ETHICAL ISSUES SURROUNDING SYNTHETIC BIOLOGY AND QUORUM SENSING

INTRODUCTION

As with any new area of research in science, synthetic biology has its supporters and critics. There are people who see synthetic biology as a powerful, beneficial tool that warrants future investigation but there are also groups that see synthetic biology as a powerful, possibly beneficial field of study, but who also see the potential that it has to do harm, and as such, are critical of it as a field. As is the goal of all ethics initiatives, both groups, when it comes to ethics, aim to prevent harm and promote safety; what differs, is what priorities each group makes in doing this. This difference in perspective makes it very important to consider the ethical issues surrounding synthetic biology. The aim of this paper is a) to analyze the viewpoints of the enthusiasts and the critics using the precautionary and the pro-actionary framework and b) to examine the ethical issues surrounding synthetic biology and quorum sensing by using the E3LS system, which is an acronym for environmental, ethical, economical, legal and social issues.

SYNTHETIC BIOLOGY AND QUORUM SENSING: A BRIEF INTRODUCTION

SYNTHETIC BIOLOGY

Drew Endy in his paper, The Foundations of Engineering Biology, defined synthetic biology as the engineering of biology: the synthesis of complex, biologically based systems, which display functions that do not exist in nature (Endy, 2005). Synthetic Biology is an emerging field of science that has generated a significant amount of interest in the last couple of years (Endy, 2005). However, for reasons mentioned above, not everyone is optimistic about this field. We will discuss the different point of views in detail in the next section.

QUORUM SENSING

Quorum sensing is a process by which microorganisms communicate and interact with each other through the use of pheromone-like molecules (Bassler, 2006). This type of communication system is used by multiple species of microbes to essentially count their neighbours and once at a critical density, co-ordinate a variety of different group activities through control of gene expression on a population level (Bassler, 2006). In this way, bacteria are able to essentially act as a multicelullar organism. The Registry of Standard Biological Parts, an online database of genetic devices, currently contains one quorum sensing signalling system: the AHL system (iGEMregistry, 2009). This year's University of Calgary iGEM project is undertaking the construction and characterization of a second quorum sensing signalling system currently not in the registry. This system, responsive to AI-2, has the potential to be used in a number of applications that require the fine-tuned coordination of bacteria. For example, in the future this system could potentially be used to coordinate bacteria to clean up oil spills, degrade harmful biofilms or even target and destroy cancer tumours.

The construction of the signalling system using synthetic biology tools obviously raises ethical questions related to synthetic biology in general. Broad issues are brought up such. Should we be tinkering with nature? How far should we go? What effects will this have on natural ecosystems? Perhaps of more interest to us however is the issues that stem from the possible applications of our project; the questions that are raised by what our circuit will be set up to do.

Our project will hopefully pave the way for a number of different applications, the implications of which need to be examined. These ethical implications no doubt have common themes that resonate through the entire field of synthetic biology however they also depend to a certain extent on the specific activities being coordinated by the bacteria. To this end we have decided to explore these issues through the use of two case studies: two possible applications of our system. We will look at bioremediation, using our system to co-ordinate bacteria to clean up oil spills, as well as the use of our system to coordinate bacteria to degrade biofilms.

PROACTIONARY VS PRECAUTIONARY: EXAMINIG THE VIEWPOINTS OF THE ENTHUSIASTS AND CRITICS

PROACTIONARY FRAMEWORK: THE ENTHUSIASTS OF SYNTHETIC BIOLOGY

When viewing synthetic biology ethics, there are several frameworks that can be used. In **Ethical Issues in Synthetic Biology: An Overview of Debate,** two frameworks through which to view Synthetic Biology ethics are brought up (Parens, Johnston and Moses, 2009). The first framework is the proactionary framework and its supporters are sometimes referred to as 'the enthusiasts' (Parens, Johnston and Moses, 2009). The enthusiasts view synthetic biology with an inherently positive attitude, feeling that the field has great potential to solve issues facing our society (Parens, Johnston and Moses, 2009). Synthetic biology and associated projects are viewed in a positive light unless there is evidence given to support the contrary. In other words, within this framework, synthetic biology initiatives are given the benefit of the doubt and encouraged to proceed unless a reason to think otherwise emerges (Parens, Johnston and Moses, 2009).

What enthusiasts fear is public scepticism. Enthusiasts worry that a lack of confidence in the general public may slow down beneficial research and halt progress in the field (Parens, Johnston and Moses, 2009). This could result in countries (particularly in North America) losing out on opportunities to excel in this emerging field, falling behind countries willing to take the risk (Parens, Johnston and Moses, 2009).

It is for this reason that enthusiasts, when undertaking ethical interventions in synthetic biology, focus more on education as opposed to regulation (Parens, Johnston and Moses, 2009). Enthusiasts believe that if the public is more educated about advances in synthetic biology, there will be less irrational fears (Parens, Johnston and Moses, 2009). Enthusiasts essentially aim to get the public on board so that the field can continue moving forward. To this end, enthusiasts feel that regulation should not be in the hands of the government where rules may not be closely followed anyways, but rather in the format of self-regulation (Parens, Johnston and Moses, 2009). Self regulation offers some criteria to be followed while aiming not to stifle creativity. Self regulation involves taking steps that undertake personal judgement and cost-benefit analysis (Parens, Johnston and Moses, 2009). If a scientist believes that the research project has more benefits than costs then it should be continued on. If he/she believes that the research project would have costs greater than the benefits then he/she should either consult other scientists and experts not continue on with the project (Parens, Johnston and Moses, 2009).

Advocates of synthetic biology believe that this self regulation (cost-benefit analysis) is better than government regulation because it would make scientists aware of the potential threats that our society might have to face if the costs are greater than the benefits (Parens, Johnston and Moses, 2009). This way the scientific society would be prepared in advance of the external threats that our society might have to face in the future. On the other hand, if the benefits are greater than the costs, then there would be advancement in the field of synthetic biology leading to medical breakthroughs that would beget better treatment of infectious diseases and other potential beneficial applications that would help improve the society and environment (Parrens, Johnston and Moses, 2009). Therefore the advocates of the field of synthetic biology strongly support self-regulation as opposed to government regulation because it not only allows for advancement in the field of synthetic biology if there is a possible benefit but it also allows to have regulations if there is possible harm (Parens, Johnston and Moses, 2009).

PRECAUTIONARY FRAMEWORK: CRITICS OF SYNTHETIC BIOLOGY

Not everyone has such an optimistic view of synthetic biology however; critics of the field hold a much more pessimistic attitude (Parens, Johnston and Moses, 2009). Their approach towards the ethical issues surrounding synthetic biology falls under the precautionary framework with their values and ideas being based on the precautionary principle. The precautionary principle is a principle that is used to approach external threats containing an element of uncertainty as to the outcome (Sandin, 1999). According to the precautionary principle, when there is a chance that something may result in harm, it should be halted until we can be sure (Sandin, 1999). In other words, if something has even the slightest possibility of causing harm, it should not be pursued. This principle aknowledges that humans are prone to making errors and mistakes, some of which are irreversible. Supporters of the precautionary framework argue that there is still a considerable amount of uncertainty in this new area of research and as a result, scientists need to exercise extreme caution when choosing directions for new projects (Parens, Johnston and Moses, 2009). They suggest that if there is even a slight chance that some work has the potential to cause harm than either the research project should be aborted or their should be extensive research on the ethical implications and the potential harms of the research project prior beginning it (Parens, Johnston and Moses, 2009).

Critics of synthetic biology propose strong government regulation and limits to what is being researched in this field as they believe that there is a considerable amount of uncertainty as to what is the ability or potential of a project to cause harm (Parens, ohnston and Moses, 2009). They see the potential harms of synthetic biology as an external threat that would cause irreversible harm therefore they call for government regulations and limits (Parens, Johnston and Moses, 2009). Critics believe that government regulations such as censorship would restrict the information to selective individuals so that the information can be deemed safe and secure (Parens, Johnston and Moses, 2009).

THIRD PARTY PANEL: A SUGGESTED COMPROMISE

There has been heated debate between the enthusiasts and the critics as to whether self regulation or government regulation is the best way to decide whether a project should be continued or not (Parens, Johnston and Moses, 2009). With this in mind, the proposition of a third party panel has been suggested (Selgelid, 2007). Such a panel would consist of equal members from the scientific community and the government (Selgelid, 2007). All members of the panel would be un-biased, highly knowledgeable and strong decision makers and would take on the role of deciding which proposed Synthetic Biology projects were ethical, safe and worthwhile (Selgelid, 2007).

Although the third party panel is a suggested compromise, arguments have been made First it would be extremely difficult to find individuals who would have qualities such as being unbiased. Second, the decision making process in the panel would be hard or sometimes even a deadlock because each individual would be pressured by its community to pass an agenda in their favour (Selgelid, 2007).

Both of these frameworks represent different extreme views that can be used to address ethical issues in synthetic biology. However both sides have issues and concerns that are valid and should not be taken granted (Selgelid, 2007).

E3LS: A WAY TO CATEGORISE THE ETHICAL ISSUES

Synthetic biology, as mentioned earlier, is a new field and the ethical aspect of this field has not been much developed. There could be a lot of ethical issues that may arise out of the field therefore we decided to categorize the ethical issues using the E3LS system. E3LS is a system that is aimed at categorizing the ethical issues into five categories namely economic, environmental, ethical, legal and social issues. We feel that this is a good framework to use as it allows for the exploration of a number of different issues, looking at both the positive as well as the negative implications. For this reason, we will examine the ethical considerations for our project using the E3LS system.

ENVIRONMENTAL ISSUES

Quorum sensing is a process that occurs naturally in many species of micro-organisms. To this end, bacteria with this system are naturally present in the environment (eg. the symbiotic relationship between *V. Harveyi* and the Hawaiian Bobtailed Squid). In both the cleaning up of oil spills and the degradation of biofilms however, the introduction of engineered bacteria directly to the environment is necessary. The bacteria, which will contain our signalling system, need to be released directly into water or into pipelines where they will coordinate group activity. Although this system is already present in some ecosystems, the potential ramifications of introducing any type of novel bacteria into nature are wildly unpredictable.

INTRODUCTION OF BACTERIA INTO THE ENVRIONMENT

Bacteria are an integral part of the natural world, inhabiting almost every part of the Earth and playing a major role in ecosystems by recycling nutrients. Introducing manufactured *E.coli* bacteria in the environment could have harmful effects by affecting the bacterial niche already existing. Mutation in synthetic organisms introduced into the system could, through reproduction of the modified genome, proliferate, spreading the mutation throughout the environment. According to Balmer & Martin (2008), if bacteria with the modified genome (and thus with the quorum sensing system) had advantages that allowed for an increased chance of survival in comparison to their 'natural' counterparts, the resulting selection would have significant impact on the available gene pool. The proliferation of the system (due to selection) in any environment could have unexpected side effects beyond coordination of a desired activity. For example, quorum-sensing could be utilized to unify the bacteria into participating in self-beneficial activities that have negative effect for other species, such as the production of harmful metabolites or introducing competition for resources against other organisms. In addition, the potential of mutation in the modified genome itself could have similar effects on the environment. By changing the dynamics of interactions both within organisms and between organisms and the environment, could upset the delicate balance of the ecosystem. Although there are concerns regarding the mutation of the signalling system itself (the genes that control the expression of proteins in the signalling cascade can be mutated), there is a growing concern about genes that are downstream from the signalling system. Imagine the AI-2 system in *E.coli* bacteria was made for degrading biofilms in pipelines and was used industrially. If there a mutation that affects the expression of proteins that degrade biofilms then this effect can potentially be amplified due to the AI-2 signalling cascade. The AI-2 signalling cascade utilizes bacterial communication to complete a specific task. If a gene is mutated downstream, regulation is altered and the problem may be amplified. It is important to not only consider mutations within the signalling cascade but also mutation downstream of the system as well. Small changes in the genomes of organisms can have profound and unpredictable effects on the ecosystem as a whole. Bacteria are a fundamental component of all ecosystems, such that changing their genetic make-up and thus changing their behaviour will affect other organisms.

POTENTIAL BENEFITS VS POTENTIAL HARMS

Obviously synthetically engineered bacteria as used in quorum sensing can pose ecological issues if not properly contained, however signalling systems also have the potential to provide a number of beneficial services for society by coordinating bacteria with one-another to perform desirable tasks. Both the cleaning up of oil spills and the degradation of biofilms are activities that offer significant environmental benefits. Thus we must consider how to implement regulations and protocols to contain the release of bacteria into the environment and thus limit the potential for negative environmental impact. What would this regulation look like? Who would be in charge of implementing and monitoring it?

In the specific case of utilizing coordinated bacterial behaviour to degrade biofilms in oil pipelines, companies must weigh the potential benefits and consequences of allowing such bacteria to proliferate and remain in the pipeline, or if they will be killed off after completing the task. In the former situation, allowing bacteria to proliferate also allows the risk of bacteria escaping the enclosed pipe and entering the ecosystem. The latter would also allow for a chance for bacteria survival and escape, but on a limited scale. Although from an environmental standpoint, the immediate elimination of bacteria after degrading biofilms may be preferable, it could be less efficient in use of time and resources. While considering environmental implications, companies would also evaluate the economic viability of both alternatives.

ECONOMIC ISSUES

If the quorum sensing signalling system is successful, it could be very beneficial to companies utilizing bacteria in processing and other initiatives. As this system allows bacteria to communicate and coordinate when optimal numbers of organisms are present, this would increase efficiency of bacterial activity. With the presence of this communication system, there is a greater chance that bacteria will perform desired functions, thus optimizing their activity. This is beneficial to companies, as key issues of concern are centred on resource availability. From any standpoint, the increased efficiency of bacteria would allow companies to profit by effectively lowering costs related with inefficiencies resulting from bacteria not performing desirably. According to Schmidt (2008), synthetic biology has huge potential to increase efficiency and reduce cost in areas such as the production of chemicals. In our example of bioremediation; using bacteria to metabolize waste in oil spills, quorum sensing would allow the bacteria to communicate, commencing the process of metabolism only when the bacteria arrived at a critical mass. This could result in the efficient cleaning of large areas simultaneously. When compared to bacteria trying to metabolize waste individually and at random, it is clear that collective organized action of a colony would be much more effective. At the same time if companies wanted to use the signalling system to destroy biofilm build up in pipes, they must consider if this is the best course of action. An important factor to consider is whether or not applications and various technologies derived from the AI-2 signal system can be sold and patented as a whole product or as separate entities. There can be tremendous debate with costs and potentially lead to various legal discussions regarding this issue. There might be other products that are more cost-effective, in which case bacteria would not be utilized.

COST EFFICIEINCY

In order to consider the economic ramifications of utilizing quorum sensing in bacteria, we must consider the costs related to its use in comparison to its benefits- in essence, an assessment of economic viability must be done. In general, if companies find that utilizing quorum sensing provides little improvement on bacterial activity, or is too expensive to employ in relation to other hypothetical optimization methods, then this system will not be employed, and thus have no influence on company profits. In relation to balancing the benefits and costs of using this signalling system (from a purely economic standpoint), there are questions we must consider regarding how this balance is determined. Firstly, can a price be put on a biological system? If so, how should this price be determined? Would it be determined by the cost to clone quorum-sensing genes into bacteria, or determined by a distributor who produces bacteria with the genes present? As well, we must also ask who should determine the cost, whether it is a company that produces bacteria with quorum sensing capabilities for its own use, or a distributor who produces them as a product. One must also consider who can have ownership of the system, whether it is the plasmid with the genes or an organism itself.

MONOPOLIES

Another issue to consider is that of monopolies and the possibility for them to form over this ‘technology’, leading to limitations in its use and profitability. In synthetic biology, these monopolies would be based on parts. As with any emerging field, there is going to be a small number of companies that become established early on and act as frontrunners in the field. These companies will initially hold power regardless of the quality of their products. Such monopolies may lead not only to economic problems, but may also serve to inhibit more research into the field. 1. As more companies emerge however, they will either fight to become the industries parts monopolist, or they will try to resist monopolization (Henkel and Maurer, 2007). To see an example of this, we can look at Linux. In the 1990's, programmer's realized that instead of working for Microsoft, a mass software company, they could avoid buying high-priced commercial modules by writing their own modules. As a result, they didn't have to split their earnings with a monopolist (Henkel and Maurer, 2007). Could this model work in synthetic biology? What if synthetic biology companies wanted to resist giving money to parts monopolists and instead donated resources to an 'open parts' collaboration? This may be a solution, however it also may slow down the industry if this 'own use' system does not provide strong enough incentive to drive high production of new parts, something that Synthetic Biology requires.

OWNERSHIP OF THE TECHNOLOGY

This also brings up the issue of control. Right now, academic scientists still control the majority of synthetic biology projects, however this could possibly change. As new technologies emerge that have commercial potential, leverage will likely switch to find itself in the hands of companies, leaving biologists with little say as to how the field evolves. Our technology in particular has the potential to add to this effect. If our system is used for either the cleaning up of oil spills or the degradation of biofilms, the technology would soon be in the hands of large oil companies. Is that a good thing? Do we want these large-scale companies to have control over which direction the field of synthetic biology takes and perhaps even have their own agenda in mind?

In addition to affecting diverse industries linked to the applications of quorum sensing, the establishment of this system could also affect the industry of synthetic biology itself. As the quorum sensing system is a tool that can coordinate a vast number of bacterial activities depending on the genes it is used in conjunction with, the potential uses are diverse. These potential applications can create interest in the field of synthetic biology, while influencing investors to invest (or not to invest) in what they may see as a profitable industry. If the applications and use of the quorum sensing system are significantly efficient and in demand, then investors will be more likely to invest in the field which allows for further development of similar systems and applications. This brings up issues of social and cultural acceptance.

ETHICAL AND LEGAL ISSUES

OWNERSHIP OF A GOOD APPLICATION

In terms of legal implications, the first major issue is that of patenting and ownership. If quorum sensing can be successfully set up in *E. coli*, the possibility of numerous applications arises. In our example of bioremediation, this system could potentially be set up to target and clean up oil spills in a very effective manner. If this were to occur, with the possibility of being a very cheap and more efficient alternative to current methods, people would obviously want to capitalize on this and patent it. Although we likely cannot patent the genes for the signalling system, we can patent systems and modified organisms. Thus, ownership of these components must be determined. Who is the owner and who has the legal rights to produce/distribute the system for certain uses? Is it our team because we cloned and set up the system in *E. coli*? Is it the University of Calgary because they sponsored our team? Is it the registry of standard Biological parts because they provided us with the standardized method that we used, and the system will ultimately go into it? Another interesting question that arises regarding patents is whether we can extract a system from nature and modify the genetic material and patent the new system.

BIOTERRORISM AND CENSORSHIP

Further questions of ownership may arise in the event of a 'bad application'. Although this system obviously has the potential to perform many beneficial tasks, or 'good applications', it unfortunately also has the potential to perform some harmful ones, both to humans and to our environment. As Tucker (2006) explains, synthetic biology, like any new technology has the potential to cause harm to the environment and to human health both through accidental mishaps as well as through the intentional development of weapons. For example, the system could potentially be used to create some form of bacterial pathogen that could be latent while growing and go undetected until it reached a certain level with enough numbers to severely and immediately compromise the human body. This could be used as a form of bioterrorism. Not only does this pose severe societal consequences, but it also raises issues of censorship. These important questions pertain to the development of intentionally bad applications, however there's also the possibility for unintentionally bad applications. What if the system is set up wrong for the application and results in more harm than gain? What if some mutation in the system causes the bacteria to behave differently than intended and as such cause harm? The question asked in both of these instances is that of responsibility. Who is responsible if something goes wrong? If someone were to use this system to for a harmful application, who would be blamed? Again would it be our team, the University of Calgary, the Registry of Standard Biological Parts? In addition, the legal ramifications as to the responsibilities of both the system's 'owner' and 'user' would have to be determined. To avoid this issue and this situation, we would most likely want some form of regulation as to whom could have access to a biological system with this much potential. Who would be in charge of regulating this though? Furthermore, what kind of people/groups would be denied access? Would it be acceptable if the military had access to this kind of system if it could potentially be of use to them?

OPEN SOURCE VS CLOSED SOURCE

Ethically, this also therefore brings up some important issues. Can we really limit access in any way? Despite the potential for bad applications, do we have the right to deny the availability of the system to anybody, be it group or individual? If one considers the legality of patents and potential monopolies over systems as discussed in the economics section, does this justify or allow owners to distribute this system in any way they see fit? Restricting access to this system would be a very difficult task, but ethically, is it even acceptable to try to control the use of a biological system? These ethical and legal issues all seem to stem from the issue of ownership and the rights that stem from this ownership, which given the potential applications this system poses, is a very important issue that needs to be examined with Quorum Sensing.

Michael J. Selgeild in his paper, A Tale of Two Studies: Ethics, Bioterrorism and the Censorship of Science, described the use of biotechnology (and scientific knowledge) as a dual use dilemma. He says that the scientific knowledge could be used for advances in medical sciences while on the other hand; it may be used as a tool for bioterrorism. Seligeild uses two case studies to illustrate this dual use dilemma. In the first case study, he mentions that some scientists in Australia were able to genetically engineer a virulent strain of the virus mouse-pox, which is similar to WHO declared eradicated infectious disease smallpox. In the second case study, he mentions that some scientists in the United States were able to synthesize a 'live' polio virus. Selgelid (2007) uses these two case studies as models to explain the dual use dilemma. He says that on one hand these advances in scientific research would significantly help find potential cures for infectious disease. However, bioterrorists or 'rouge' nations might use this scientific knowledge to develop bio-weapons. Again the much debated of open source versus close source comes into play. Advocates of open source argue that this scientific knowledge that it makes people and scientists aware of the potential threats out there in the world. It also gives other scientists an opportunity to verify these discoveries, come up with medical breakthroughs and add to the existing scientific knowledge. Critics of open source argue that the materials and the methods to make biological weapons is much easier than to make nuclear weapons. They also argue that the sources for life sciences knowledge are relatively open to other scientific knowledge.

Whenever assessing the applications of this system, the question of moral responsibilities in relation to the use of this technology is raised. This signalling system can be used essentially to coordinate and thus amplify many different functions of bacteria, depending on the genes used. With these capabilities, individuals must consider all aspects of the potential impact of what they plan to use the signalling system with. Since the signalling system is added to an open source registry, would the University of Calgary or the Registry of Biological parts be responsible for any legal responsibilities? If the system is used for an application and it can potentially harm society and the environment, who would hold the responsibility? We must consider what sort of responsibilities these individuals hold in upholding societal values, and what legal boundaries must be put in place to ensure that this system is used responsibly.

SOCIAL ISSUES

As an example of considerations described in the above section, possible applications of Quorum Sensing may have social impacts that must be taken into account, both positive and negative. This depends on the function of the bacteria, and how they are used. When taking the initiative to use quorum sensing in biological systems, individuals must consider how it may be used to further a social agenda. This year the University of Calgary iGEM team focused heavily on building a synthetic biology in Alberta, especially in Calgary. One might argue that the team is not approaching it the correct way. We focus heavily on the advantages that synthetic biology can contribute to society and genetic engineering research efforts, but rarely mention the potential harmful effects that this type of research can lead to in society. Is the University of Calgary team building the synthetic biology community in the correct way? Should the team take an enthusiastic approach or should we provide all the potential advantages and issues that surround synthetic biology? From the extreme example of bioterrorism, it could potentially be used to further a social agenda of targeting and discriminating against specific social groups.

POSITIVE SOCIAL IMPACTS

Our project in particular has the potential for strong positive social impacts. In particular, in the outreach portion of our project, we are working towards building up a synthetic biology community in Alberta. To do this, we are trying to generate interest in the field by educating high school students as well as the general public about synthetic biology and its possible applications. With increased awareness, we hope to remove any misconceptions that people might have about synthetic biology and promote a forum for communication. By promoting learning about synthetic biology, we can allow for comprehensive and accurate discussions of the implications when exploring this field. This is one positive social impact of our project, however there are also possible negative impacts as well that need to be explored.

Although Quorum sensing no doubt has the potential to generate various beneficial applications, as previously mentioned, we cannot guarantee the success of the system. With quorum sensing, there is the possibility for both unintentionally and intentionally negative consequences such as the creation of biological weapons. This obviously poses legal issues in terms of responsibility, however it also would have social impacts. Not only could society suffer the negative consequences of things such as biological weapons, but this could also hurt the synthetic biology community. A negative consequence could result in blame being put on synthetic biologists as well as the field in general. These negative applications of quorum sensing may compel the society to turn against the concepts and applications of synthetic biology. This could result in the credibility of synthetic biology and its applications being challenged. Going back to the possible application of bioremediation in the cleanup of oil spills, the public perception of the success or failure of using quorum-sensing modified bacteria would consequently alter their perception of the benefits and/or costs of synthetic biology in general.

CONCLUSION

The field of synthetic biology is new and there hasn't been much done about the ethical issues surrounding it. However, it is very important to consider these issues because this field has the potential to do harm as well as provide benefits. Therefore for the applications of quorum sensing, we used two theoretical frameworks to assess the potential harms and benefits namely the precautionary/proactionary framework and the E3LS system. The precautionary/proactionary framework helped us analyze the viewpoints of the critics and enthusiasts and the E3LS helped us analyze the ethical issues surrounding quorum sensing and synthetic biology.

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