# High school science fair: Experiences of undergraduate bioscience majors

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# Abstract

In this paper, we report findings based on voluntary and anonymous surveys completed by post high school students on bioscience education trajectories -- summer undergraduate research fellows (SURF students) who were doing research at UT Southwestern Medical Center during 2014-2019 and biology undergraduates who participated in the 2019 Howard Hughes Medical Institute annual Science Education Alliance (SEA) summer symposium. About 25% of the students who completed surveys indicated that they had participated in high school science fair, but more than half attended high schools where science fairs were unavailable. Effectively, therefore, 6 out of every 10 students participated in science fair if available. Students who could have participated in high school science fair but chose not to do so identified *not enough time* and *coming up with their project idea* as major reasons why not. About half the SURF students favored requiring non-competitive science fair regardless whether they themselves had participated in science fair. On the other hand, less than 1 in 5 thought that competitive science fair should be required. *Introduction to the scientific process* and *general learning* were mentioned most frequently as the reasons to require non-competitive science fair; these reasons were mentioned rarely in connection with competitive science fair. Unlike the national cohort of high school students we surveyed previously, who mostly did science fair in 9$^{th}$ and 10$^{th}$ grades, SURF students participated in science fair throughout high school and were twice as likely as high school students to have carried out science fair more than once. Re-evaluation of the national cohort of high school students based on grade level showed that for those doing science fair in 12$^{th}$ grade, about 80% indicated that they were interested in careers in science or engineering up from 50% in 9$^{th}$ grade, and those uninterested in a career dropped from 35% to 3% over the same period. In conclusion, our findings show that participation of undergraduate bioscience majors in high school science fair occurs far more frequently than recognized previously. We emphasize the importance of incentivizing rather than requiring science fair participation and the potential value of developing non-competitive science fairs, especially for students in 9$^{th}$ and 10$^{th}$ grades.


# Introduction

"Science investigation and engineering design should be the central approach for teaching and learning science and engineering," according to recommendation #1 of the 2019 National Academies Report *Science and Engineering for Grades 6-12* [1]. The idea that students should experience for themselves the eight practices of science and engineering [2] has become an underlying assumption of *Next Generation Science Standards* (NGSS) [3]. How to achieve this goal as a practical matter remains uncertain [4].

Since their origination almost 100 years ago, science fairs have come to attract a lot of public attention [5]. Some educators suggest that science fairs offer an ideal opportunity for students to experience the eight practices of science and engineering [6-10]. However, research aimed at determining if science fair participation in high school encourages science education engagement post high school suggested only a small effect. According to the national OPSCI survey of students, participation in a STEM competition was connected with a 5% greater likelihood of STEM career interest at the end of high school [11]. These findings and an earlier study [12] concluded that the major impact of STEM competitions was to help retain students already interested in STEM rather than attract those previously uninterested. In the Microsoft Corporation STEM perceptions study, only about 5% of the students said that they became interested in STEM because of science fairs

and contests [13] In a study of students at a Queensland science and engineering university, 7% listed science fair as the reason they became interested in STEM [14]. However, high school seniors from a Texas charter school system exhibited no significant difference in STEM interest that could be attributed to participation in science fair [15].

Several years ago, we began an empirical assessment to learn what students report in anonymous, voluntary surveys about their high school science fair experiences regarding help, obstacles, value, and impact. We hoped to identify strengths and weaknesses and potential improvements that might enhance learning outcomes. In previous surveys, we compared two different groups: (i) during 2015-2016, a regional group of high school students, mostly from a North Texas school district that encourages but does not require students to carry out a science fair project; (ii) during 2014-2015, a combined group of post high school students from UT Southwestern Medical Center consisting of summer undergraduate research fellows (SURF students), biomedical science graduate students, and medical students. The results showed overall broad similarities between the responses of the high school and post high school groups on the various questions suggesting that students' high school science fair experience in the US has developed a national character [16]. One interesting difference was that both high school students and post high school students opposed (4:1) requiring competitive science fair, but the post high school students were much more positive than high school students about requiring science fair if non-competitive [17].

To learn if high school students' attitudes about requiring non-competitive science fair might vary according to their interests in a career in the sciences or engineering, we added new survey questions in 2017 to make this determination. Also, we switched our focus from the regional group of high school students to a larger and more diverse national group of high school students. Unlike the regional group, of whom only 6% were required to participate in science fairs [16], most of the high school students in the national group (~70%) surveyed in 2017 and 2018 said that they were required to participate in science fair. Regardless of their interests in science and engineering, high school students were opposed to being required to participate in science fair. Moreover, students required to participate reported reduced interest in the sciences or engineering and an increased likelihood of engaging in research misconduct [18]. Required participation in science fair had not been recognized previously as an important variable regarding the impact of science fair. Our research provided empirical evidence that as best practices, student participation in high school science fair should be incentivized rather than required [19]. Also, from the 2014-2015 surveys, we learned that about one quarter of the post-high school students who completed surveys participated in high school science fair [16]. New survey questions added in 2016 aimed to learn the reasons why the post high school students did not participate including the possibility that science fairs were unavailable in their schools.

In this paper, we report findings based on the 2016-2019 surveys of SURF students as well as the findings for another bioscience undergraduate group, students who participated in the 2019 Howard Hughes Medical Institute (HHMI) annual Science Education Alliance (SEA) summer symposium. We also compare the science fair experiences of the combined 2014-2019 SURF student groups with the national group of high school students. Overall, our findings show that participation of undergraduate bioscience majors in high school science fair occurs far more frequently than recognized previously. We emphasize the importance of incentivizing rather than requiring science fair participation and the potential value of developing non-competitive science fairs, especially for 9$^{th}$ and 10$^{th}$ grade students. We show some evidence suggesting that SURF

females had a more positive high school science fair experience than SURF males. Finally, we suggest incorporating research integrity into high school programs teaching bioethics. Details are reported herein.

# Materials and methods

This study was approved by the UT Southwestern Medical Center IRB (#STU 072014-076). Study design entailed administering to students a voluntary and anonymous online survey using the REDCap survey and data management tool [20]. Survey recipients were SURF students at UT Southwestern Medical Center during 2014-2019 and biology undergraduates who participated in the 2019 HHMI SEA summer symposium. For students at UTSW, survey access was accomplished by providing REDCap with student UTSW email addresses. REDCap then sends the students survey invitations directly. For undergraduates attending the 2019 HHMI SEA summer symposium, the HHMI program office provided the students with a public online link to the REDCap survey. No incentives were offered for participation.

Survey content was the same as that used previously [17] except modified beginning in 2016 to include questions about (i) whether students had science fairs available at their high schools, and (ii) if they could have participated in science fair but chose not to do so, then why not. The survey can be found in supporting information (S1 Survey), and the complete survey data set can be found in supporting information (S1 Dataset). Results presented from the high school student national cohort surveys can be found in supplemental data from reference [18].

Quantitative data were analyzed by frequency counts and percentages. Data were sorted to compare different answer selections. Significance of potential relationships between data items was assessed using relevant statistical methods, e.g., Chi-square contingency tables for independent groups. Results shown in the figures are presented two ways -- graphically to make overall trends easier to appreciate and in tables beneath the graphs to show the actual numbers. A probability value of 0.05 or smaller was accepted as statistically significant but actual p values are indicated.

Qualitative text analysis for the open-ended text questions was accomplished as described previously [17] using an approach modeled on NVivo [21, 22] based on grounded theory [23]. Approximately 80% of the students who completed surveys wrote comments about why science fairs should be optional or required. Two members of the research team (FG and SD) independently coded students' comments, which were categorized into a matrix of shared student reasons (nodes). The independently coded matrices were revised and harmonized into 15 *Reason* categories why science fair should be required or optional. Longer student comments sometimes expressed more than one reason why, in which case the comments were coded into more than one category. As a result, the number of reasons counted exceeded the total number of student comments. The complete set of student answers to the *Reason Why* question and corresponding reason category assignments can be found in supporting information (S2 Dataset).

# Results

# SURF student participation in high school science fair

Table 1 summarizes SURF student demographics and science fair participation based on surveys conducted during 2014-2019. A total of 621 students received survey invitations. 286 (46%) returned completed surveys. More girls than boys completed surveys. A small percentage of students indicated that they were unfamiliar with science fair. 73 students indicated that they had participated in high school science fair and, of these, 44% indicated that they were required to do so.

**Table 1. SURF student demographics and science fair requirement**

| Survey Answers | | SURF Students % (#) |
|---|---|---|
| Students sent surveys | | 621 |
| Students completed surveys | | 46.1 (286) |
| Gender | Female | 56.6 (162) |
| | Male | 43.0 (123) |
| Participated in science fair? | Yes | 25.5 (73) |
| | No | 71.3 (204) |
| | Unfamiliar with science fair | 3.1 (9) |
| **Of 73 SURF students participated in science fair % (#)** | | |
| Was your science fair project required? | Yes | 43.8 (32) |
| | No | 41.1 (30) |
| | No, but satisfied a school project requirement | 15.1 (11) |

Table 2 and Figure 1 show that SURF students participated in science fair to a similar extent each year of high school unlike the national cohort of high school students that we surveyed during 2017 and 2018 who participated in science fair mostly in 9$^{th}$ and 10$^{th}$ grades [18]. Also, twice as many SURF students carried out science fair more than once compared to the high school students.

**Table 2. SURF student science fair participation**

| Survey Answers | | 73 SURF Students % (#) | 363 HS Students % (#)* | P value (Chi Sq) |
|---|---|---|---|---|
| In what grade did you carry out science fair? | 9th | 26.0 (19) | 40.5 (147) | .020 |
| | 10th | 20.5 (15) | 32.2 (117) | .047 |
| | 11th | 19.2 (14) | 11.3 (41) | .064 |
| | 12th | 32.9 (24) | 11.0 (40) | <.001 |
| Carried out science fair more than once | | 63.0 (46) | 31.1 (113) | <.001 |
| Science fair should be required if… | Non-competitive | 53.4 (39) | 25.7 (93) | <.001 |
| | Competitive | 15.1 (11) | 20.9 (76) | .252 |

*From [18]

**Fig 1: SURF vs. High school students - Grade in which students participated in science fair**

One possible interpretation of the findings in Table 1 and Figure 1 was that high school students who were most interested in science and engineering participated in science fair throughout all of high school, whereas those less interested in science did so mostly in 9th and 10th grades. Previously, we described high school student interest in science and the impact of science fair [18], but we did not analyze possible differences depending on a student's grade level. Figure 2 now shows that comparison, and it is consistent with the above interpretation. That is, 50% of the 147 high school students who participated in science fair in 9th grade said that they were interested in a career in the sciences or engineering compared to 80% of the 40 students who participated in science fair in 12th grade. The number of high school students unsure about their career interests remained the same all four years, but the number of students uninterested in science or engineering careers dropped from 35% in 9th grade to 3% in 12th grade. In parallel, 55% of the high school students who participated in 9th grade said that their science fair experience increased their interest in the sciences or engineering, which increased to 80% of the students who participated in science fair in 12th grade.

**Fig 2: Differences in career interests and impact of science fair depending on grade in which high school students participated in science fair**

# SURF student reasons why science fair should be optional or required

Table 2 also shows that more than 50% of the SURF students agreed that non-competitive science fairs should be required in high school but opposed by 5:1 requiring competitive science fairs; the high school students opposed any type of science fair requirement. In our previously studies of post high school students carried out during 2014-2015, for most comparisons including student reasons why science fairs should be required or optional, we combined SURF students with graduate students and medical students to obtain a sufficiently large number of respondents to evaluate [17]. With the addition of the 2016-2019 results, it became possible to study the SURF students separately.

Figure 3 shows the reasons based on comments of 280 SURF students (84.1%) about non-competitive science fair, and 262 students (78.7%) about competitive science fair in response to the question about requiring science fair. Because some comments contained more than one reason, the number of reasons counted was greater than the number of comments. For non-competitive science fair, positive reasons (#1-#7) outnumbered negative reasons (#8-#15) (190 vs. 154); for competitive science fair, negative reasons predominated (253 vs. 68). The categories of reasons differed. The students' positive reasons about non-competitive science fair included *introduction to the scientific process* (82 times) and *general learning* (37 times); these reasons were mentioned only 11 times total with regard to competitive science fair. *Competition incentive* was the only positive value that more students mentioned for competitive science fair compared to non-competitive science fair. Only two categories of negative reasons were similar regarding both competitive and non-competitive science fair – *negative student behaviors and consequences* and *not everyone interested in science*.

**Fig 3: Students' reasons why science fair should be optional or required**

## SURF student science fair experiences, gender differences, and comparison to high school students

Fig 4 presents a graphical summary of 2014-2019 SURF student survey answers to questions regarding sources of help, types of help received, obstacles encountered, and ways of overcoming obstacles. The corresponding supplemental figures S1-S4 show the details. Selections made by >40% of the students are labeled. These were: (A) sources of help -- parents, teachers, articles on the internet and articles from books and magazines; (B) types of help received -- developing the idea and fine tuning the report; (C) obstacles faced -- getting the idea, limited resources, limited knowledge, limited skills, and time; (D) overcoming obstacles -- picked a familiar topic, do more background research, and perseverance. None of the students indicated that they used someone else's data (D, #12), but 4 students (5.5%) said they made up their data (D, #13) (see S4 Fig).

**Fig 4: Summary of student science fair experiences regarding help and obstacles.**

Several apparent gender-dependent differences occurred in SURF students' science fair experiences. Table 3 shows that females experienced getting motivated as an obstacle less frequently than males, but females were more likely to report limited resources as an obstacle. Males were more likely than females to stop working on their projects as a way of overcoming obstacles, whereas females were more likely to have someone else keep them on track. Four students (about 5% of all those surveyed), all males, reported that they made up their data.

We asked students who did not participate in science fair to answer hypothetically the questions about obstacles encountered and overcome. Table 3 (bottom section) shows that students who did not participate in science fair anticipated more obstacles and more ways to overcome obstacles but no apparent gender differences in their responses. About 20% of the students who did not participate in science fair anticipated that students would make up their data, which was consistent with earlier findings [16].

**Table 3. Gender differences in SURF student science fair experience**

| **Survey answers by students who participated in science fair** | | **Males 33 students % (#)** | **Females 40 students % (#)** | **p Value (Fisher)** |
|---|---|---|---|---|
| What obstacles did you encounter? | Getting motivated | 45.4 (15) | 12.5 (5) | .003 |
| | Limited resources | 54.5 (18) | 77.5 (31) | .048 |
| How did you overcome obstacles? | Stopped working on the project for awhile | 21.2 (7) | 2.5 (1) | .020 |
| | Had someone else keep me on track | 3.0 (1) | 22.5 (9) | .019 |
| | Made up the data | 12.1 (4) | 0 (0) | .038 |
| **Survey answers by students who did not** | | **Males** | **Females** | **p Value** |

| participate in science fair | | 86 students % (#) | 117 students % (#) | (Fisher) |
|---|---|---|---|---|
| What obstacles do you think students who do science fair will encounter? | Getting motivated | 62.8 (54) | 60.7 (71) | .773 |
| | Limited resources | 76.7 (66) | 80.3 (94) | .603 |
| How do you think students who do science fair will overcome obstacles? | Stop working on the project for awhile | 16.3 (14) | 14.5 (17) | .843 |
| | Have someone else keep on track | 44.2 (38) | 49.6 (58) | .479 |
| | Make up the data | 23.3 (20) | 19.7 (23) | .603 |

We also compared the 2014-2019 SURF students' experiences with previously reported findings for the national cohort of high school students surveyed during 2017 and 2018 [18]. Although the overall patterns of student experiences were as similar, SURF students reported access to more sources of help, received more types of help, and utilized more ways to overcome obstacles. On the other hand, the SURF students reported limited resources, knowledge, and skills as obstacles twice as frequently as the high school students.

**Table 4. Surf students vs. high school students – differences in science fair experiences**

| Survey Answers | | 73 SURF Students % (#) | 363 HS Students % (#)* | P value (Chi Sq) |
|---|---|---|---|---|
| Sources of help received | Used books or magazines | 42.5 (31) | 24.0 (87) | 0.001 |
| Types of help received | Development of the idea | 56.2 (41) | 26.2 (95) | < .001 |
| | Fine tuning the report | 52.1 (38) | 32.2 (117) | 0.001 |
| Obstacles faced | Limited resources | 67.1 (49) | 36.1 (131) | < .001 |
| | Limited knowledge | 68.5 (50) | 30.6 (111) | < .001 |
| | Limited skills | 47.9 (35) | 22.0 (80) | < .001 |
| Ways to overcome obstacles | Picked familiar topic | 43.8 (32) | 29.8 (108) | 0.019 |
| | More background research | 71.2 (52) | 48.5 (176) | < .001 |
| | Perseverance | 65.8 (48) | 44.4 (161 ) | < .001 |
| | | | | *From [18] |

## SURF students' opportunity to participate in high school science fair and reasons not to do so

The effective rate of SURF student participation in high school science fair at 25% (Table 1) could have been higher since it did not take into account whether science fairs were available to the students. Indeed, the High School Longitudinal Study of 2009 reported that only about 1/3 of the

900 schools surveyed "holds math or science fairs, workshops or competitions" [24]. Table 5 shows that of the 180 students who completed our surveys during 2017-2019, which included the new questions about science fair availability, more than 50% attended high schools where science fair was not available. Overall, therefore the effective rate of science fair participation by the SURF students was almost 60%. Students who could have participated in science fair but did not do so, most frequently chose *not enough time* and *did not have a good idea for a project* from the list of the six choices shown in Table 5 as reasons not to participate. However, students who chose not to participate in science fair were just as likely as those who participated to favor requiring non-competitive science fair.

**Table 5. Availability of high school science fair to SURF students and reasons not to participate.**

| **Survey Answers** | | **Students % (#)** |
|---|---|---|
| Students sent surveys | | 404 |
| Students completed surveys | | 44.6 (180) |
| Did you participate in science fair? | Science fair not available at my school | 55.6 (100) |
| | Could have participated but chose not to do so | 18.3 (33) |
| | Yes | 25.0 (45) |
| **Reasons selected by 33 students who chose not to participate in science fair even though it was available** | | |
| Not enough time | | 57.6 (19) |
| Did not have a good idea for a project | | 51.5 (17) |
| Not interested | | 33.3 (11) |
| Did not want to compete | | 24.2 (8) |
| Not enough help available | | 21.2 (7) |
| Too expensive | | 3.0 (1) |

| **Student attitudes about requiring science fair depending on opportunity to participate** | | | |
|---|---|---|---|
| Students say science fair should be required if: | Participated in SF 45 students % (#) | Chose not to participate in SF 33 students % (#) | Participating in SF not an option 100 students % (#) |
| Non-competitive | 51.1 (23) | 48.5 (16) | 37.3 (38) |
| Competitive | 17.8 (8) | 12.1 (4) | 6.9 (7) |

# HHMI SEA students' opportunity to participate in high school science fair

UT Southwestern SURF students represent a national cohort of undergraduates coming from schools all over the United States. Nevertheless, to test further the generality of our findings, we surveyed another national student group, biology undergraduates participating in the 2019 HHMI SEA summer symposium. Table 7 shows that 23% of the HHMI SEA students had participated in

high school science fair and, of these, 80% said that they were required to participate. Similar to the SURF students, the majority of the high schools attended by the HHMI SEA students did not offer science fair. Overall, 12 of the 16 HHMI SEA students who could have participated in science fair did so.

**Table 6. HHMI SEA student participation in high school science fair.**

| Survey Answers | | HHMI SEA % (#) |
|---|---|---|
| Students sent surveys | | 150 |
| Students completed surveys | | 35.3 (53) |
| Did you participate in science fair? | Science fair not available at my school | 64.2 (34) |
| | Could have participated but chose not to do so | 7.5 (4) |
| | Yes | 22.6 (12) |
| | Unfamiliar with science fair | 5.7 (3) |
| Was science fair required if available? | Yes | 83.3 (10) |
| | No | 16.7 (2) |

# Discussion

Several years ago, we began an empirical assessment to learn what students report in anonymous, voluntary surveys about their high school science fair experiences regarding help, obstacles, value, and impact. We hoped to identify strengths and weaknesses and potential improvements that might enhance learning outcomes. Our previous research reports focused on surveys of regional (during 2015-2016) and national (beginning in 2017) cohorts of high school students and a combined group of post high school students (during 2014-2015) at UT Southwestern Medical School including graduate and medical students and SURF students [16-18]. SURF students are the primary focus of the current research report. In addition, to increase the generality of our findings regarding frequency and availability of participation in science fair, we also surveyed biology undergraduates who participated in the 2019 Howard HHMI SEA summer symposium.

Overall, 25.5% of the 286 SURF students who completed surveys between 2014-2019 and 22.6% of the 53 HHMI SEA students who completed surveys in 2019 participated in science fair. By contrast, only about 5% of the 23,500 students surveyed in the High School Longitudinal Study of 2009 participated in a science competition [24]. Similarly, only about 5% of the almost 16,000 students surveyed in the OPSCI college outreach survey of students in introductory freshman (mostly English) classes reported participating in high school science fair [11]. Therefore, the SURF student participation rate in high school science fair was five times higher than most students. Another finding of the High School Longitudinal Study of 2009 was that only ~1/3 of the 900 schools surveyed reported “holds math or science fairs, workshops or competitions” [24], and only about 40% of the SURF and HHMI SEA students reported attending high schools where high school science fair was available. Effectively, therefore, about 6 out of every 10 SURF students who had high school science fair available participated in science fair. All of the students that we

surveyed were on bioscience education trajectories. Whether this high level of high school science fair participation occurs for students with other disciplinary interests is unknown.

The SURF students who could have participated in science fair but chose not to do so indicated *not enough time* and *no good idea for a project* as the most frequent reasons why not. Regardless whether the students were required to participate in science fair, chose not to participate, or did not have science fair available as an option, they uniformly opposed requiring competitive science fair (6:1, 8:1, and 14:1 respectively). On the other hand, regarding non-competitive science fair, the students were much more positive with 51%, 49%, and 37% in favor of a requirement. Their positive reasons why emphasized *introduction to the scientific process* and *general learning*, which were mentioned almost 120 times in connection with non-competitive science fair but only 11 times total in connection with competitive science fair. Indeed, the only positive reason mentioned frequently for competitive science fair (35 times) was *competition incentive*. In short, non-competitive science fair was viewed as emphasizing learning; competitive science fair as emphasizing winning.

44% of the SURF students and 83% of the HHMI SEA students reported that their participation in science fair was required. For the national cohort of high school students surveyed previously, about 70% reported that science fair was required [18]. Since the survey does not provide students with ancillary information regarding what it means for science fair to be required, their answers reflect how they felt about their participation. We cannot tell if they understand *required to do science fair* differently from what their schools intended, e.g., required to participate in science fair to get into an advanced class or to increase one's grade. In some cases, we know that science fair was required for advanced science classes based on comments by the high school students, e.g., "It made a lot of people choose not to take honors science, and it was a lot more work than thought out to be" [18]. Consequently, *required to do science fair* might mean different things at different stages of a student's high school science education. In any case, as indicated by the student's comment above, requiring science fair can become a disincentive to pursuing advanced science education [18].

The pattern of science fair experiences of the SURF students was mostly similar to the national cohort of high school students studied previously [18], but the percentages of SURF students was in many cases higher for sources and types of help received and ways to overcome obstacles. One noticeable difference -- the SURF students reported *limited resources*, *limited knowledge*, and *limited skills* as obstacles encountered twice as often as the high school students. One possible explanation is that given their interests in science, the SURF students attempted more ambitious science fair projects in high school. Another possibility is that the SURF students looking back from a more advanced time in their science education trajectories recognized their earlier limitations.

One major difference between the SURF students and high school students concerned the timing and frequency of participating in science fair. Unlike the national cohort of high school students we surveyed previously, who mostly did science fair in 9$^{th}$ or 10$^{th}$ grade [18], SURF students participated in science fair to a similar extent throughout high school and were twice as likely as high school students to have carried out science fair more than once. Upon re-evaluating the national high school student cohort [18] according to grade level-dependent differences in students' interests in science or engineering, we observed that students doing science fair could be divided overall into two groups. One group of students, those interested in careers in science or

engineering, accounted for about half the students doing science fair in 9th grade and 80% of the students doing science fair in 12th grade. The other group, those not interested in careers in science or engineering, accounted for 35% of the students doing science fair in 9th grade and 3% of those doing science fair in 12th grade. Students unsure about their interests remained constant at around 15%. These findings suggest that effectively two science fairs are going on in high school – one involving students from every grade who are interested in a science career; the other involving students mostly in 9th and 10th grades who are not interested in a science career.

This difference in timing and frequency of science fair participation by students interested or not interested in a science and engineering career helps explain why a major impact of STEM competitions appears to be to help retain students already interested in STEM rather than attract those students previously disinterested [11, 12]. Given that increasing student interest in science represents one of the most important potential positive outcomes of science fair, and taken together with the SURF students' experiences and views described above, we suggest that high schools should consider formalizing a difference between science fair in 9th and 10th compared to 11th and 12th grades. For instance, in 9th and 10th grades, science fair could be non-competitive or have a non-competitive option but in 11th and 12th grades competitive. If competitive throughout, then science fair could be incentivized rather than required in 9th and 10th grades.

SURF students reported several subtle but potentially important gender differences. Females experienced *getting motivated* as an obstacle less frequently than males even though they were more likely than males to report experiencing *limited resources* as an obstacle. Males were more likely than females to *stop working on their projects* as a way of overcoming obstacles, whereas females were more likely to *have someone else keep them on track*. These differences suggest that participating in science fair was overall a more successful experience for the females. Consistent with this possibility, all of the SURF students who reported *making up their data* were males. Students who did not participate in science fair anticipated a higher level of obstacles compared to those who did participate but no gender differences in their responses. About 20% of the students anticipated that to overcome obstacles high school students would resort to *making up their data* consistent with our findings several years ago with a smaller number of post high school students [16]. Promoting research integrity has become an important goal of the scientific community in recent years [25]. Education about research integrity should be incorporated into high school programs that aim to teach students about diverse topics in bioethics [26, 27] and especially in conjunction with science fair.

In conclusion, our findings show that participation of undergraduate bioscience majors in high school science fair occurs far more frequently than recognized previously. We emphasize the importance of incentivizing rather than requiring science fair participation and the potential value of developing non-competitive science fairs, especially for 9th and 10th grade students. We show some evidence for gender differences in students' experiences. Finally, we suggest incorporating research integrity into high school programs teaching bioethics.

# Acknowledgments

We are grateful to Dr. Viknesh Sivanathan and Dr. David Asai from the Howard Hughes Medical Institute Science Education program for their help to survey the 2019 HHMI SEA summer symposium participants. Use of REDCap survey and data management tool was facilitated by the

UTSW Department of Population and Data Sciences and Clinical and Translational Science Training Program.

# References Cited


1. National Academies of Sciences E, and Medicine. Science and engineering for grades 6-12: Investigation and design at the center: National Academies Press; 2019.
2. National Research Council. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, D.C.: National Academies Press; 2012.
3. NGSS Lead States. Next Generation Science Standards For States, By States. Volume 1: The Standards—Arranged by Disciplinary Core Ideas and by Topics. Washington, D.C.: National Academies Press; 2013.
4. Rudolph JL. How We Teach Science-What′ s Changed, and Why It Matters: Harvard University Press; 2019.
5. Grinnell F. Reinventing Science Fairs. Issues in Science and Technology. 2020;36(3):23–5.
6. McComas WF. Science fair: A new look at an old tradition. The Science Teacher. 2011;78(8):34-8.
7. Rillero P, Zambo R. The Judge's Perspective. The Science Teacher. 2011;78(8):44.
8. Paul J, Lederman NG, Groß J. Learning experimentation through science fairs. International Journal of Science Education. 2016;38(15):2367-87.
9. Mackey K, Culbertson T. Science fairs for science literacy. Eos, Transactions American Geophysical Union. 2014;95(10):89-90.
10. Tai RH, Mitchell CE. Science Fairs. SAGE Encyclopedia of Out-of-School Learning, edited by Kylie A Peppler. 2017;http://ebookcentral.proquest.com/lib/utd/detail.action?docID=4839834:676-8.
11. Miller K, Sonnert G, Sadler P. The influence of students' participation in STEM competitions on their interest in STEM careers. International Journal of Science Education, Part B. 2018;8(2):95-114.
12. Dabney KP, Tai RH, Almarode JT, Miller-Friedmann JL, Sonnert G, Sadler PM, et al. Out-of-school time science activities and their association with career interest in STEM. International Journal of Science Education, Part B. 2012;2(1):63-79.
13. Interactive H. STEM perceptions: Student and parent study. Microsoft Corp, New York. 2011.
14. Dawes LA, Long S, Whiteford C, Richardson K, editors. Why are students choosing STEM and when do they make their choice? Proceedings of 26th Annual Conference of the Australasian Association for Engineering; 2015: School of Engineering, Deakin University.
15. Sahin A. STEM clubs and science fair competitions: Effects on post-secondary matriculation. Journal of STEM Education. 2013;14(1):5-11.
16. Grinnell F, Dalley S, Shepherd K, Reisch J. High school science fair and research integrity. PLOS ONE. 2017;12(3):e0174252.
17. Grinnell F, Dalley S, Shepherd K, Reisch J. High school science fair: Student opinions regarding whether participation should be required or optional and why. PLOS ONE. 2018;13(8):e0202320.
18. Grinnell F, Dalley S, Reisch J. High school science fair: Positive and negative outcomes. PLOS ONE. 2020;15(2):e0229237.
19. Grinnell F, Dalley S. How to Make Science Fairs More Effective. NSTA Reports. 2020;31 (5):3.

20. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. Journal of biomedical informatics. 2009;42(2):377-81.
21. Welsh E, editor Dealing with data: Using NVivo in the qualitative data analysis process. Forum Qualitative Sozialforschung/Forum: Qualitative Social Research; 2002.
22. Hutchison AJ, Johnston LH, Breckon JD. Using QSR-NVivo to facilitate the development of a grounded theory project: an account of a worked example. International Journal of Social Research Methodology. 2010;13(4):283-302.
23. Martin PY, Turner BA. Grounded theory and organizational research. The journal of applied behavioral science. 1986;22(2):141-57.
24. National Center for Education Statistics. HSLS (High School Longitudinal Study of 2009). https://ncesedgov/onlinecodebook. 2020.
25. Elliott SL, Fischer BA, Grinnell F, Zigmond MJ. Perspectives on Research Integrity. Washington, D.C.: ASM Press; 2015.
26. Solomon MZ, Vannier D, Chowning JT, Miller JS, Paget KF. The pedagogical challenges of teaching high school bioethics: Insights from the exploring bioethics curriculum. Hastings Center Report. 2016;46(1):11-8.
27. Chowning JT, Griswold JC, Kovarik DN, Collins LJ. Fostering critical thinking, reasoning, and argumentation skills through bioethics education. PloS one. 2012;7(5):e36791.

# Supporting information

**S1 Data set.** Excel dataset showing all of the survey questions and answers.

**S2 Data set.** Excel dataset showing the complete set of reason category assignments.

**S1 Survey**. Survey questions.

**S1 Fig. Frequency of student answers to the question "Who helped you with your science fair project?"**

**S2 Fig. Frequency of student answers to the question "What kind of help did you receive doing science fair?"**

**S3 Fig. Frequency of student answers to the question "In your science fair project, what obstacles did you face?"**

**S4 Fig. Frequency of student answers to the question "In your science fair project, how did you overcome obstacles?"**

Fig.1: SURF vs. High school students - Grade in which participated in science fair

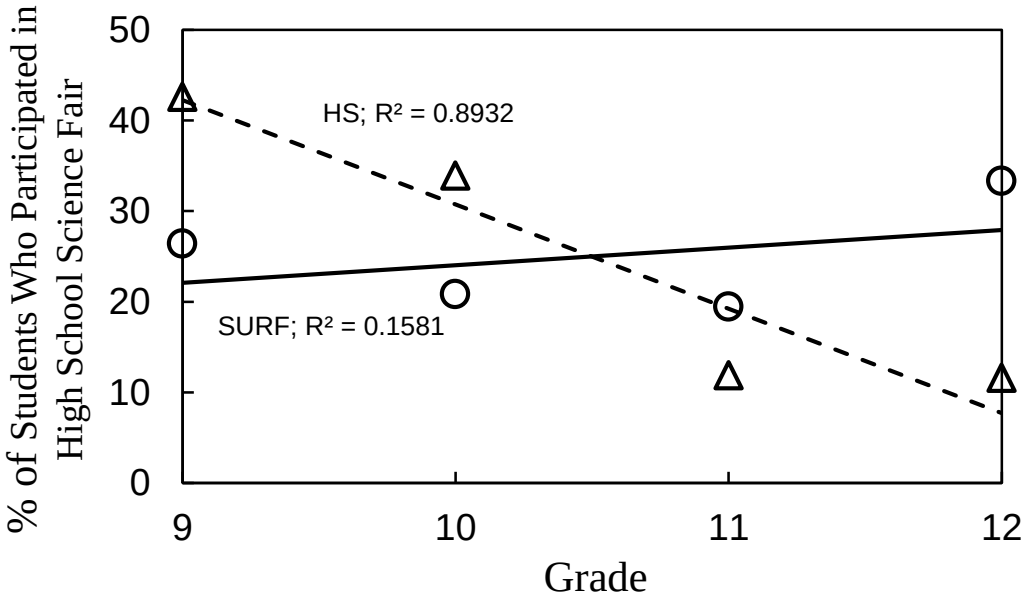
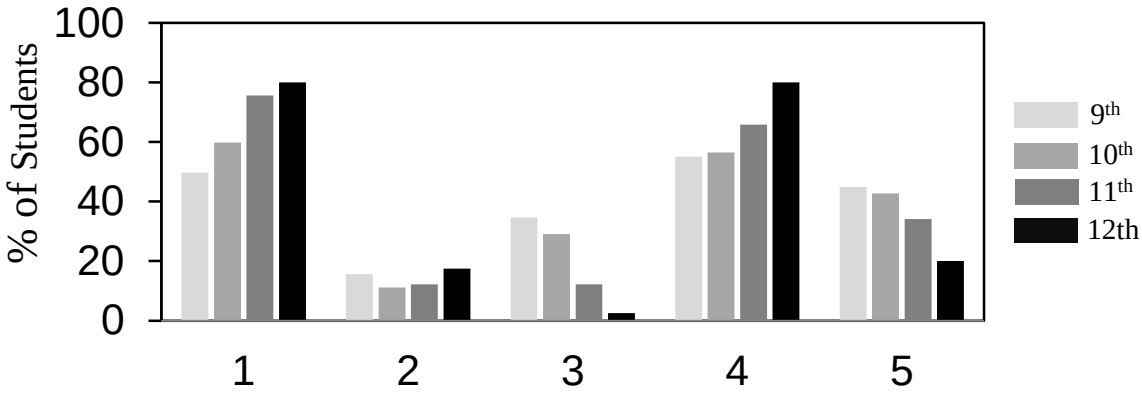


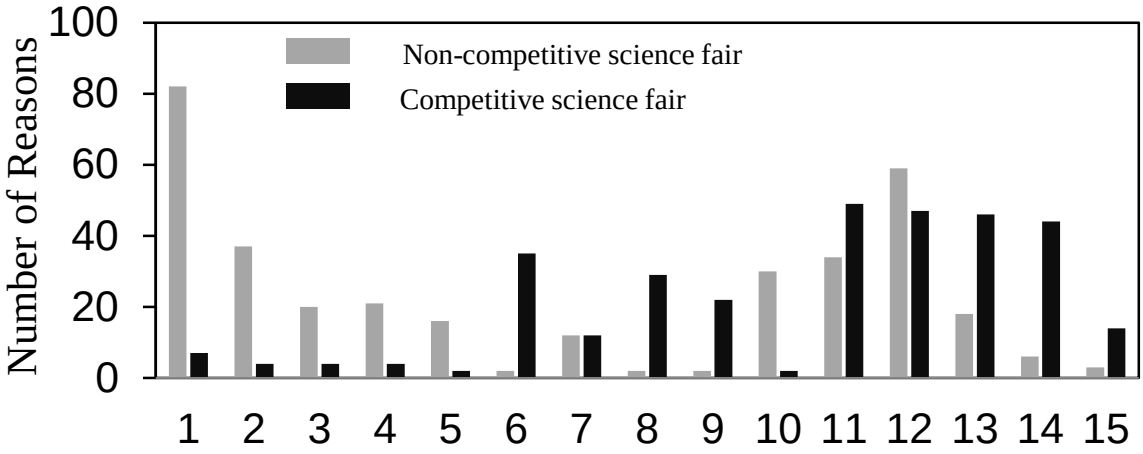
Fig. 2: High school students - Differences in career interests and impact of science fair depending on grade in which students participated in science fair.




| # | Grade (students) ---------- Survey Item | | 9th (147) | 10th (117) | 11th (41) | 12th (40) |
|---|---|---|---|---|---|---|
| | | | % (#) who reported | | | |
| 1 | Interest in a career in the sciences or engineering | Yes | 49.7 (73) | 59.8 (70) | 75.6 (31) | 80.0 (32) |
| 2 | | Unsure | 15.6 (23) | 11.1 (13) | 12.2 (5) | 17.5 (7) |
| 3 | | No | 34.7 (51) | 29.1 (34) | 12.2 (5) | 2.5 (1) |
| 4 | Science fair experience increased my interest in sciences or engineering. | Yes | 55.1 (81) | 56.4 (66) | 65.9 (27) | 80.0 (32) |
| 5 | | No | 44.9 (66) | 42.7 (50) | 34.0 (14) | 20.0 (8) |

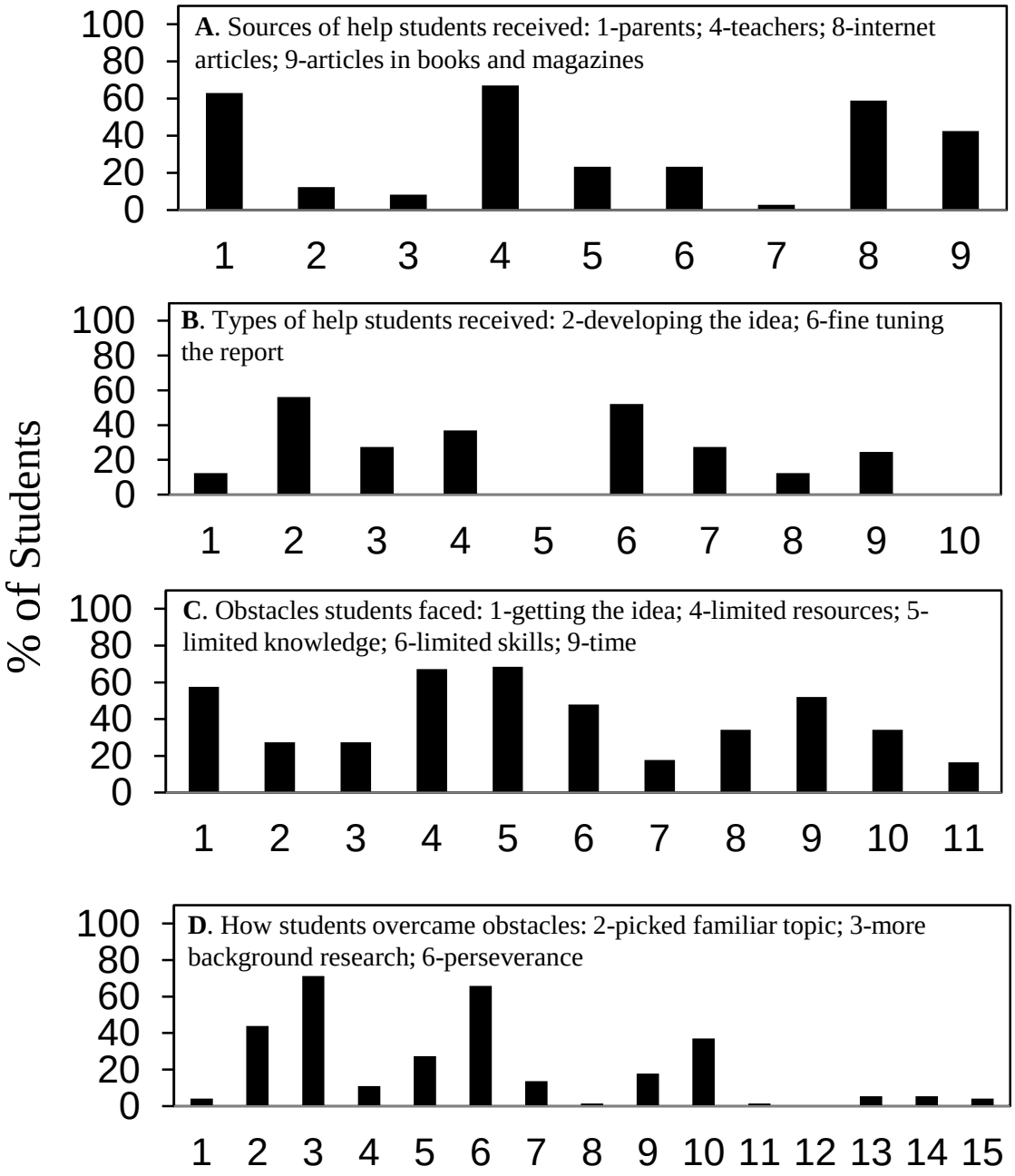
*From {Grinnell, 2020 #121}

Fig. 3: Students reasons why science fair should be optional or required

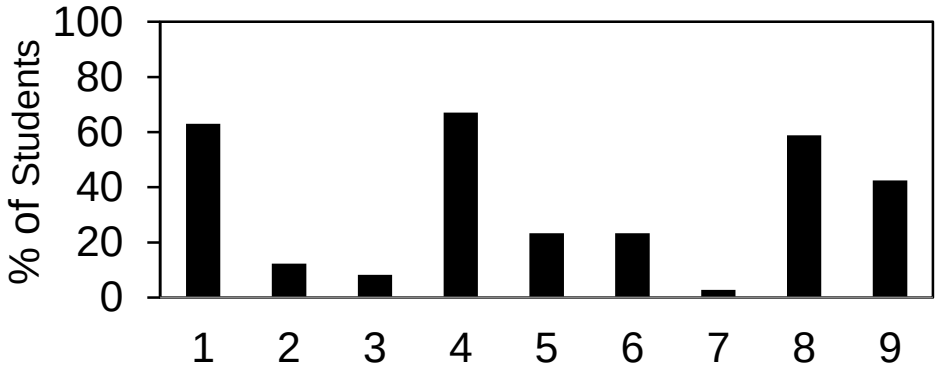



| Reason Category | | Frequency reason category is mentioned | |
|---|---|---|---|
| | | Non-competitive science fair | Competitive science fair |
| 1 | Intro to the scientific process | 82 | 7 |
| 2 | General Learning | 37 | 4 |
| 3 | Communication or presentation skills | 20 | 4 |
| 4 | Research skills | 21 | 4 |
| 5 | Career interests | 16 | 2 |
| 6 | Competition incentive | 2 | 35 |
| 7 | Other positive | 12 | 12 |
| | Total # positive reasons (%) | 190 (55.2) | 68 (21.2) |
| 8 | Emphasizes winning vs. learning | 2 | 29 |
| 9 | Don't like to compete | 2 | 22 |
| 10 | No enjoyment and negative attitude | 30 | 2 |
| 11 | Negative behaviors and consequences | 34 | 49 |
| 12 | Not everyone interested in science | 59 | 47 |
| 13 | No time/money | 18 | 46 |
| 14 | No value | 6 | 44 |
| 15 | Other negative | 3 | 14 |
| | Total # negative reasons (%) | 154 (44.8) | 253 (78.8) |

Figure 4: SURF summary of student experiences regarding help and obstacles

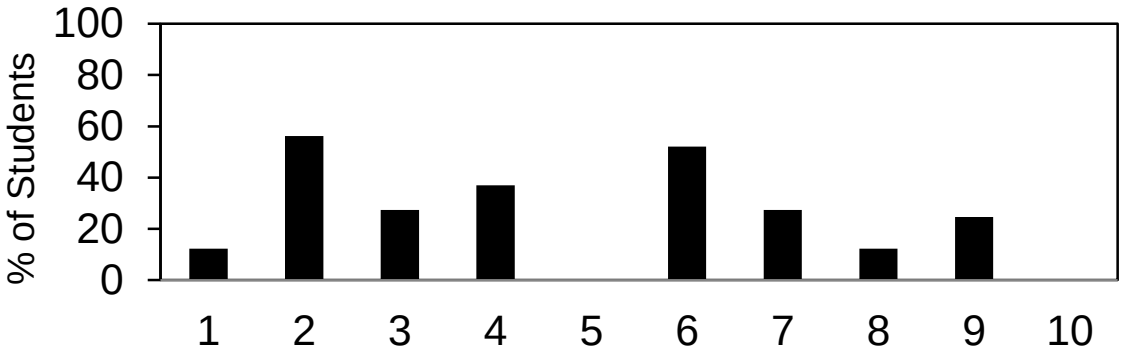


S1_fig. Sources of help students received in science fair.




| # | Different sources of help received | % (#) receiving help from |
|---|---|---|
| **1** | Parents | 63.0 (46) |
| **2** | Siblings | 12.3 (9) |
| **3** | Other family members | 8.2 (6) |
| **4** | Teachers | 67.1 (49) |
| **5** | Other students | 23.3 (17) |
| **6** | Scientists | 23.3 (17) |
| **7** | A paid mentor | 2.7 (2) |
| **8** | Articles on the Internet | 58.9 (43) |
| **9** | Articles in books or magazines | 42.5 (31) |

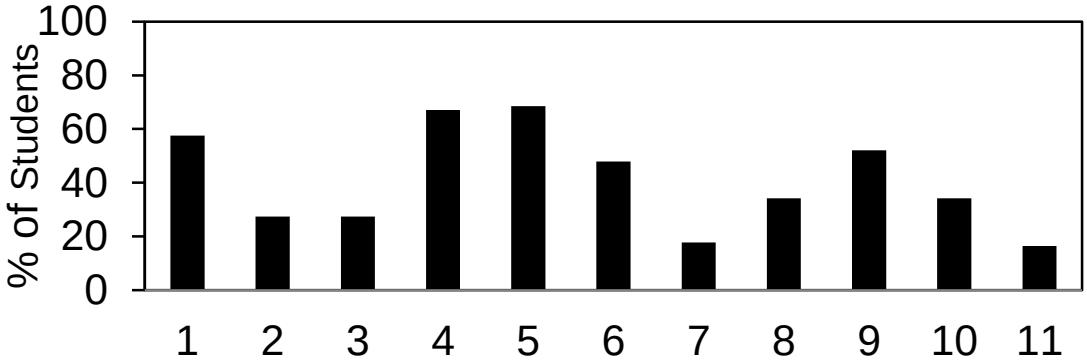
S2_fig. Types of help students received in science fair.




| # | Different types of help received | % (#) receiving type of help |
|---|---|---|
| **1** | Being given the main idea | 12.3 (9) |
| **2** | Development of the idea | 56.2 (41) |
| **3** | Background information & finding research site and participants | 27.4 (20) |
| **4** | Performing experiments | 37.0 (27) |
| **5** | Writing the report | 0.0 (0) |
| **6** | Fine tuning the report | 52.1 (38) |
| **7** | Designing the poster board | 27.4 (20) |
| **8** | Produce charts or graphs | 12.3 (9) |
| **9** | Coaching for the interview with judges | 24.7 (18) |
| **10** | Copying the project from someone else | 0.0 (0) |

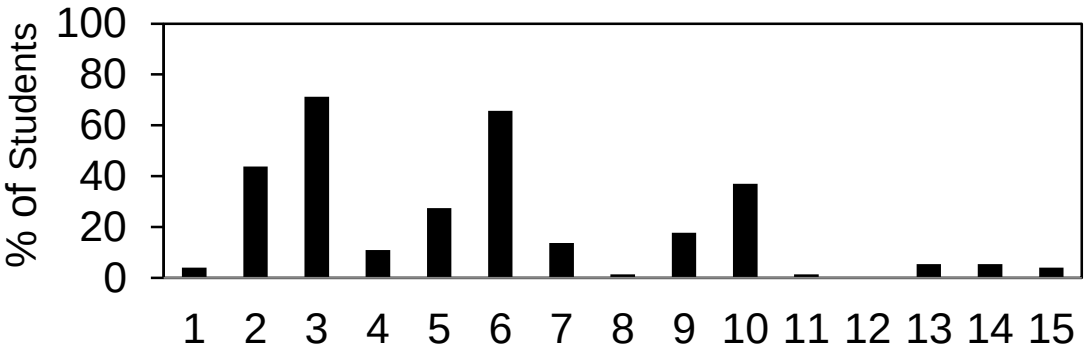
| | |
|---|---|
| Received the kind of help wanted from teachers | 75.3 (168) |
| Received amount of help wanted from teachers | 78.5 (175) |

S3_fig: Obstacles students encountered in science fair.




| # | Obstacles encountered in science fair | % (#) obstacle encountered |
|---|---|---|
| **1** | Coming up with the main idea. | 57.5 (42) |
| **2** | Getting motivated to do the project. | 27.4 (20) |
| **3** | Becoming disappointed with the project. | 27.4 (20) |
| **4** | Limited resources. | 67.1 (49) |
| **5** | Limited knowledge. | 68.5 (50) |
| **6** | Limited skills. | 47.9 (35) |
| **7** | Limited cooperation. | 17.8 (13) |
| **8** | Getting organized. | 34.2 (25) |
| **9** | Time pressure. | 52.1 (38) |
| **10** | Not enough money. | 34.2 (25) |
| **11** | Results not as expected. | 16.4 (12) |

S4_fig: How students overcame obstacles in science fair.




| # | Means to overcome obstacles | % (#) using means to overcome obstacles |
|---|---|---|
| **1** | Used someone else's main idea. | 4.1 (3) |
| **2** | Picked a familiar/interesting topic. | 43.8 (32) |
| **3** | Did more background research. | 71.2 (52) |
| **4** | Stopped working on the project for a while. | 11.0 (8) |
| **5** | Made a timeline to follow. | 27.4 (20) |
| **6** | Perseverance and self-discipline. | 65.8 (48) |
| **7** | Had someone else to keep me on track. | 13.7 (10) |
| **8** | Had someone else do the math. | 1.4 (1) |
| **9** | Changed the research plan. | 17.8 (13) |
| **10** | Collected more data. | 37.0 (27) |
| **11** | Had someone else collect the data. | 1.4 (1) |
| **12** | Used someone elses data. | 0.0 (0) |
| **13** | Made up the data. | 5.5 (4) |
| **14** | Changed the hypothesis to fit the data. | 5.5 (4) |
| **15** | Changed the data to fit the hypothesis. | 4.1 (3) |