International Genetically Engineered Machine (iGEM) Jamboree integrates materials research

By **Chia-Suei Hung**

Descending like flocks of migrating birds, thousands of enthusiastic aspiring scientists arrive in Boston, Mass., in October every year for the annual International Genetically Engineered Machine (iGEM) Jamboree. The iGEM Jamboree is not your standard science fair nor are the students run-of-the-mill scientists. Rather, each project takes a holistic approach to science, where both scientific advancements and human/societal impacts play equally important roles. The students are dedicated to their projects and employ the most advanced synthetic biology techniques to solve challenging problems facing the world and humanity.

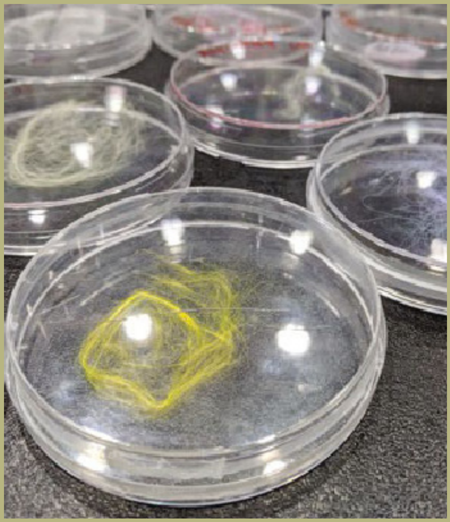
Born out of a month-long course during the Independent Activity Period at the Massachusetts Institute of Technology, iGEM grew from a five-team competition in 2004 to 353 teams from more than 40 countries in 2019. Synthetic biology research is at the heart of the iGEM competition. Every year, each team conceives of a theme for its project and employs various synthetic biology techniques—ranging from cell-based to cell-free to DNA technologies—combined with engineering principles to tackle problems such as biotechnology, disease detection (for either human, animal, or plant diseases), therapeutics, and biomaterials production. Mathematical modeling or software programming is an integral part of the project. In addition, iGEM teams are encouraged to take their science outside of laboratories for public engagements, such as scientific outreach, public education, industrial interaction, and policy discussion with governmental organizations. Furthermore, each team maintains a Wiki website detailing its team members, project theme, research design, research progression, and public engagements.

Top: A group of iGEM students interacting with and being questioned by a judge at their poster presentation. Credit: Amy Breedon, iGEM team mentor.

Left: Oral presentation at the 2019 Giant Jamboree. Credit: iGEM Foundation and Justin Knight.

The yearlong science project crescendos at the annual gathering of the Giant Jamboree in Boston. The teams present their research to their peers and a panel of judges through an oral and a poster presentation. Teams are judged not only on their scientific quality but also on wiki design, public engagement, education outreach, and policy/societal impacts. Based on completion metrics, each team receives bronze, silver, or gold medals. However, as the name implies, the annual competition is also an opportunity for teams to interact with each other, making new friends or reaffirming their friendships with teams whom they have collaborated with during the year, and exchange knowledge. That sentiment is well-reflected by iGEM participants. Annie Bete, currently a student at The Ohio State University and formally a member of the US_AFRL_CarrollHS team, said, "It's one thing to email back and forth with a person from another team, but when they come to your presentation and tell you afterwards how much your collaboration helped both of your projects, it really demonstrates both of your teams' hard work." The event is truly more of a Jamboree than a competition and imprints a lasting impact on the students.

Nevertheless, each team vies to best each other in competition for the ultimate Grand Prize, a trophy in the form of a large Lego piece, within each category of Overgrad (graduate students), Undergrad, and High School. These are rotating trophies that each winning team could keep for the duration of the year and serve as bragging right for the teams. In addition, iGEM teams also compete for various Project Track and Special Awards.



Top: Using synthetic biology for materials production could soon be a reality. The high-school team GreatBay SZ demonstrated silk fibers spun with chromoprotein-mini-spidroin fusion proteins at the 2019 Giant Jamboree. Credit: Amy Breedon, iGEM team mentor.

Bottom: The highest award for each category is called the "Grand Prize." The actual trophy is a large Lego piece that is passed down from year to year (green colored for high-school category and silver colored for undergrad and overgrad categories). Each winning team keeps it for one year, and then at the following year's Jamboree, the winning team brings the Lego trophy back and in return receives a glass trophy to keep. Credit: iGEM Foundation and Justin Knight.

In the Overgrad category in 2019, team EPFL (École Polytechnique Fédérale de Lausanne) from Switzerland took home the Grand Prize with their project entitled "ViTEST." Team EPFL focused on developing a rapid detection and identification method to distinguish different phytoplasma diseases, an insect-born bacterial infection, in grapevines for wine growers. The team engineered a simple device that would extract DNA from diseased grapevine leaves, amplify a relevant region of bacterial DNA, and, with the aid of cell-free protein synthesis, determine the specific type of phytoplasma disease. In addition to winning the Grand Prize, Team EPFL also won the Best Environment Project Track Award and Best Human Practice Special Award. The team Wiki can be found here: 2019.igem.org/Team:EPFL.

In the Undergrad category, team NCKU Tainan (National Cheng Kung University) from Taiwan won the Grand Prize with their project cleverly titled "Oh My Gut." Team NCKU Tainan aimed to reduce the incidence of chronic kidney disease. They did this through detection of uremic toxin, *p*-Cresol, in patient blood and its elimination in the GI tract, the origin of the uremic toxin. (Uremia consists of an excess of amino acid and protein metabolism end products.) The team engineered probiotic *Escherichia coli* bacteria to attack *Clostridium* bacteria, the *p*-Cresol producer, and to convert excess tyrosine amino acid, the *p*-Cresol precursor, into an antioxidant molecule, *p*-Coumaric acid. Team NCKU Tainan also engineered the probiotic *E. coli* to detect *p*-Cresol molecules. In addition, the team engineered and fabricated a small-scale and low-cost device to separate serum from other components of blood for *p*-Cresol detection by the engineered bacteria. Team NCKU also won Best Therapeutic Project Track Award and Best Hardware, Best Model, Best Presentation, and Best Measurement Special Awards in its category. The team Wiki can be found here: 2019.igem.org/Team:NCKU_Tainan.

In the High-School category, GreatBay SZ (Shenzhen area high schools) from China scored the Grand Prize with their project titled "SPIDERMAN" (SPIDroin EngineerRing with chroMoprotein and Natural dye). This high-school team achieved something that many scientists in research institutions have either not accomplished or steered away from. The team produced recombinant mini-spidroin protein with engineered bacteria and spun silk fibers, then took it a step further. The team fused chromoproteins (green, red, and blue fluorescent proteins) to the mini-spidroin protein to produce silk fibers of different colors. Furthermore, by mixing different ratios of uncolored and colored mini-spidroin proteins, team GreatBay SZ produced silk fibers of different colors and shades. Team GreatBay SZ was one of the most successful teams in 2019 by also winning the Best Hardware, Best New Basic Part, Best Part Collection, Best Presentation, Best Wiki, and iGEMer's Prize Special Awards. The team Wiki can be found here: 2019.igem.org/Team:GreatBay_SZ.

Because of the nature of the technology, synthetic biology has largely been used for biological and therapeutic applications. This was also reflected through the iGEM projects. However, an increasing number of teams have been undertaking the challenge to use synthetic biology for materials production. The success of team GreatBay SZ was a prime example. Through protein and organism engineering, biomaterials production in a reasonable and testable quantity could be realized.

Several 2019 iGEM teams, although less successful, have focused their project on materials synthesis with synthetic biology, as presented in the sidebar (next page). The sidebar also lists non-biomaterials and energy production projects accomplished through synthetic biology.

For many of these aspiring scientists, space is not the final frontier. The iGEM team Brown-Stanford-Princeton, mentored primarily by NASA scientists, embarked on a project titled "Towards an Astropharmacy." The team targeted materials production in the resource-limited environment of space travel. Team Brown-Stanford-Princeton engineered different bacteria for the production of various protein-based therapeutics through both cell-based and cell-free systems. The team also engineered microfluidics for the purification of therapeutics and disease diagnosis. The combined synthetic biology and engineering effort aimed to achieve personalized medicine for astronauts.

Mentored by university faculty members, research scientists, or students, iGEM teams are excellent vehicles for developing young scientific talents. As iGEM projects are interdisciplinary by nature, teams often are comprised of students from different scientific disciplines with diverse career interests. Participation in iGEM teams allows students of different scientific backgrounds to learn from each other and foster an "out-of-the-box" mind-set. Scientists from the US Air Force Research Laboratory sponsored and mentored a local high-school iGEM team—US AFRL Carroll High School—as part of its science-technology-engineering-mathematics (STEM) outreach program. One of the participants, Jason Dong, currently a student at Duke University, said that iGEM has taught him how to be "part of a team and figure out how to divide work and accomplish the objectives" among the group. Peter Menart, currently a student at The Ohio State University, expressed similar sentiments. Furthermore, Menart said that iGEM has given him more "confidence in doing research" and allowed him to support synthetic biology research with "graphic design, coding, and communication" skills that he already had prior to joining an iGEM team.

Synthetic biology has combined the traditionally disparate biological disciplines of protein, genetic, and metabolic engineering and applied engineering principles to create a multidisciplinary science. Through the "design-build-test-learn" cycle, synthetic biology is gaining acceptance among the materials research community for materials synthesis. A combination of protein and metabolic engineering allows for production of chimeric protein fusions without substantial burden on cells. Genetic engineering combined with metabolic flux analysis/engineering permits the synthesis of petrochemical replacement molecules or hard-to-synthesize large molecules. As more genetic tools and "parts" are developed for nonconventional organism chassis (e.g., organisms other than *E. coli* bacteria and *Saccharomyces cerevisiae* yeast), more suitable organisms could be used for materials production at the manufacturing scale.

Although iGEM has been traditionally considered a STEM talent development mechanism, several of the technologies have transitioned into industries or startup companies. The iGEM event also provides a venue to test high-risk/high-reward projects. Materials researchers interested in novel materials or materials processing developments should strongly consider synthetic biology as their next toolset and contemplate involvement with iGEM.

SYNTHETIC BIOLOGY PROJECTS

S.P.L.A.S.H.–Suckerin Polymer Layer to Achieve Sustainable Health
by Leiden, The Netherlands
Recombinantly produce engineered suckerin proteins to make hydrogels for healing of burn wounds.

Armour from the Sea: A Microbial Manufacturing Band-Aid Made of Mgfp-5 and Masp-1
by Shenzhen SFLS, China
Engineered *E. coli* to produce DOPA-containing mussel foot proteins (Mgfp) for strong-adhering and waterproof Band-Aids.

Novosite–A Novel and Modular Antimicrobial Bandage
by Linkoping, Sweden
Engineered antimicrobial peptide-cellulose binding domain fusion proteins, which were designed to bind to bacterial nanocellulose mat as an antimicrobial bandage.

NON-BIOMATERIALS & ENERGY PRODUCTION THROUGH SYNTHETIC BIOLOGY

A Circular BioEconomy: How Toxic Waste Is Converted into Nano-Electrocatalysts and Fuel
by NU Kazakhstan, Kazakhstan
Engineered and optimized cyanobacteria to convert wastewater into hydrogen. At the end of life, the engineered bacteria are burnt and converted to graphitic material for electrode production.

BioSo–A Solar Cell Using a Pigment Producing Bacterium to Catch Sunlight
by UiOslo Norway, Norway
Engineered *E. coli* to produce lycopene, a carotenoid precursor, which could be incorporated into a tryptophan-TiO_2-containing device to make dye-sensitized solar cells.

Waste Cartons to Renewable Bioproducts by *Zymomonas mobilis*
by HUBU-WUHAN, China
Engineered nontraditional bacteria, *Zymomonas mobilis*, to degrade cardboard paper and produce poly-β-hydroxybutyrate and isobutanol.

Cinergy Project: Degrading Cigarette Butt Filters to Produce Electricity and Limit Their Environmental Impact
by Ionis Paris, France
Engineered *E. coli* to degrade cellulose acetate, primarily a component of cigarette butt filters, into glucose and acetate. Glucose and acetate were further converted into lactate and flavins. The resulting molecules were then used by *Shewanella oneidensis* bacteria to produce electricity.

Chlamy Yummy–Revolutionizing Plastic Degradation by Introducing *Chlamydomonas reinhardtii* as a Eukaryotic Secretion Platform
by TU Kaiserslautern, Germany
Engineered green algae that naturally has a high affinity to plastic, *Chlamydomonas reinhardtii*, to degrade poly(ethylene terephthalate) (PET) plastic into terephthalic acid (TPA) and ethylene glycol (EG). TPA could be further processed to make PET, while EG could be converted to ethanol or used as a food source for *Chlamydomonas*. In addition to protein and organism engineering, the team also created a conceptual design of bioreactors to facilitate PET degradation by the green algae.

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