The Biophysicist

Curiosity-Based Biophysics Projects in a High School Setting with Graduate Student Mentorship

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Introduction

We describe a project-based learning (PBL) program that combines student-driven projects with year-long mentorship to inspire high school students to pursue science, technology, engineering, and math (STEM). Previous studies indicate that PBL improves learning outcomes, teamwork, and long-term interest (1–4). Separate work suggests that long-term mentorship (LTM) programs can promote a pipeline into higher education and STEM for students from underrepresented backgrounds (5, 6).

We sought to combine PBL and LTM through a single program called Future Advancers of Science and Technology (FAST). FAST was started at Andrew P. Hill High School (AHHS), a public magnet school in San Jose, CA. Fifty-eight percent of students at AHHS receive free lunches, and 10% receive reduced-price lunches. AHHS academic staff had identified a need for reliable and positive role models in students' lives, especially in STEM fields. FAST aimed to fill that need and help students explore science and engineering through small-group projects.

Each FAST program year (Fig 1) begins by working with science teachers from partner schools to identify and recruit students who are "curious, but in need of inspiration." FAST then matches students with mentors, who are graduate students from a local university. With the guidance of their mentors, students then spend the next 6 months investigating an open question in science or prototyping a solution to an engineering problem. Mentees are encouraged to let their own interests steer the direction of projects, while mentors use their

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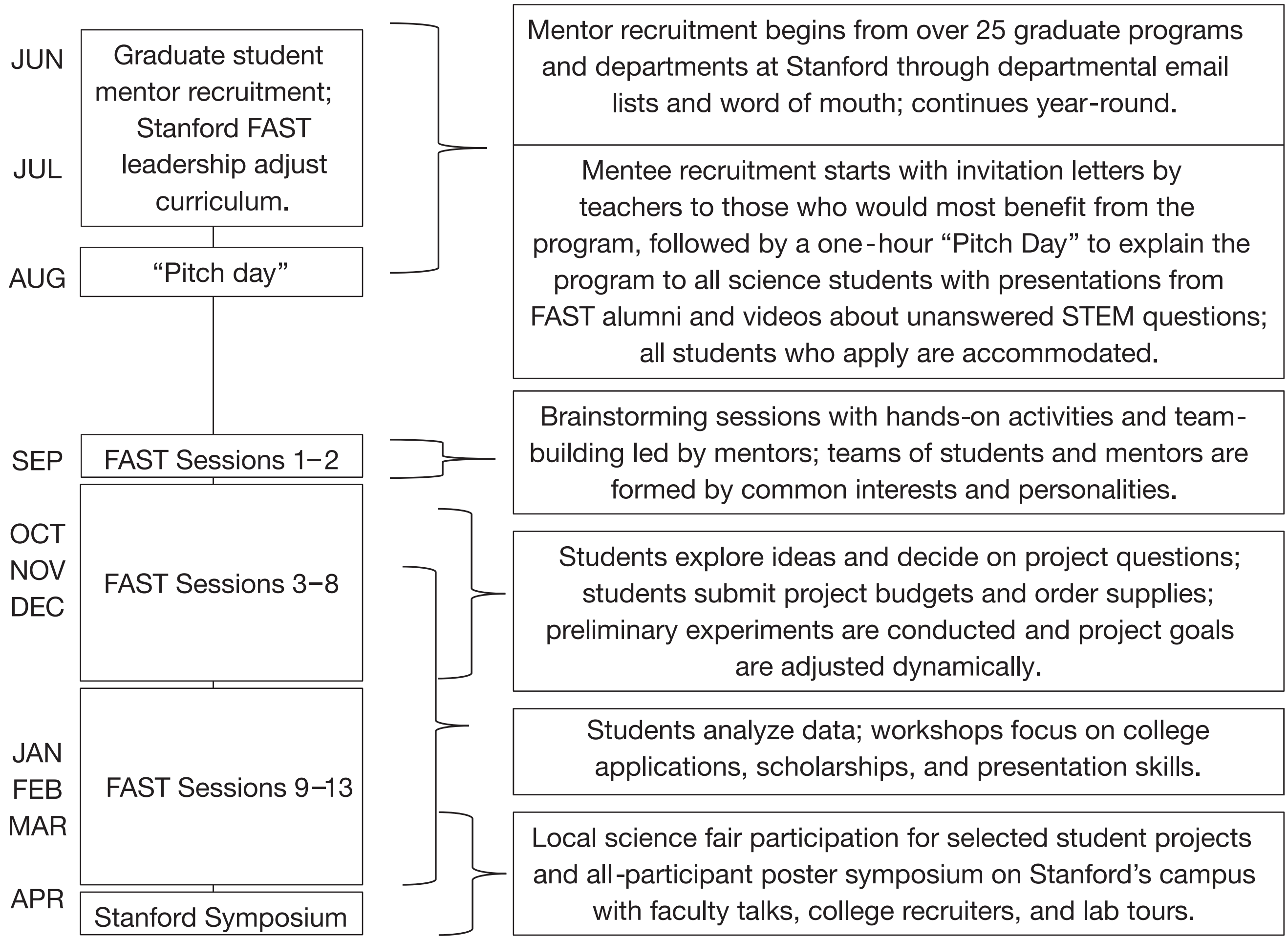

Fig 1. FAST curriculum workflow.

scientific experience and ability to gather information to help develop their mentees' ideas. Projects are conducted in 3 phases of approximately 2 months each: (1) brainstorming and problem definition, (2) performing experiments, and (3) analyzing results and presenting work at local science fairs and a culminating symposium at Stanford University. Over the past 5 years, participation in the FAST program has grown significantly (Table 1), as the program has expanded from AHHS to operate at 3 Bay Area high schools. At AHHS, self-reported participant demographics (Table 2) are generally reflective of the AHHS student body (7).

Here, we highlight 3 examples of student–mentor teams that worked on biophysics projects, a significant component of the FAST program. These teams illustrate the dynamics of the student–mentor relationship that FAST was designed to foster. Mentor expertise helps students adapt their projects over the year, but students' personal interests control the project direction. Mentors can also provide scientifically relevant social and cultural capital ("science capital" [8]) that allows

Table 1. Annual FAST program enrollment.

	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020
Mentors	20	35	61	70	80
Students	36[a]	52[a]	70[a]	79[a]	110[b]

[a] Students who completed a project, attended over 75% of sessions, or both.
[b] Students who presented at the culminating symposium, completed a written project report and/or attended over 50% of sessions.

Table 2. Overall FAST program statistics 2018–2020.

	Underrepresented minorities in sciences[a]	Would be first generation to attend college	Seniors planning to pursue STEM majors (100% are matriculating)
2018–2019[b] (%)	90 ($n = 66$)	53 ($n = 66$)	100 ($n = 12$)
2019–2020[c] (%)	77 ($n = 79$)	43 ($n = 82$)	92 ($n = 12$)

[a] As defined by US congress bill HR4803, 2016 (13), and the National Science Foundation.
[b] End-of-year survey response rate, 84% (2018–2019).
[c] End-of-year survey response rate, 72%–75% (2019–2020).

students to pursue detailed and rigorous projects. Interviews with student participants suggest that this process of student-driven project development leads to personal growth and encourages the pursuit of higher education in STEM fields, especially in biophysics and related disciplines. With LTM and a modest budget of $100/yr, each FAST student could create a novel, rigorous science or engineering project in a relatively low-resource setting.

Simulating the biophysical effects of climate change on lake shrimp swimming

Initially, AHHS junior and FAST participant TP said she was not “the science or engineering type,” but persisted with the program because she formed strong connections with a few of the mentors. TP was interested in how climate change would affect marine life in local salt lakes, especially by altering physical and chemical properties of the lake water. After 6 wk of brainstorming activities with her mentors, TP proposed a project where she would vary salinity, viscosity, and pH of the water and monitor their effects on the reproduction rate of brine shrimp.

The project experienced a setback as TP found she was not able to raise enough brine shrimp to gather meaningful data on reproduction rates. Thus, TP decided to switch from observing reproduction to observing swimming behavior. Her mentor suggested quantitative measurements she could make to aid her analysis. As TP varied salinity and viscosity of the water, she tracked individual shrimp swimming speeds with microscopy videos recorded on her cell phone and free image analysis software (9). TP found that doubling and tripling salt concentrations had no substantial effect on swimming speeds. On the other hand, adding a polymer that increased the viscosity by 5%–10% led to a surprising 50%–75% decrease in swimming speed.

In this project, TP and her mentors transformed an unfortunate scientific setback into an insightful science project. TP led the changes and pivoted her project on the basis of her observations, supported by her mentor’s knowledge of biophysics, which complemented her parallel classroom learning in chemistry. TP found a community in the FAST program, and she became a FAST student leader the following year. As a leader, in addition to carrying out a second project, she helped to recruit additional students and shape the program curriculum. TP reported that her FAST projects inspired her to study Civil and Environmental Engineering at UCLA.

Chemical composition of makeup primers affects growth of skin bacteria

AHHS sophomores CN, NN, and CT had never taken a chemistry or physics class, and they each had varying levels of engagement with their science classes, which ranged from “slightly interested” to “not motivated at all.” Over 10 weeks of iterating through ideas and reading scientific literature with their mentor, a Stanford Biology PhD student, the team refined a research question that affected their everyday lives: how do various types of makeup primers lead to different rates of acne or bacterial growth on the surface of skin?

The students classified 6 different makeup primer brands as water-, oil-, or silicone-based and measured how well 2 bacterial species commonly found on the skin grew on nutrient media supplemented with different makeup primers. They quantitatively confirmed that oil-based primers led to higher levels of bacterial growth for both strains than either water- or silicone-based primers. To understand this result, they reasoned that opportunistic bacteria may colonize areas of the skin following an overproduction of oil, which leads to inflammation.

All 3 students reported that this project helped them learn important lessons about time management and resilience and increased their motivation in science classes. NN wrote, "FAST has allowed me to gain more confidence in my abilities to present my ideas and it has given me an outlet for my creativity. My ability to express my thoughts in a more meaningful way has markedly improved. I am eager to experiment and ask more questions about the unknown." The students successfully presented this project at local science fairs, and then were invited to compete at the California Science & Engineering Fair. The next year, NN, CN, and CT all returned to FAST to pursue new research questions. This case study demonstrates how student interest in a real-world problem (side effects of different cosmetics) was built into a rigorous scientific project with mentor guidance.

CRISPR editing and the cell cycle

In their second year participating in FAST, AHHS seniors HN, ST, and EP wanted to improve CRISPR gene editing efficiency. They identified that biophysical changes in DNA organization during the cell cycle may affect DNA accessibility and hypothesized that arresting cells in different stages of the cell cycle would alter CRISPR editing efficiency. However, they did not know how they might be able to test this in a high school on a budget.

Their mentor identified a Cas9 transgenic yeast strain donated from the San Jose Tech Museum that could be easily screened for Cas9 activity based on the color of the colony. The students treated yeast with cell cycle–inhibiting drugs while inducing Cas9 expression, finding that blocking DNA replication with hydroxyurea or cell division with nocodazole increased CRISPR editing over controls by 98% or 36%, respectively.

The students won a Grand Prize at the regional science fair and a trip to the International Science and Engineering Fair (ISEF). The experience of attending ISEF was a "culture shock" for EP, where he met students from all over the world, many of whom had access to considerable resources. Despite the excitement of ISEF, HN recounts that "The biggest prize for us was getting our results and finding out they were meaningful." All 3 students were awarded college scholarships and expressed that FAST and ISEF inspired them to pursue a STEM-related field.

This project demonstrates how mentors with access to science capital (8), such as networks with other scientific institutions, can enable students to fully pursue their ambitions.

Strengths of the program

These 3 specific examples of FAST biophysics projects demonstrate the effectiveness of LTM in fostering curiosity-driven, project-based informal learning. A similar pattern emerges from data at a program-wide scale, with students consistently self-reporting they are more likely to apply to college after participating in FAST, despite the fact that many would be the first in their family to matriculate (Table 2).

The examples also highlight key features of the FAST program that may contribute to its success, such as student ownership of project directions. Students have reported that after developing a project through FAST, they have felt more empowered to express themselves scientifically and they have better understood the process of pursuing further scientific training. In contrast, prior work has described a disconnect between STEM content in the classroom and its practical application in the real world (10). FAST students have also reported feeling confident in the science-related skills they developed. This development process is typical of effective PBL, wherein students derive a better understanding of scientific content by engaging directly in problem-solving and critical thinking (11, 12).

The case studies presented here demonstrate that successful mentorship involves connecting students to their mentors' science capital (8). This can manifest as guidance—stemming from the mentors' technical experience—that allows students to adapt their project over the course of the year. Additionally, mentors have knowledge of specific resources that allow students to surpass common expectations of high school science project depth and rigor. It is possible that these practices are particularly effective for interdisciplinary subjects like biophysics; in our experience, students are curious about biophysical questions but have not covered enough material in high school to be able to design the experiments independently to test their questions without some guidance from their mentor.

FAST mentors are motivated to join the program to support the development of the next generation of scientists and inventors. By joining a graduate student volunteer community, mentors are able to build confidence and develop their mentoring skills. Mentors have also reported growth in their perspectives of the capabilities of underprivileged/underresourced students.

Future directions

Work is ongoing to broaden participation continually in Stanford FAST via inclusive recruitment. Efforts are also ongoing to assess program outcomes quantitatively through evidence-based surveys administered over the course of the academic year. Analysis of these survey data will inform efforts to improve the quality and reproducibility of the program. Former FAST student organization leaders have started a FAST 501(c)(3)–designated charitable organization (fastprogram.org) for supporting the development and dissemination of FAST to broader audiences and new chapters. For educators interested in starting chapters or similar programs, key ingredients will include commitments from enthusiastic science teachers together with demonstrated needs arising from students who have potential science interests but are lacking access to resources or science capital.

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AUTHOR CONTRIBUTIONS

Original manuscript development: CJG, KNL, ASK, SKT, AD, TAGL. Case study supporting materials: TP, DL, AAB, HN, EP, ST, NN, CN, CT. Case study interviews: KNL, ASK, AD, CJG. Program supervision: CJG, KNL, ASK, AD, GH, PA. Manuscript editing and organization: CJG, KNL, ASK, SKT, AD, TAGL, PA, ZB.

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