# FORUM

## Science Fairs for Science Literacy

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Scientific discovery, technological revolutions, and complex global challenges are commonplace in the modern era. People are bombarded with news about climate change, pandemics, and genetically modified organisms, and scientific literacy has never been more important than in the present day. Yet only 29% of American adults have sufficient understanding to be able to read science stories reported in the popular press [*Miller,* 2010], and American students consistently rank below other nations in math and science [*National Center for Education Statistics,* 2012].

In 1985, the year the world welcomed a revisit of Halley's Comet, the American Association for the Advancement of Science formed a working group tasked with improving science literacy for U.S. students. The group took the name Project 2061, referring to the next year the comet would again be visible from Earth, as "a reminder that today's education will shape the quality of [students'] lives as they come of age in the 21st century amid profound scientific and technological change" [*American Association for the Advancement of Science* (*AAAS*), 2009]. Project 2061 defined science literacy as understanding scientific concepts, processes, and practices necessary to participate in civic and personal decision making and thinking objectively and critically about science issues facing society [*AAAS,* 1990; *National Research Council,* 1996].

To follow the guidelines set by Project 2061, educators have increasingly turned to research projects as an avenue for students to gain scientific literacy. Students can increase science literacy by conducting research projects, and science fairs and symposia (e.g., http://www.jshs.org/ for high school students) offer the perfect venue.

### *Science Fairs Foster Science Literacy*

Science fairs first gained popularity in the 1950s. Fervor over Sputnik, the advent of television, and advances in atomic energy kindled excitement over science and technology.

Half a century later, the late 20th and early 21st centuries saw massive expansion and diversification of science fairs, from small, local school competitions to large international competitions. At the Intel International Science and Engineering Fair, the largest in the world, more than 1500 students from 70 countries compete each year for scholarships and prizes totaling more than $4 million (https://student.societyforscience.org/intel-isef).

Currently, several hundred thousand American high school students participate in science fairs each year nationwide [*Harmon,* 2011]. For making a lasting impression, the hands-on experience of conceiving and conducting an experiment is second to none. Science fairs put students in scientists' shoes: Asking questions; applying the scientific method; demonstrating scientific principles; doing scientific reporting; and working with scientific collections, inventions, and original computer programs all provide new perspectives on how science works in the real world.

The attitudes formed about science during childhood carry over into adulthood, shaping the way that people perceive, understand, and interpret scientific findings as adults. In addition, for a subset of students who go on to become scientists, science fairs can build a strong foundation for future research practices.

Getting the most science literacy out of science fairs requires students, teachers, and mentors to work together. The suggestions described here stem from our involvement mentoring students and judging science fairs as a researcher (Mackey) and mentoring projects and running fairs as a science and math teacher (Culbertson).

Together we have been involved in small, local school fairs as well as large national competitions and have had the opportunity to discuss learning outcomes and long-term science literacy goals with science fair organizers, judges, scientists, and hundreds of students. Here we distill the lessons we have learned and suggest three major areas scientists and engineers should emphasize to help students acquire the greatest gains in science literacy.

### *The Hypothesis: An Idea You Can Test*

Perhaps the most consistent feature of science fair project requirements for older students is that the experiment should be based on a hypothesis. The hypothesis is a central component of the scientific method, emerges from observations or curiosity about a topic, and presents a testable idea.

Crucially, the hypothesis shapes the experimental design by determining what types of measurements and comparisons to make. Familiarity with basic science practices, like asking questions for scientists (or defining problems for engineers), helps students understand how scientific knowledge is developed, established, and refined and shows the different approaches to investigating, modeling, and explaining the world.

At the outset of a project, mentors can help students identify key words and basic questions to use for a background literature review. Providing access to primary scientific literature or abstracts is helpful to older students, and being available to answer technical questions on the readings is a must for all ages. Online resources like http://www.sciencebuddies.org provide background information and topic areas on projects for a range of ages and complexity levels.

The concept of "an idea you can test" is fairly straightforward, but students may struggle with constructing a solid, unambiguous hypothesis. Mentors should help students tweak the language so that the hypothesis is actually testable. Avoid relative words in favor of quantitative or categorical ones.

For example, the hypothesis "plants will grow better with added nitrogen" is too vague. An improved version, such as "bean seedlings will grow taller/have more leaves/make more pigment with added nitrogen" is much more specific and offers clues for how to design the experiment.

Forming a concise hypothesis is a skill that improves both science literacy and critical thinking across disciplines. Understanding that science is methodical, precise, and controlled is a step toward understanding data and interpreting trends and implications when information is presented in the popular press. Furthermore, the ability to distill information to a single, testable hypothesis or defensible thesis is an important inductive reasoning skill in any discipline, not just science.

### *Building Confidence With Feasible, Organized Projects*

Every hypothesis can be tested with different levels of rigor, and mentors should guide students to design projects of the appropriate scope and difficulty level. This will vary depending on the student's age, aptitude, course requirements, and free time. Mentors must walk a fine line: The project should be challenging enough to generate confidence but not so laborious as to become a burden. This may mean scaling back experimental complexity or the number of variables to improve the project's chances of success.

More than conducting sophisticated research, projects should improve the students' confidence in their abilities to understand and participate in science. These positive feelings can stay with students into adulthood, giving them the confidence to engage in public discourse involving scientific concepts as adults. Astrophysicist Neil deGrasse Tyson said it best: "People like it when they understand something that they previously thought they couldn't understand. It's a sense of empowerment."

Riskier topics and experimental designs are appropriate for advanced students with a propensity for science and interest in research, but mentors must make sure to have a contingency plan. For these projects, mentors should consider guiding students to test more than one hypothesis, where one is "high risk, high reward" and the other is more straightforward "low-hanging fruit."

### *Graphing and the "S" Word: Statistics*

Graphing is perhaps the quintessential scientific skill. Whether in the setting of a science fair, where students need to understand dependent and independent variables and clearly illustrate and communicate results, or in the general flow of a science class, the capacity to create and interpret graphs must become a focus of science education.

John Tukey, a father of modern statistics, wrote, "The greatest value of a picture is when it forces us to notice what we never expected to see." Graphs provide students with a visual image with which to make those mental leaps. By visually representing data, students see and recognize statistically valuable concepts such as patterns and correlations.

Graphing is a progressive skill that evolves with grade level and confidence. The rudimentary graphs made by young students give way to more complex graphs by older students, who may utilize averages, trend lines, and scatterplots. High school–aged students may further modify graphs by including *r* values, standard deviations, and statistical comparisons. Constructing graphs, crafting explanations based on data, and communicating findings build science literacy.

The use of statistics in science fair reports is likewise progressive. By high school, many students have been exposed to basic concepts like mean, median, and mode. However, probability theory is complex, and teaching upper level statistics (e.g., Student's *t* test and chi-square test) falls squarely between the purviews of math and science, making it easy to overlook in curricula that are already stretched thin. Science fairs provide an opportunity to convey key statistical principles without requiring extensive mathematical training.

Mentors can explain statistical principles using plain language and graphs in lieu of calculations. Graphs make spotting obvious outliers easy and illustrate the empirical, real-world variability of data. The latter point introduces the concept of replication and reproducibility. Younger students may opt to plot all of their replicates in lieu of calculating averages, and this is perfectly acceptable if the graph provides a sense of the data's spread and overlap.

Familiarity with statistical concepts will also help correct confusion about the scientific meaning of "uncertainty." Whereas scientists use it to describe probabilities, the term has in some cases been coopted to mean "unsure," "unresolved," or "ambiguous" and used to argue for a take-no-action approach toward issues such as curbing carbon emissions or adopting clean energy technologies [*The Guardian,* 2013]. Basic statistical concepts—with or without the associated math—are critical for individuals to draw their own conclusions about model predictions.

### *Science Literacy Changes Worldviews*

A scientifically literate citizenry pushes the boundaries of science by expecting and enabling greater strides to be made. Scientist and author Steven Pinker noted, "If you give people literacy, bad ideas can be attacked and experiments tried, and lessons will accumulate." Encouraging scientific literacy should start young, through hypothesis testing, graphing, age-appropriate statistical concepts, and building confidence through a job well done.

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