	Canada
Ioan Notingher	University of Nottingham	U.K.
Molly Shoichet	University of Toronto	Canada
Ronald Sims	Utah State University	USA
Maryam Tabrizian	McGill University	Canada
Robert Ulanowicz	University of Maryland	USA
Thomas Webster	Brown University	USA

We thank all of our editors, reviewers, and authors for helping to make *JBE* a success in such a short period of time.

JBE continues to seek outstanding manuscripts from the breadth of topical areas within biological engineering. Submit your manuscript today to help to continue to build our field. Advantages of publication in JBE are a fast and fully electronic review process, online publication with open access (which means that anyone, anywhere with an internet connection can view your work), and availability of posting video and other data not easily conveyed in a traditional print journal.

Lastly, my term as Editor-in-chief of *JBE* is set to expire Dec 31, 2008 with Mark Eiteman from University of Georgia to take over the reins. I aim to stay involved but step back from the day to day duties. Mark has been intimately involved in *JBE* and I will be working with him this fall to ensure a smooth transition. This has been an enjoyable process and I am grateful for the tremendous support provided by the IBE members.

What Biological Engineering Means to Me

Brahm Verma

Engineering is a profoundly creative process of designing workable solutions under constraints. In 'old' engineering, biology provided for establishing design constraints; it was not a source of the creative process for conceptualizing design possibilities. In my own experiences in engineering for agricultural and food systems, the properties of agricultural/food materials, physiology and/or the environment within which they must be maintained constituted *physical* design constraints. Components of an envisioned design were also thought in only the physical sense.

In the early 1980's, as a newly appointed department head, the words of the late Professor C.O. Reed of the Ohio State University spoken in 1930's that agricultural engineering "is the engineering of biology" were poignant to envisioning futurist new research directions. I could think of engineering *for* biological systems, but not engineering *of* biological systems.

My moment of epiphany was during an evening discussion meeting in Columbus, Ohio [ironically on the campus of Professor C.O. Reed] on October 27, 1987 when elaborating on his speech on "The Age of Biology" given earlier that day Carl Hall said, *we do not have engineering that is based on biology like we have engineering based on physics; we should think about the discipline of biological engineering that is based on the science of biology [paraphrased statement.]* Since then my exploration for a numinous foundational frame of reference for the discipline for biological engineering has lead to the following perspectives.

I started to question what is needed to build the foundational framework of biological engineering. For example: How to define *biological* properties of materials, structures of biological materials that give unique properties not found in physical materials and secrets of living systems that give adaptability to a changing environment? How to understand governing principles of complexity in living organisms that are not amenable to reductionism? How can we shift from function to organization, mechanistic to system view? Does object level matters, or similitude across biological scales holds? Was engineering captive to the reductionism of the physical sciences and a new design paradigm is needed where holism and reductionism are complementary? Can our designs have physical components and also biological parts? Will biological engineering provide foundation for designing systems that do not have biological materials, e.g., a thermostat? I often asked rhetorically, can we design a thermostat to regulate room temperature that is not an electro-mechanical devise but rather a biological device? What biological framework is necessary to engineer such a design?

I did not have answers to these questions; however, I did envision the possibilities of mimicking living systems intentionally in an engineered design, whether it would be mimicking the creative structure of a spider web, or using protein for computer memory or advancing techniques for designing genetics to express predictive characteristics in products. By mid-1990's I had surmised Biological Engineering to be an engineering that shares its worldview with the science of biology and whose body of foundational knowledge is quantitative representations of living systems in forms useful for design. Biological engineering design paradigm combines reductive (function) and holistic (system) approaches concurrently. Its application domain is ubiquitous; and combining biological engineering foundational knowledge and frame of reference with best practices in an application domain (e.g., medicine, food and environment) will lead to remarkable designs that mimic biology itself. An important observation made by others was that Biological Engineering has core operational concepts, e.g., transport of energy, mass and information across interfaces; locomotion; kinetics; biological properties of materials; similitude in biological engineering (from genetic to eco-levels); and design principles of biological systems.

Finding biological analogs for components familiar to engineers, e.g., molecular motors and synthetic biologists creating BioBrick standard biological parts for designing novel biological machines bear evidence to the designing *of* biology. Fortunately the advances in mathematical and computer sciences simultaneously provide new and promising tools for these approaches. These advances are unraveling the numinous foundational frame of reference of biological engineering in the many ways envisioned earlier for creating a 'new' engineering.

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Through these years I have evolved to where I believe that Biological Engineering is changing engineering at its core. It is taking us beyond designing physical components and assembly that work in specific ways to creating possibilities of designing systems that mimic defining characteristics of living systems – adaptation, self-organization and emergence. Designing systems in which emergence of functions is guided by its environment (that is, adaptable) and intelligent guiding systems 'designs' components (both physical and biological) and assembly (that is, self-design) in ways to perform the adapted functions are the essence of the engineering of the 21st century. We are getting there faster than most of the engineering community anticipated in 1990's. IBE is uniquely providing leadership in this disruptive change.

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tissues, organs, cells, or biomaterials. The study may also center on information about living things such as bioinformatics , biosimulations, or bioimaging. All of these examples trace back to the study of biology and specific topics that relate to living systems.

To me, biological engineering is not just a pure and basic engineering discipline but also a common meeting place for people who love biology and are drawn to ask and answer questions with the exacting tools of engineering. Adapting the tools of engineering for their use in biology and learning how to appropriately interpret the outcomes of the engineering analyses are major parts of the learning process for engineers who study biology. As we progress through the Century of Biology, biological engineers will become more confident in the value and uniqueness of their field as they make major contributions in studying biology and gain the proper respect they deserve.

3rd Place Bioethics Essay
2008 IBE Meeting

Clones, and Immortals, and Bears! Oh, My!

by William Richbourg
University of Maryland

Genetic engineering, like any other branch of science or technological progress, must undergo an ethical "review" by the public before being fully accepted and funded. But unlike every other branch of science or technological improvement, the possibilities of genetic engineering appear to be limitless as well as controversial. Whenever the general public perceives scientists to be "playing god," ethical and moral concerns are bound to be raised. When human life is involved, these ethical concerns can quickly become uninformed, media-fueled, hysteria. Designer babies! Attack of the Clones! Super-humans! All are future possibilities of genetic engineering, but they are extreme examples utilized by the media. Genetic engineering of bacteria has made it possible for diabetics to obtain affordable insulin, yet this triumph is downplayed and even dissociated from the controversial field.

Genetic engineering has been around for thousands of years, although not in the same sense that many think of it today. Any time a breeder of plants or animals selects for specific traits, they are manipulating the genetics of the offspring and changing the randomness of nature. All of the variations of dogs that are kept as domesticated pets today are the result of thousands of years of genetic engineering. This is the "accepted" variation of the term; accepted because it has been common practice for much of human history. Whenever a scary, new technology emerges there are groups of people (generally of the previous generation), who are adverse to it, and there are groups who embrace or simply are oblivious to it. Genetic engineering becomes "scary" when it is accomplished in the lab by scientists, as opposed to on the farm by breeders. When E. coli bacteria spontaneously begin producing insulin after a specific human gene sequence is engineered into their genetic code, the fear of what may come next can begin to brew. Super-resistant, and super-deadly pathogens falling into, or even being engineered in, the wrong hands are a legitimate ethical concern. Nearly every other advanced technology has somehow developed into a weapon of war, and there is no reason to believe that genetic engineering of pathogens will be any different. Strict regulations exist to control this kind of activity, but it is certainly an ethical concern. The idea alone that any technology may be used for harm cannot be used to stop the advancement of science.

Religion and science often clash, and never have the two been at further odds than in the debate regarding the manipulation of human life in the lab. Genetic engineering will soon reach the point where parents will be able to select for not only the sex of their child, but for appearance and possibly intelligence as well. Obviously, intelligence is a trait governed

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by many genes as well as development and cannot simply be "turned on," but it is of great ethical concern whether parents should be able to manipulate nature at all. Even if designer babies are deemed acceptable, the ethical concern arises regarding the widening gap between the rich and the poor. Now, not only will the rich receive every "nurture" advantage, they would receive "nature" advantages in their carefully selected genetics. Non-engineered babies may fall further and further behind the bioengineered, eventually dividing the country into a class system reminiscent of Huxeley's *Brave New World.* Those born as epsilons would, on the whole, stay epsilons if the advantages of engineering outweigh the values of hard work. While these fears are likely radical, the ethical concerns of designer babies extend beyond religion, and into economics.

Humans have a natural tendency to seek out ways to extend their own lives and the lives of their kin. It is natural that such behavior should result from evolutionary selection. Therefore, it is hard to understand the concern with the possibility of greatly extending life through genetic engineering. Equally difficult to comprehend is an unwillingness to utilize genetic engineering in conception to avoid the possibility of genetic disease. Although, once again, scientists are "messing with the natural way of things," the scientific and technological advancements that have occurred over the last several thousand years have already extended human life expectancy in civilized countries by over 50 years. Given the choice, every mentally capable human being would rather live 75 years than 25, and future progress in genetic engineering will simply add to that. There are ethical concerns in terms of increased strain on the economy to support the elderly and with the possibility of overpopulation. Both concerns are impossible to address without considering the actual results of dramatic life expectancy increases on the human body. It is likely that "healthy life-time" will be increased, allowing people to contribute to society for many more years before they become elderly and, in turn, s negative strain on the system. Overpopulation is not a concern in civilized countries as with education, reproduction rates tend to fall. Overpopulation will still be the same concern it is today in many parts of the world, but these parts of the world are not on the forefront of research in genetics.

Human cloning is often at the center of ethical debates regarding genetic engineering, and for good reason. It is scary to think that it may one day be possible to create "Einstein reborn" in a lab. The ethics lie in the fact that every human being is unique, yet unreasonable expectations would lie on the shoulders of Einstein 2.0. Although genetics are likely a very important factor in intelligence, development and learning experiences also play a role. The ability to bring people back into the world lies in very shaky moral territory for many, and this would be the ultimate example used by many of "science gone too far." In addition to human cloning, human physical enhancement also lies in the ethical gray zone. Humans can already utilize drugs to improve physically, but athletic competition is in most cases limited to "natural" means of physical improvement. The line drawn is between what is allowed and what is not is arbitrary, and if genetic enhancement were to make its way into sports, the resulting arms race would be both dangerous and incredible to witness. Professional athletes are naturally gifted individuals and given experimental genetic modifications to keep up with the competition, super-humans would rapidly emerge.

The vast possibilities of genetic engineering make it an ethical and moral center of debate, but it is in effect no different than the emergence of other great leaps in science. People tend to fear change, often legitimately so, and there is no greater change in the history of science than the ability to manipulate the very foundation of life. The genetic code makes each organism unique, and when man gains the ability to mix and match genes and organisms, powers formerly reserved only for God are called into question. If man can generate life from scratch using simple nucleotides, religion is backed into a corner, which, for some, is the greatest ethical concern of all.

Honorable Mention
Bioethics Essay
2008 IBE Meeting

The Bioethics of Bt Corn

by Stevephen Hung
University of Maryland

Humans now have the genetic tools to create perfect corn: sweet, nutritious, and even insect resistant. Bt corn is a genetically modified food that is resistant to many insect pests. The debate over the bioethics of Bt corn represents a larger controversy over bio-engineered foods, whether they are worth the cost, whether they are safe for human consumption and safe for the environment, and whether it is right for humans to intervene in the genetic makeup of another organism. Often the fuel for controversy stems from unclear or incorrect conceptions of the technology and its effects.

Bacillus thuringiensis (Bt) is a remarkable bacterium that makes a crystal protein which breaks down and becomes an endotoxin in the digestive tract of insect larvae (10). Bt is an active ingredient in many insecticidal sprays, like Dipel Dust (4), and has been used by farmers to control for many insect pests. Bioengineering has made it possible to isolate, cut, and insert the toxin-making gene from Bt to corn plant DNA, using restriction enzymes and ligases(1). Bt corn varieties make Cry protein 1Ab, which is commonly used against the European Corn Borer (ECB) and the Southwestern Corn Borer (SCB). A new variety of Bt corn makes Cry1F protein, which is effective against also armyworms and black cutworm (3).

The advantages of Bt corn seem obvious for its agricultural and economic potential to maximize yield and profit. Corn is the third most planted crop worldwide, and the possibility of having consistent food yields is especially promising for developing countries. Developed and developing countries alike have begun to cultivate Bt corn (7). In the US, ECB is the biggest threat to corn crops, and is estimated to incur damages of more than one billion dollars a year (1). Bt crops provide insurance by killing pests where the spray can not reach, specifically ECB and SCB that bore into the corn stalk. Compared to regular insecticide spray that kill on average 80% of first generation and 67% of second generation ECB larvae, respectively, Bt corn varieties kill on average 96-99% of first and second generation ECB larvae(1). Bt corn is also free of mycotoxins, a byproduct of pest activity, that is carcinogenic to animals and humans (3). Economic profit calculations are dependent on many confounding factors, such as insect pressures, market fluctuations, and soil conditions. In 2001 the Environmental Protection Agency estimated that a maximum of $219 million/year in benefits could be attributed to Bt corn (3). In Argentina, the benefits to cost ratio was enormous for large farmers(8), while modest profits were calculated for farmers in the Philippines(7). Some have questioned the economic sense of costly Bt seeds for poor farmers (2). Overall the trend seems to indicate that bigger farmers have more access and make more profit on Bt corn.

In weighing the benefits and costs of growing Bt corn, there are three primary concerns that should be addressed. First and foremost, Bt corn must fulfill its primary goal: to be safe for human consumption. All economic or ecological considerations are negligible if this condition is not satisfied. Secondly, Bt corn must not cause unforeseen or uncontrollable environmental changes that result in detriment to other organisms and humans. Thirdly, Bt corn must not violate ethical principles that may cause us to slip down the slippery slope of bioengineering applications with wider implications.

With regards to food safety, the EPA and the Food and Drug Administration (FDA) provide definite answers. Based on twenty years of testing, the EPA concluded in 1996 and again in 2001 that Cry proteins are not harmful to humans or to mammals in general (3). The fact that it is a protein means it is sensitive to pH; lab tests confirmed Cry proteins in gastric juice break up within seven minutes into their amino acid building blocks. Thus no chronic exposure effects are possible. Comparison of the protein to known allergens showed no probability of the proteins inducing an allergic response. Acute oral toxicity tests on mice showed no significant effects. With the EPA showing the Cry proteins to be safe, the FDA found nothing unsafe, or indeed, different about Bt from normal food, to even require companies to label Bt corn as bio-engineered (11).

Any ecologist well knows the effects of introducing a new species like insect resistant corn will lead to far-reaching consequences for the environment. Most obviously target caterpillar and worm populations will fall, and competitor populations may rise. Field studies on the effects of Bt spray on ecosystems revealed that shrews and birds that prey on caterpillars and moths either migrated or had to find other sources of food(10). The effects of Bt corn on primary and secondary consumers should be no better, but no worse either. Bt does not harm non-target insects or soil microbes (1). In fact, Bt spray has more potential to harm indirectly other beneficial insects like parasite wasps that control ECB populations. There is no risk of biomagnification of Bt up the food chain, once again because of degradation of protein in digestion (10). One study (5) that seriously discredited Bt corn reported that monarch butterfly larvae that fed on milkweed coated with Bt pollen had a lowered survival rate. But other studies (6), later supported

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by EPA, showed that only one variety of Bt corn (event-176) posed risk to monarchs at a critical density, and these crops were less than 2% of total corn acreage.

The most harrowing aspect of ecological consequences is the possibility that insects will develop resistance to Bt corn, as they do for many other insecticides. The EPA responded with a two-prong attack: 1) the high dose regulation (Bt corn must have 25X the amount of toxin required to kill 99% of insects) is needed to insure that no partially resistant insect survives and passes on the resistance gene to future generations and 2) the structured refuge approach reserves 20-50% of the field to non-Bt crops where insects would develop without resistance and dilute the frequency of the resistance allele by mating with resistant insects(3). And thus far these measures have worked; there have been presently no reported incidents of insects developing resistance to Bt crops (9).

The last concern, unlike the previous ones, is not answerable by case studies or human experience. It deals with the ethics of humans manipulating the genes and designing the characteristics of another organism. I believe that biotechnology is merely a step forward in the general trend of humans applying knowledge to their fit their needs. Since the time of Mendel people have cultivated hybrid crops to exhibit desired traits (11). Biotechnology has met controversy for simply making more efficient the process of creating and maintaining these crops. Bt corn serves as a model of success by responsible management, through monitoring for insect resistance and ecological impact and enacting the appropriate regulations. Creating insect-resistant corn is not the same as creating animals or human beings with desired traits. The distinction lies in the line that divides plants and animals. The same responsibility in protecting the environment is equally critical in preventing us from falling down a slippery slope towards applications of biotechnology which we are not prepared for.

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The Ethics of Biological Re-Writing

by Bryan Hofferbert
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Originally, synthetic biology was the way of looking at biology in attempts to gain a broader understanding of living things and natural systems through a combination of biological research techniques. More recently, however, with the vast strides made in engineering technology, this definition has shifted to the recreation and modification of these living things and natural systems. However, with this recent advancement in technology and engineering, the question of ethics comes into play.

A particular situation where the ethical basis of research is questioned concerns the progress made primarily by biologist Drew Endy at the Massachusetts Institute of Technology and his process of biological *re-writing*. Re-writing expands on the concept of genetic engineering, which involves the exchange of DNA from one species to another to achieve desired traits. Instead, re-writing involves the design and production of living systems that possess desirable and predictable traits. Additionally, these organisms are able to use interchangeable parts and sometimes contain an expanded genetic code. These capabilities allow these living systems to do things that no natural living system can.

The mere concept of designing living systems catered to our needs as people rises ethical questioning. Evolution has occurred over billions of years to produce each and every living system in the natural world today. Is it really our place to tamper with or accelerate this slow but time-proven process? Religion aside, life has competitively adapted since the beginning of time to produce natural systems in the world today, and will continue to do so barring some world-devastating catastrophe; this is the natural course of things. Interfering with the natural course of things can have devastating effects on the natural world. For example, we can already be held accountable for wiping out entire species from existence. Although this is not nearly an identical situation, it exemplifies the drastic consequences of our irresponsibility towards the natural world and even life itself.

Obviously, re-writing can in no way directly affect the natural order of things to drastically alter life on this planet. However, certain consequences of this process may act to do so. Though engineered in the seclusion of a lab, many re-written organisms are designed to have applications outside of those labs. Since this process is still in the early stages of development, the current focus is on the recreation of certain strands of bacteria with applications including modern medicine, warfare, and ecology. When working with synthetic bacteria in the natural world, an emphasis must be placed on isolating the natural world from the synthetic organisms.

If synthetic organisms were accidentally released into the natural world, natural competition would most certainly be altered. If the synthetic organisms had an evolutionary advantage over natural organisms, the natural organisms may struggle for survival and, in extreme cases, may even become extinct. However, since we are not intentionally modifying organisms to possess evolutionary advantages but rather as tools for human gain, this is an unlikely scenario. A more likely scenario, however, would be synthetic organisms with evolutionary disadvantages. The synthetic organisms could end up filling the spot of a natural species for natural selection. This could potentially lead to unnaturally large or even explosive and uninhibited growth for certain natural populations.

When considering the ethics of a situation, the gain must be evaluated. When doing so, the potential benefit of biological re-writing is abundant. An example of recent studies includes bacteria that are able to digest TNT. Recreating these organisms with an added gene that causes them to glow during this specific metabolic action would have a useful application in modern warfare and land mine detection. Another example revolves around the modification of bacteria to contain the genetic information of the wormwood shrub. The wormwood shrub produces trace quantities of *artemisinin*, which is a potent medicine for malaria. If artemisinin could be produced in mass quantities by bacteria, the medicine would be cheaper and more accessible to areas that desperately need it. Similarly, the potential research that could be achieved using re-written organisms seems astronomical. One example includes the modification of cells that could be used for cancer research. These cells would have a sort of easy-to-read counter that make cell-division easy to record and observe. When thinking about the amount of human lives that could be saved indirectly by re-written organisms, it seems almost like we have an ethical obligation to do so.

However, as with any great achievement or power, with the process of re-writing a living organism comes great responsibility. As with any scientific research involving natural systems, reverence must be paid to all life. Although most of the current focus of the research is on bacteria and cells, the potential for expansion is limitless. When thinking about higher organisms, the concept of using living organisms as tools for human gain seems ethically questionable at best. Therefore, care and respect must be given to the organisms of study. It would be best if the organisms could be modified to achieve the desired effect through their natural metabolism or natural actions.

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Additionally, as mentioned before, it would be an ethical obligation of research to take every precaution when re-writing organisms. Every genetic modification should be made with a purpose, and random experimenting should be prohibited. This could lead to engineered organisms with deadly properties or applications. Moreover, not only could this occur by accident, but it could be an intended effect. This technology could potentially be used to re-write organisms as biological weapons. This sort of application is very ethically wrong and unjust.

When considering the ethical validity of this research, another aspect must be weighed into account. Though not immediately relevant, the eventual re-writing of people is a circumstance that seems very unethical. If keeping in line with the basic premise of the research that re-written organisms are used as tools for human gain, the re-writing of humans could either be weighed as out of the question or as an ethically bankrupt concept. The thought of creating people genetically predisposed as slave laborers or workers makes my spine tingle.

In conclusion, when taking a stance on the ethics of the situation, the good must be weighed with the bad. In the case of re-writing organisms, the potential to save many lives and vastly improve the quality of life exists abundantly. However, the possibility for the disruption of natural systems as well as the possibility for its applications in ethically deficient situations, including the manufacture of biological weapons or even the creation of people, exists almost in equal abundance. It is a sad case when the potential to do so much good and provide ourselves with so much benefit must be denied due to the sometimes evil nature of humankind as a whole. Therefore, I would have to say that the process of biological re-writing is ethically unjust.

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