High School Science Fair: What Students Say -- Mastery, Performance, and Self-Determination Theory

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Abstract

Based on free text comments by 1191 students who participated in our national science and engineering fair (SEF) surveys during 2021-22 and 2022-23, we have learned new information about SEF participation and student interest in S&E. The positive reasons that students mentioned most frequently about why SEF participation increased their interest in S&E were: learned new things; experience doing research; enjoyed/fun experience; and career choice. The negative reasons most frequently mentioned by students were: participation was not fun/stressful/boring; not a good project; not interested in science; and required to participate. Overall, students who received coaching and help from scientists made the most positive comments. Students who participated in school-only level SEFs made the most negative. Reasons students gave why SEF participation increased their interest in S&E aligned with mastery criteria. By contrast, reasons students gave in a previous study regarding whether competitive SEFs should be required aligned with performance criteria. Mastery and performance orientations integrate differently with the three elements of self-determination theory: motivation, competence and community engagement. Recognizing these differences in relationship to the interests of high school students who participate in SEFs has the potential to enhance the impact of SEF participation on student STEM interests and knowledge.

Introduction

In recent years, ideas about how best to accomplish science education in the United States have focused increasingly on hands-on practice experience of science and engineering [1-3]. As described in Next Generation Science Standards (NGSS), student experience of the practices of science is one of three essential dimensions of science education -- *students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves* [4, 5].

Science and engineering fairs (SEFs) began almost one hundred years ago under the auspices of a civic organization called the American Institute of the City of New York [6]. At a 1932 meeting, the city's science teachers and administrators discussed bringing after-school science clubs together into a federation. The stated goals of the federation were the same as contemporary STEM education -- *to aid in the development of the scientific leaders of the next generation and at the same time foster a better understanding of science among its laymen* [7]. Since then, SEFs have become part of science education not only in the United States, but also worldwide, e.g.,[8-13].

The number of U.S. high school students who participate in SEFs is not known exactly. The 2009/12 NCE-HSLS report found that 5% of high school students participated in science competitions during high school [14], which would correspond to about 750,000 students annually given the overall U.S. public high school population of 15 million [15] (does not include about 10% of students attending private schools [16]). Similarly, about 5% of the almost 16,000 undergraduate students surveyed in the college Outreach Programs and Science Career Intentions survey (students in introductory freshman, mostly English, classes) reported participating in SEFs in high school [17].

SEFs have been suggested to potentially promote three important and desirable STEM outcomes: (i) mastery of science and engineering (S&E) practices; (ii) interest in STEM; and (iii) interest in STEM careers [8, 12, 18]. The idea that SEF participation could have a positive impact on high school students is consistent with research showing that science project-based learning and journal writing advances students' STEM understanding and interests at both the high school [19-24] and undergraduate levels [25-27]. Also, innovative high school programs that combine student participation in SEFs with student and teacher support promote STEM engagement and learning for all students including those from under-represented ethnic minorities and low socioeconomic backgrounds [28-33]. In general, student engagement in STEM research projects fits into

the recent emphasis in STEM education on self-determination theory that focuses on the importance of student autonomy in decision making, competence to master the work at hand, and connectedness with the STEM community [34, 35].

In 2015, we initiated an ethnographic study of high school SEF culture -- first regional and then national -- aimed at understanding the experiences of students who participated in SEFs. We approached the research from the perspective of grounded theory [36, 37] using quantitative anonymous and voluntary surveys. The overall goal of our research has been to establish a base of knowledge about high school SEFs. We believe that having this information will help to identify best practices leading to more effective, inclusive, and equitable SEF learning opportunities thereby enhancing successful student participation and outcomes [38].

Some key recommendations based on our findings – (i) Promote student autonomy -- incentivize rather than require SEF participation, currently required for more than 60% of high school students nationwide [39]. (ii) Promote student competence -- most high school students participate in SEFs in 9th and 10th grades (75%), but the younger students are less interested in S&E careers. Therefore, recognize and develop different SEF objectives and assessments for 9th/10th vs. 11th/12th grades[40]. (iii) Promote connectedness with the STEM community. Develop outreach programs to provide students with coaching for the SEF interview and help from scientists. Less than 15% of students receive coaching for the interview. Less than 10% receive help from scientists. However, more than any other types of help, those students who receive coaching and help from scientists achieved better SEF outcomes [41] including indicating that SEF participation increased their interest in S&E [42]. Others have found similar consequences of students getting access to outside-of-school facilities [43], research resources [8], and help from scientists [29].

Our demographic findings suggested that SEFs can support the goal of STEM education for everyone and not just for the scientists and engineers of the future. Female and male students indicated similar SEF experiences as also reported by others [44-46]. Students from urban and suburban high schools reported similar SEF experiences [39]. And a significant percentage of all students indicated that SEF participation increased their interests in S&E, although outcomes were higher for Asian and Hispanic students (60-70%) compared to Black and White students (40-50%) [39, 41].

When we asked students from a local school district the quantitative question whether competitive SEF participation should be optional or required, the overwhelming response (about 80%) was optional [47]. This response was confirmed by our later national surveys where we also asked the students the *Reason Why?* optional or required as a free text answer. Only about one third mentioned positive reasons to require SEF participation. The most frequent positive reason why was competition incentive (51%). Introduction to the scientific process was rarely mentioned (3%). The most frequently mentioned negative reasons were many students don't like to compete (29.6%) and no enjoyment (17.3%) [42]. Therefore, the free-text answers were complementary to and important for interpreting the results of the quantitative questions.

Despite the negative comments described above, most students (about 60%) still indicated that SEF participation increased their interest in S&E. To better understand the appeal of SEF participation, we now have added a free text *Reason Why?* question regarding why SEF participation increased or not the student's interest in S&E. In this paper, for the first time, we report and analyze the positive and negative comments by 1191 students who participated in our national SEF surveys during 2021-22 and 2022-23 and provided free text reasons.

Materials and methods

This study was approved by the UT Southwestern Medical Center IRB (#STU 072014-076). The study design entailed administering to students a voluntary and anonymous online survey using the REDCap survey

and data management tool [48]. Survey recipients were U.S. high school students using Scienteer (www.scienteer.com) for online SEF registration, parental consent, and project management during the 2021/22, and 2022/23 school years. Although we treat the Scienteer SEF population as a national group of U.S. high school students, it should be recognized that these students come from seven U.S. states: Alabama, Louisiana, Maine, Missouri, Texas, Vermont, and Virginia. We have no information about the locations where SEF fairs are held within each of the seven states.

After giving consent for their students to participate in SEFs, parents can consent for their students to take part in the SEF survey. However, to prevent any misunderstanding by parents or students about a possible impact of agreeing to participate or participating in the survey, access to the surveys is not available to students until after they finish all their SEF competitions. When they initially register for SEFs, students whose parents gave permission are told to log back in to Scienteer after completing the final SEF competition in which they participated. Those who do so are presented with a hyperlink to the SEF survey. Scienteer does not send out reminder emails, and no incentives are offered for remembering to sign back in and participate in the survey. Since 2016, when we began surveying the national Scienteer cohort of SEF students, more than 4,000 students have completed surveys, an overall response rate of about 3%. Given that student participation in the surveys involves an indirect, single electronic invitation without incentive or follow-up, this level of response would be expected [49-51].

The survey used for the current study can be found in supporting information (S1 Survey). The current version is similar to the original survey first adopted in 2015 [52]. However, since then new questions have been added about level of SEF competition; interest in a career in S&E, and whether SEF experience increased S&E interest [42]; about student ethnicity [41]; and about location of the student's high school (urban, suburban, rural) [39]. Beginning in 2021, following quantitative survey question *20 -- Did your science fair experience increase your interest in the sciences or engineering?* -- we added the free text answer option *20A -- Reason Why?*

The students' answers to the foregoing free text answer Reason Why? question is the focus of the current study. Qualitative text analysis was carried out as previously [42, 47] using a grounded theory-based approach [37] modeled by NVivo [53, 54]. Of the students who completed SEF surveys, approximately 70% (1191) wrote comments about SEF participation and their interests in S&E. Two members of the research team (FG and SD) independently coded students' comments, which were categorized into a matrix of shared student reason groups. The independently coded comments were subsequently revised and harmonized. Longer student comments often expressed more than one reason why, in which case a single student comment was coded into more than one reason group and explains why the total number of grouped comments exceeded the total number of student comments. Occasionally a student's comments also could be put into more than one group. The complete set of student answers to the *Reason Why?* question and corresponding positive and negative group category assignments can be found in supporting information (S1 Dataset).

Overall quantitative survey data for the student group is summarized with frequency counts and percentages. Significance of potential relationships between data items was assessed using Chi-square contingency tables for independent groups. A probability value of $p = 0.05$ or smaller was accepted as statistically significant but actual p values are shown. No adjustments are made for multiple comparisons.

Results

Beginning in 2021, after the survey question -- *Did your science fair experience increase your interest in the sciences or engineering?* – we added the free text answer option, *Reason Why?* In response, 1191 out of

1790 students provided text comments. S1 Table in supporting information shows that for these 1191 students, the 2021-22 and 2022-23 quantitative results were similar regarding demographics, opinions about SEFs, help received, obstacles encountered, and ways of overcoming obstacles. Moreover, S2 Table shows that the quantitative SEF outcome experiences of this group of students was similar to previously reported findings [39, 41, 42]. That is, more than half the students indicated that SEF participation increased their interests in S&E. Asian and Hispanic students were more positive than Black and White students as were students in older grades compared to younger students. No gender differences were observed. Consistent with previously reported quantitative findings, significant positive SEF experience outcomes correlated with student interest in S&E careers, optional vs. required SEF participation, SEF competition beyond the school-only level, coaching for the interview, and help from scientists.

Overview of qualitative survey responses

In the following sections, we report and analyze the positive and negative comments by the students. Table 1 and Figure 1 show the frequency and distribution of answers to the *Reason Why?* question organized into positive and negative groups. Overall, positive reasons (1315) outnumbered negative reasons (821). Therefore, the percent of positive reasons – 61.6% -- was slightly higher than the 56.1 percent of students who indicated a positive impact of SEF participation in their quantitative responses (S2 Table). Supplemental Figure 1 (S1 Figure) shows that the distribution of grouped students' comments was similar from year to year, i.e., 21-22 vs. 22-23.

The top five groups of positive comments accounted for about 83% of all the students' positive comments regarding why SEF participation increased their interest in S&E. The most frequent group fit into the category of non-specific general affirmation, **affirmed - expanded interest** - 308 out of 1315 total. The next most frequent examples of positive student comments fit into the category **learned new things** (296 comments), which could mean not only the students' project itself – *seeing your results is always rewarding,* but also, learning about new topics, categories and fields to study. Next came the **experience doing research** (224 comments) such as learning how to set up an experiment or to collect data. One student commented, *made me feel as if I were an actual researcher.* The third group with more than 100 comments was **enjoyed/fun experience** (160 comments) ranging from general comments e.g., *enjoyed learning and doing all of these skills*, to one student's *thrill of getting a project to work.* Finally, the last group was **career choice** (113 comments), which often reflected confirming a student's career interests but sometimes concerned establishing a new trajectory, e.g., *changed my interest in space and environmental studies.* Students also made positive comments but less frequently that fit into the categories **see other proje**cts, **solve society problems**, and **experience presenting research**.

The top five groups of negative comments accounted for about 81% of all the students' negative comments regarding why SEF participation did not increase their interest in S&E. The most frequent examples fit into the category **not fun/stressful/boring** (179 comments) -- *the experimental process is not something I enjoy*. Next most frequent was **not a good project** (147 comments) for diverse reasons ranging from SEF restrictions -- *the bounds with which the science fair experiment had to be conducted were extremely limiting and did not allow me to pursue my interests* -- to failure of student engagement -- *I chose a quite boring project idea due to lack of imagination, creativity, and curiosity*. Next came non-specific **no change in interest** (133 comments). The fourth group **not interested in science** (116 comments) concerned the student's lack of interest in science and engineering, sometimes mentioning non-S&E career trajectories. Finally, dislike of being **required** (89 comments) was the last of the most frequent negative comment groups, especially being required to participate even if not interested in S&E. For instance, *there is no need to force students to do an impractical experiment they don't want to do. It adds a lot of stress to their already busy schedule and lives.*

Some students mentioned limited time and resources in their negative comments but not as frequently as

other concerns. Also, based on the students' quantitative survey answers (S1 Table), about 1/3 participated in SEFs as part of a research team. However, very few students made comments about their project partners. Of those who did, the comments were equally divided between the positive and negative impacts.

Table 1. Frequency of free text student comments in answer to the *Reason Why?* question

Figure 1. Distribution of students' comments in answer to the *Reason Why?* question

Some students wrote just a short phrase in answer to the *Reason Why?* question. However, many students expressed their thoughts in complex sentences. When a student comment expressed more than one reason why, then the comment was coded into more than one comment group, which is why the total number of grouped comments (2136) almost doubled the total number of students' comments (1191). Also, occasionally a student's comments could be put into more than one group. Tables 2 and 3 show examples of student comments for each of the groups listed in Table 1 illustrating the complexity. Italics shows the text based on which the comments were assigned to a particular group. For instance, in the first entry in Table 2, the phrases *deeper understanding, topic I enjoy, and want to keep on studying* resulted respectively to the comment assignments **P2** (**learned new things)**, **P4** (**enjoyed/fun experience**) and **P1** (**affirmed - expanded interest**). In the first entry in Table 3 (negative student comment groups), the phrases *didn't seem fun, forced to do, topics I wanted*, and *shut down by my teacher* resulted respectively to the comment assignments **N1** (**not fun/stressful/boring**), **N5** (**required**), **N2** (**not a good project**) and **N8** (**negative judging and teachers**).

Table 2. Examples and group assignments of positive student comments in answer to the *Reason Why?*

Table 3. Examples and group assignments of negative student comments in answer to the *Reason Why?*

Qualitative responses in relationship to students' interests and experiences

Subsequent tables and figures report the frequency and distribution of students' positive and negative comments in relationship to student demographics and SEF experiences. The tables show the numbers of students in each experience group and their overall positive and negative comments. The bar graphs beneath the tables show the distribution data for the most frequently selected *Reason Why?* categories as comments per 100 students in the group. S3 Table in supporting information shows the number of comments per 100 students numerically.

Figure 2 shows that if the students' comments were sorted according to whether they answered quantitatively *yes* or *no* to the question of whether SEF participation increased their interests in S&E, then 98% of the comments that sorted into the positive groups were from students who answered *yes* compared to 13% positive of the students who answered *no*. Distribution data showed that in every category, the frequency of qualitative comments was similar to the students' overall quantitative responses.

Figure 2. Frequency and distribution of free text student comments sorted according to student's *yes* or *no* answers to the SEF participation outcome question.

Figure 3 shows that the overall frequency of qualitative comments also corresponded, albeit not as closely, with whether students indicated an interest in an S&E career. Of the 712 students who indicated they were interested in an S&E career, almost 75% made positive comments about SEF participation but 25% made negative comments. Conversely, of the 176 students who indicated no interest in an S&E career, about 75% made negative comments but 25% were positive. Those unsure about careers were in between -- 55% positive comments and 45% negative.

Distribution data showed that students who were uninterested in an S&E career made the fewest positive comments in every category and, as might be expected, the most negative comments about **not interested in science**. Students uninterested in a S&E career also were more likely to comment that SEF participation was not **fun/stressful/boring** and more likely to comment negatively about SEF participation being **required.**

Figure 3. Frequency and distribution of students' comments depending on students' interests in a S&E career.

Figure 4 shows the frequency and distribution of students' comments in relation to whether students were required to participate in SEFs. The more autonomous and self-motivating the students, as measured by whether they chose to participate in SEFs, the more likely they made positive comments about their SEF experiences. For the 224 students for whom participation in SEFs was optional, the frequency of positive comments was 89.3% compared to 52.6% of the 743 students required to participate in SEFs. For the 188 students who were required to carry out a school project and chose SEF participation as that project, 65.1% made positive comments.

The overall distribution pattern of positive comments was similar compared to all students (Figure 1) except students for whom SEFs were optional commented more regarding **learned new things** and the **experience doing research**. Students required to carry out a school project who chose SEF participation made as many positive comments about enjoying SEF participation and career choice as did those students for whom SEF participation was completely optional. Unexpectedly, the distribution pattern of negative comments showed a more binary response pattern. Unlike students for whom SEF participation was required or a project was required, students who chose to participate in SEFs made very few negative comments in any reason category regarding SEF participation.

Figure 4. Frequency and distribution of students' comments depending on SEF participation requirement.

More than any other types of help, students who receive coaching and help from scientists achieve better quantitative SEF outcomes including indicating that SEF participation increased student interest in S&E [41,42]. Figure 5 shows the frequency and distribution of students' comments in relation to whether students received help from scientists or coaching for the interview. Both types of help had a positive influence -- 85.7% vs. 59.5% and 88.3% vs. 58.7% respectively -- on the frequency of positive student comments.

The overall distribution pattern of positive comments differed somewhat for help from scientists and coaching. Students who received help from scientists were especially likely to make more positive comments about the **experience doing research** and **career choice**. Students who received coaching also made more positive comments about **learned new things**. Both types of help resulted in a high level of student satisfaction with their SEF experience judging from the low number of negative comments in any category.

Figure 5. Frequency and distribution of students' comments depending on coaching and help from scientists and teachers.

Figure 6 shows the frequency and distribution of students' comments in relation to whether students participated in school-only or more advanced SEFs, i.e., district, regional or state levels. Not all students indicated the SEF level in which they participated, which is why the number of students is lower than in the other comparisons. About half the students who commented participated in school-only SEFs. The other half advanced to district, region and state SEF levels.

Students who participated in more advanced SEFs made twice as many positive comments about SEF participation compared to those who participated at the school only level -- 84.5% vs 44.7%. Indeed, except for

the group of students who indicated no interest in S&E careers (see Figure 3), the students who participated in school-only SEFs were the only ones in the current study for whom less than half the student comments were positive about their experience. The distribution data showed students who competed in more advanced SEF competitions were more likely to comment positively and less likely to comment negatively in every category.

Figure 6. Frequency and distribution of students' comments depending on SEF competition level.

Figure 7 shows the frequency and distribution of students' comments in relation to grade level. Previously, we learned from survey data that most students participate in SEFs during 9th and 10th grades, whereas students in 11th and 12th grades were more likely to be interested in S&E careers and to indicate that SEF participation increased their interests in S&E [40]. Consistent with the previous survey studies, students in 11th and 12th grades made more positive comments explaining why SEF participation increased their interest in S&E compared to students from 9th and 10th grades.

According to the distribution results, 12th graders made more positive comments in every category, whereas 11th graders especially mentioned **learned new things** and the **experience doing research** as reasons that SEF participation increased their interest in S&E. Students in 12th grade also were the least likely to make negative comments except some indicated an interest in careers other than in the sciences, which we reconfirmed in the comment dataset (S1 Dataset). Students in 9th and 10 grades were most likely to comment that SEF participation was **not fun/stressful/boring** as the reason why SEF participation did not increase their interest in S&E.

Figure 7. Frequency and distribution of positive and negative comments depending on student grade

Figure 8 shows the frequency and distribution of students' comments in relation to student ethnicity. Students of all ethnicities were positive overall, but Asian and Hispanic students made more positive comments than black and white students consistent with previous quantitative survey findings [39, 41]. According to the distribution results, Asian and Hispanic students were more likely to comment positively about **learned new things** as the reason why SEF participation increased their interests in S&E. Asian students also were more likely than others to comment positively about the **experience doing research**. Black students were the least likely to comment positively about **career choice**. On the negative side, Black and White students were most likely to complain that SEF participation was **not fun/stressful/boring** as the reason why SEF participation did not increase their interest in S&E, and white students were most likely to comment **not a good project**.

Figure 8. Frequency and distribution of students' comments depending on ethnicity

Discussion

In this paper, we present findings based on free text comments by 1191 students who participated in our SEF surveys during 2021-22 and 2022-23. In the quantitative part of the surveys (S2 Table), almost 60% of these students indicated that SEF participation increased their interest in S&E. When asked the *Reason Why?* SEF participation increased or not their interest in S&E as a free text question, students provided 1315 positive reasons and 821 negative ones. Aside from non-specific affirmed/expanded interest (23.4%), the positive reasons most frequently mentioned were learned new things (22.5%); experience doing research (17.0%); enjoyed/fun experience (12.2%); and career choice (8.6%).

The above comments match well the ideal goals of SEF participation [8, 12, 18] but differ markedly from the surveys carried out previously in which we asked students if competitive SEF participation should be optional or required [42]. In that case, the students' answers tended to focus on the competition not the SEF

learning experience, i.e., the most frequently mentioned positive reason was competition incentive (50%); the most frequently mentioned negative reason was many students don't like to compete (29.6%).

We suggest that these two types of student answers about SEF participation reflect two different ways to understand the educational value of SEF participation. On one hand, mastery orientation, i.e., emphasis on understanding and improving STEM skills and knowledge; and on the other hand, performance orientation, i.e., competing with others with an emphasis on demonstrating high ability [55-57]. Mastery and performance orientations reflect the two different objective of the National Research Council Framework definition underlying NGSS -- science for everyone and science for the scientists and engineers of the future [4].

Mastery and performance orientations integrate differently with the three elements of self-determination theory: motivation, competence and community engagement [34, 35]. Mastery more clearly aligns with intrinsic motivation and demonstrating competence but not necessarily with community engagement. Performance more clearly aligns with extrinsic motivation, demonstrating competence, and enhanced community engagement. Recognizing these differences in relationship to the interests of high school students who participate in SEFs has the potential to enhance the impact of SEF participation on student STEM interests and knowledge.

Previously, we learned that black students who participated in our surveys were less likely than other students to indicate an interest in S&E careers [41]. Consistent with this finding, we found that black students were less likely than others to write that SEF participation increased their interests in S&E because of career choice. Conversely, career choice was mentioned frequently by students who received help from scientists and coaching as the reason SEF participation increased their interest in S&E. The success of innovative programs to provide the latter kind of support shows the possibility of enhancing SEF outcomes for black students as well as others [28-33].

The most frequently mentioned negative reasons students gave as to why SEF participation did not increase their interest in S&E, aside from non-specific no change in interest (16.2%), were participation was not fun/stressful/boring (21.8%); not a good project (17.9%); not interested in science (14.1%); and required to participate (10.8%). Ironically, although time pressure was mentioned in quantitative surveys as a SEF obstacle by more than 60% of students and to a greater extent than any other obstacle [41] (e.g., S1 Table), less than 5% of students mentioned time constraints as their reason why SEF participation did not increase their interest in S&E.

Not a good project was by far the most important reason that white students said SEF participation did not increase their interest in S&E. In general, not a good project meant limitation in the project the student was allowed to do or assigned. The comments about not a good project are particularly concerning because in a sense not a good project represents SEF project failure, the opposite of competence. From the perspective of self-determination theory, being required to participate in SEFs and in addition being assigned a failing project not of one's own choosing undermines the positive value of motivation more than any other combination.

Based on the frequency and distribution of negative reasons why SEF participation did not increase student interest in S&E, students who participated in school-only SEFs had a SEF experience worse than any other overall group. The number of students who can advance to SEFs beyond the school-only level will depend not only on student performance, but also on the number of SEF entries that a school or district permits to advance. How many typically will be governed by individual school and district policies. If school-only SEFs are the other possible option, then other SEF structures might be more successful such as incorporating SEFs into community STEM festivals [58, 59].

Previously we learned that most high school students participate in SEFs in 9th and 10th grades, but the younger students are less interested in S&E careers [40]. Also, we learned that SEF outcomes were better for

Asian and Hispanic students compared to Black and White students [39, 41]. In the current studies, we found older students were more likely to mention learned new things and the research experience as reasons explaining their positive SEF outcomes. Both Asian and Hispanic students mentioned learned new things; Asian students mentioned the research experience. For the younger students and for Black and White students, not fun stood out as a reason why SEF participation did not increase student interest in S&E. For White students, not a good project was a frequent complaint.

In conclusion, based on free text comments by 1191 students who participated in our national science and engineering fair (SEF) surveys during 2021-22 and 2022-23, we have learned new information about SEF participation and student interest in S&E. The positive reasons that students mentioned most frequently about why SEF participation increased their interest in S&E were: learned new things; experience doing research; enjoyed/fun experience; and career choice. The negative reasons most frequently mentioned by students were: participation was not fun/stressful/boring; not a good project; not interested in science; and required to participate. Overall, students who received coaching and help from scientists made the most positive comments. Students who participated in school-only level SEFs made the most negative comments overall. Reasons that students gave why SEF participation increased their interest in S&E aligned with mastery criteria. By contrast, reasons students gave in a previous study regarding whether or not competitive SEFs should be required aligned with performance criteria [42]. Mastery and performance orientations integrate differently with the three elements of self-determination theory: motivation, competence and community engagement. Recognizing these differences in relationship to the interests of high school students who participate in SEFs has the potential to enhance the impact of SEF participation on student STEM interests and knowledge.

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Supporting information

S1 Survey. Survey questions.

S1 Table. Quantitative student responses to the SEF survey year by year.

S2 Table. Summary of quantitative student responses about the effects of SEF participation on their interests in S&E.

S3 Table. Distribution of students' positive and negative comments in relationship to student demographics and SEF experiences

S1 Figure. Year by year distribution of students' comments in answer to the *Reason Why?* question.

S1 Dataset. Complete set of student answers to the *Reason Why* question and corresponding positive and negative group category assignments.

S2 Dataset. Excel dataset showing year by year answers to the survey questions.

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Table 1. Frequency of free text student comments in answer to the *Reason Why?* question

Overall Group	Comments	# Comments	% of Overall Group	Group ID
Positive (1315)	Affirmed/expanded interest	308	23.4	P1
	Learned new things	296	22.5	P2
	Experience doing research	224	17.0	P3
	Enjoyed/fun experience	160	12.2	P4
	Career choice	113	8.6	P5
	See other projects	77	5.9	P6
	Solve society problems	76	5.8	P7
	Experience presenting research	54	4.1	P8
	Positive experience with project partners	7	0.5	P9
Negative (821)	Not fun/stressful/boring	179	21.8	N1
	Not a good project	147	17.9	N2
	No change in interest	133	16.2	N3
	Not interested in science	116	14.1	N4
	Required	89	10.8	N5
	Not enough time	39	4.8	N6
	Too much work	31	3.8	N7
	Negative judging and teachers	24	2.9	N8
	Waste of time	17	2.1	N9
	Inadequate resources	16	2.0	N10
	Didn't learn anything	16	2.0	N11
	Not good at science	8	1.0	N12
	Negative experience with project partners	6	0.7	N13

Figure 1. Distribution of students' comments in answer to the *Reason Why?* question

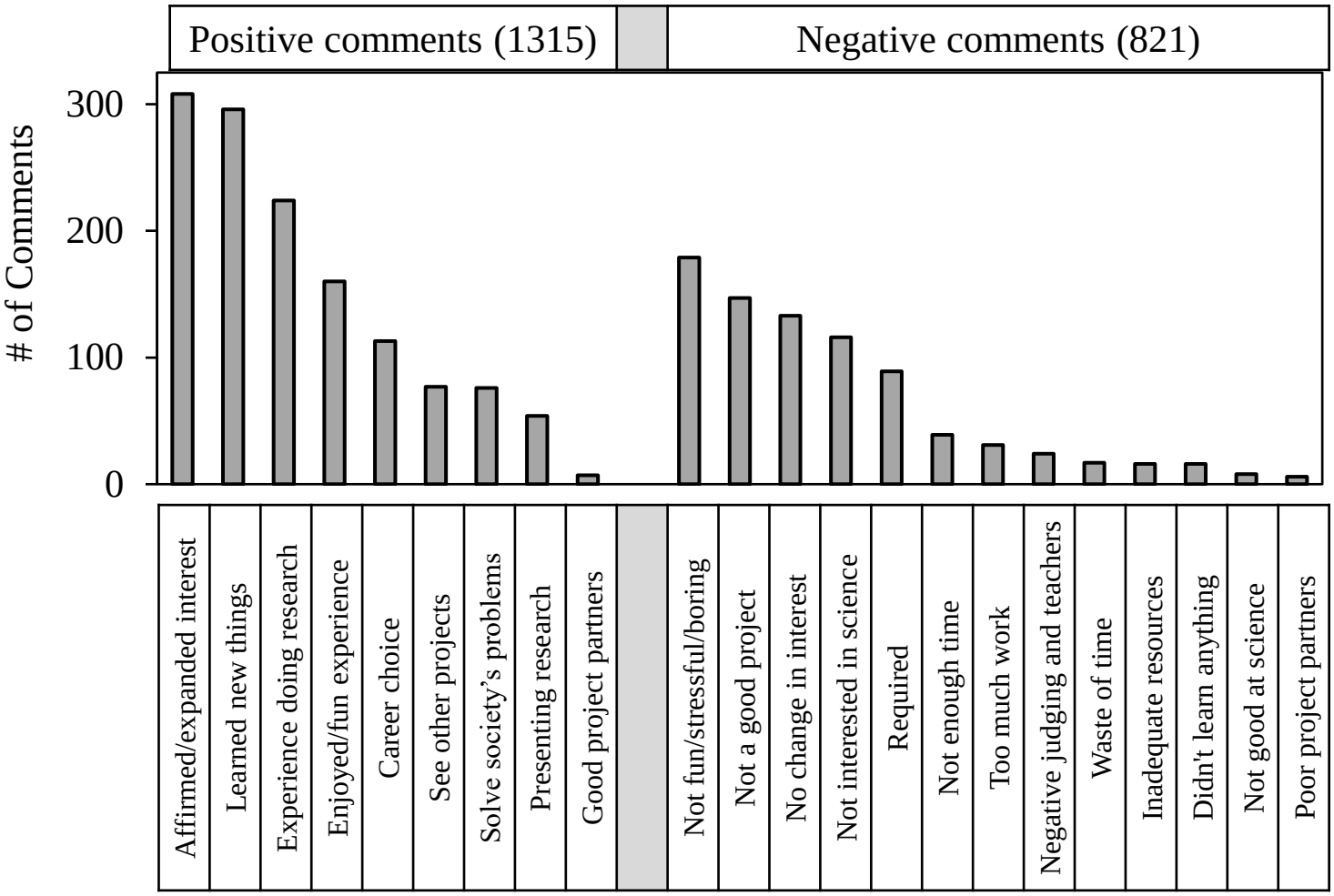


Table 2. Examples of positive student comments in answer to the *Reason Why?* question

Examples of Positive Comments	Group ID
It gave me a *deeper understanding on a topic I enjoy*, and it made me *want to keep on studying about it*.	P2, P4, P1
It helped me *develop further interest* after being able to research and *actually experience how to research and collect data* in a lab	P1, P3
I have *always wanted to major* and *pursue a career* in science.	P1, P5
Saw *tons of cool projects* there which made me *gain interest*.	P6, P1
It is always inspiring to *see what others do* with science fair and it gives a *hands on experience*.	P6, P3
Science fair allowed me to realize how science can be applied to *make the world a better place*.	P7
It allowed me to *go deeper into a concept* and overall. I *really enjoy* working on a project for a year then *presenting that project*.	P2, P4, P8
Although making the project was sometimes stressful, it was *still fun*. I got to *research new things* and *meet a good partner*.	P4, P3, P9

Table 3. Examples of negative student comments in answer to the *Reason Why?* question

Examples of Negative Comments	Group ID
The Science fair *didn't seem fun* it just seemed like an assignment I was *forced to do*. I do not look forward to doing a science fair in the future. I was already interested in biology but the biology *topics I wanted* to were *shut down by my teacher*.	N1, N5, N2, N8
No, because the *project did not spark* my area of interest in science.	N2, N3
I'm *more interested and dedicated* to politics and business rather than the STEM and sciences.	N4
Honestly, it felt like *unnecessary work added* onto my already large pile of work for this and other classes. It felt *stressful* and I *didn't really get anything* out of it.	N5, N1, N11
The *time pressure* and *stress* sometimes became overwhelming.	N6, N1
Because I like science but *I don't like the amount of work*.	N7
Free *time wasted + not helpful*	N9, N11
With *time and material constraints*, I wasn't able *to pick a topic I enjoyed.*	N6, N10, N2, N1
I'm *not good at it* and science *isn't something I'd like to do* in the future	N12, N4
My partner and I *did not get along* and the results of the project were blamed on me, so I *did not enjoy* doing the science fair.	N13, N1

Figure 2. Frequency and distribution of students' comments sorted according to whether they answered yes or no that SEF participation increased their interests in S&E.

Survey Question	Survey Answer	# (%) Students	Comments	
			Positive # (%)	Negative # (%)
All Students		1191 (100)	1315 (61.6)	821 (38.4)
SEF participation increased my interest in S&E	Yes	668 (56.1)	1192 (98.3)	21 (1.7)
	No	523 (43.9)	123 (13.3)	800 (86.7)

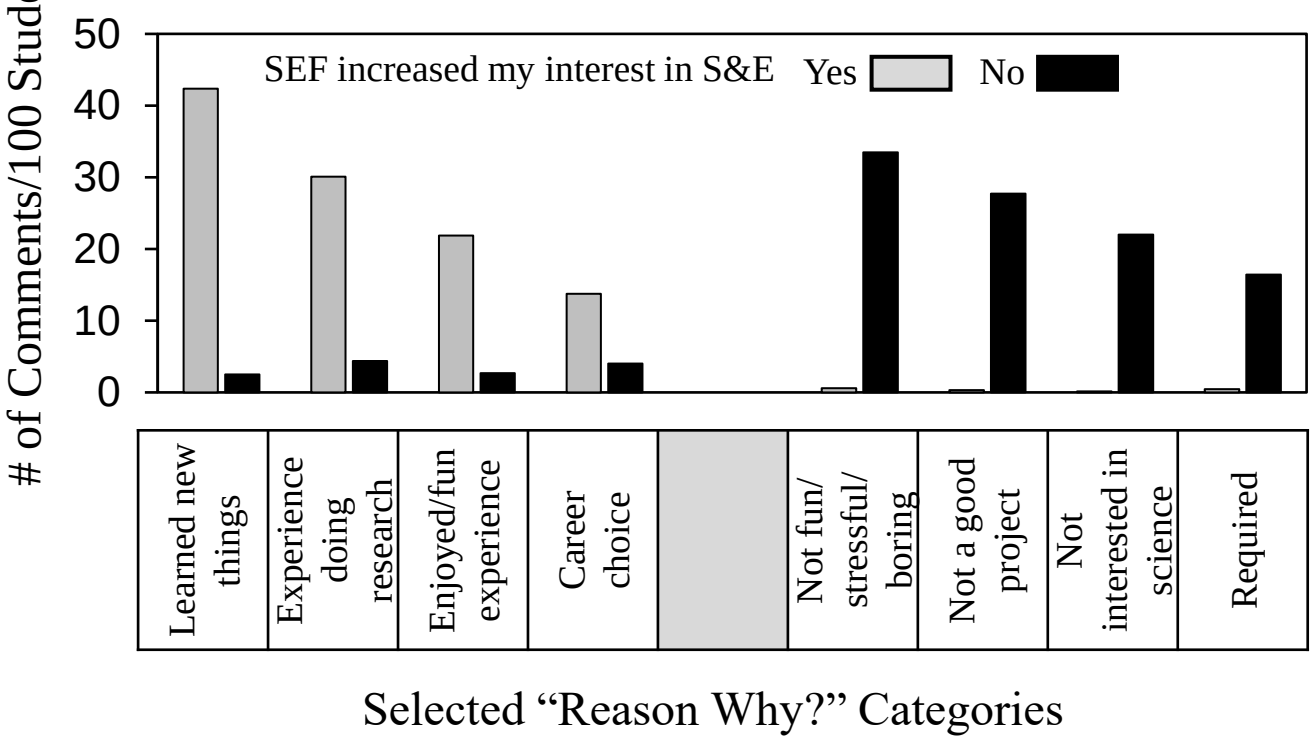


Figure 3. Frequency and distribution of students' comments sorted according to students' interests in a S&E career.

Survey Question	Survey Answer	# (%) Students	Comments			
			Positive # (%)		Negative # (%)	
Interest in a career in S&E	Yes	712 (59.9)	979	(74.6)	360	(44.4)
	No	176 (14.8)	66	(5.0)	228	(28.1)
	Unsure	300 (25.3)	276	(20.4)	223	(27.5)

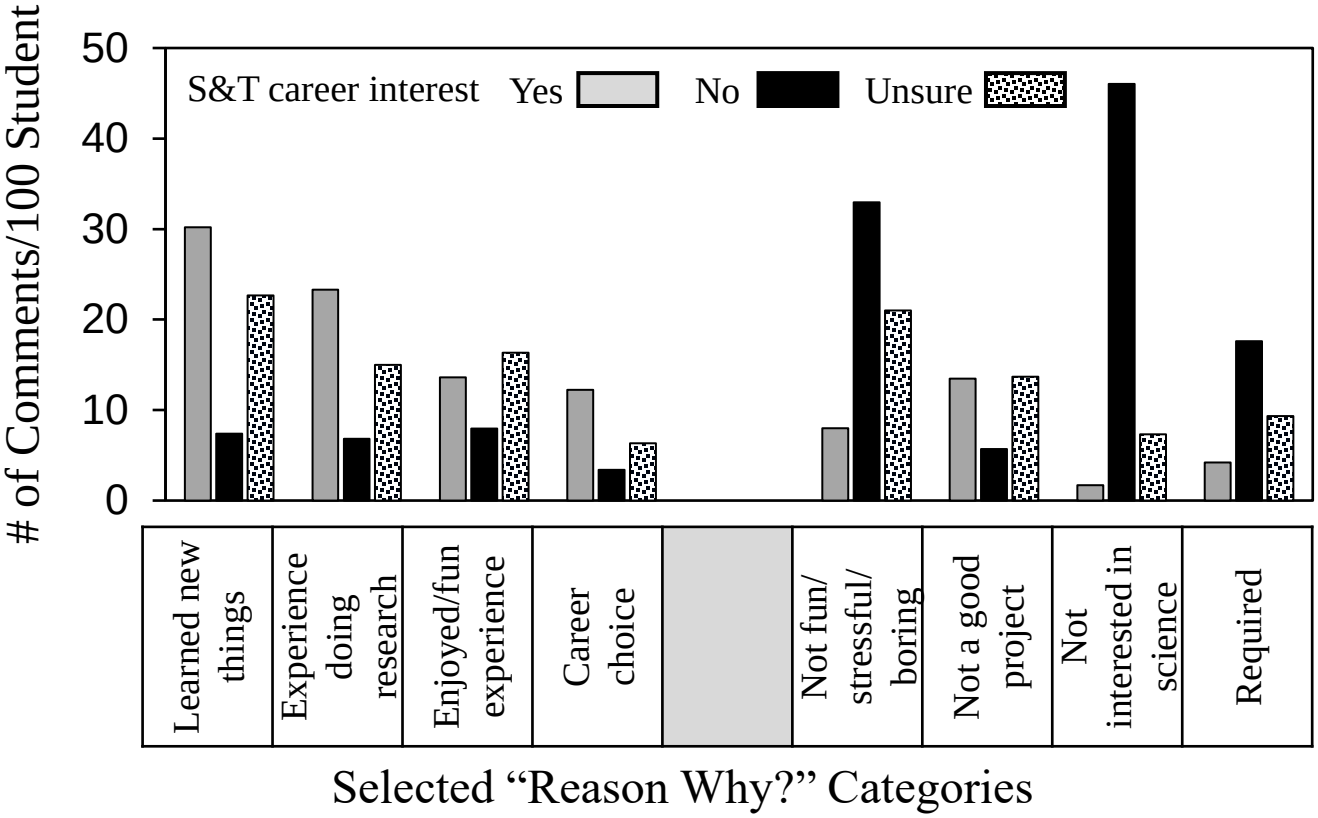


Figure 4. Frequency and distribution of students' comments depending on SEF requirement

Survey question	Survey answer	# (%) Students	Comments			
			Positive # (%)		Negative # (%)	
Science fair requirement	Optional	224 (19.0)	369	(89.3)	44	(10.7)
	Required	743 (62.9)	691	(52.6)	623	(47.4)
	Project	188 (15.9)	229	(65.1)	123	(34.9)

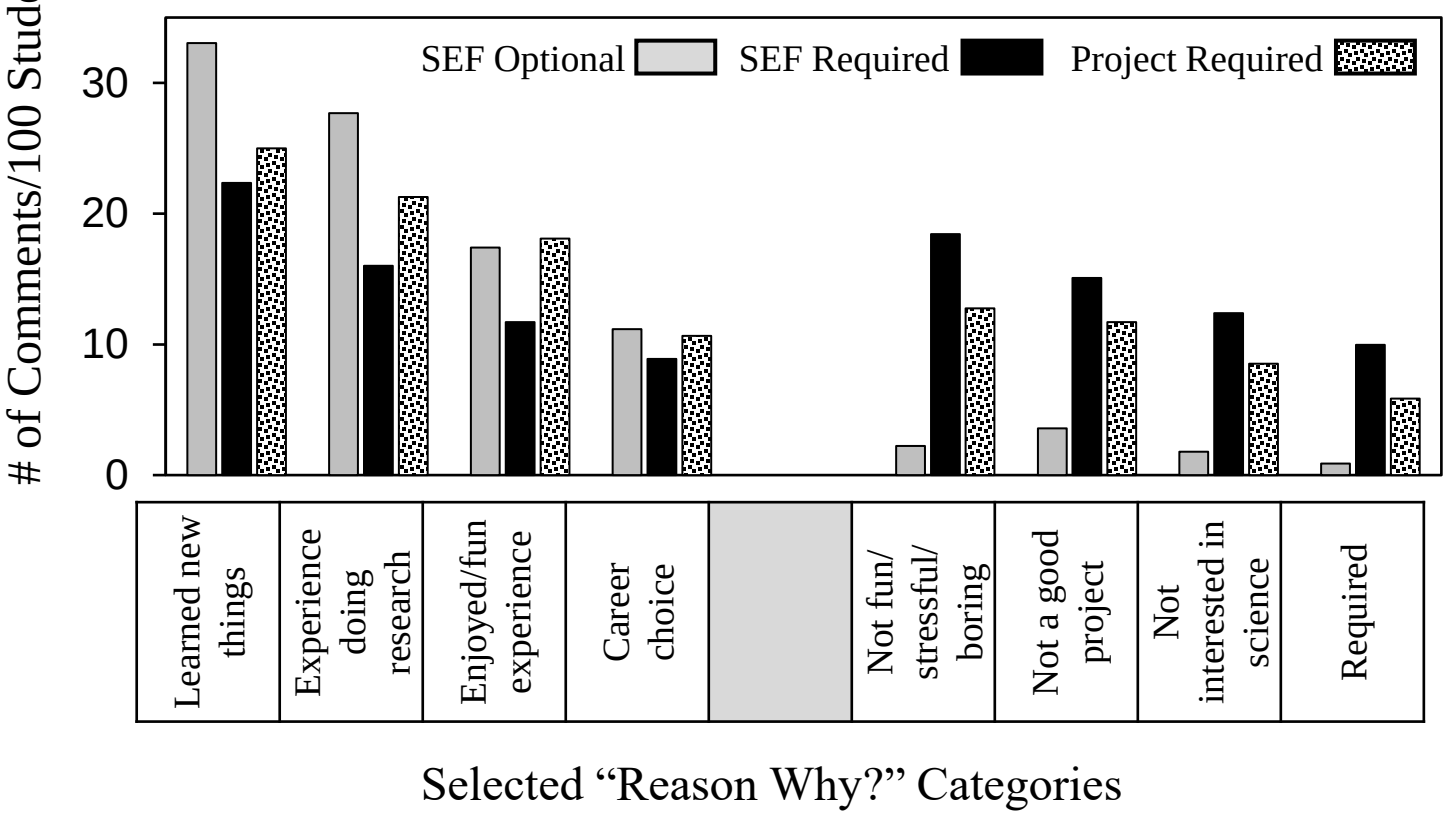


Figure 5. Frequency and distribution of students' comments depending on coaching for the interview and help from scientists and teachers.

Survey question	Survey answer	# (%) Students	Comments	
			Positive # (%)	Negative # (%)
Help from scientists	Yes	82 (6.9)	144 (85.7)	24 (14.3)
	No	1109 (93.1)	1171 (59.5)	797 (40.5)
Received coaching	Yes	112 (9.4)	182 (88.3)	24 (11.7)
	No	1080 (90.6)	1133 (58.7)	797 (41.3)

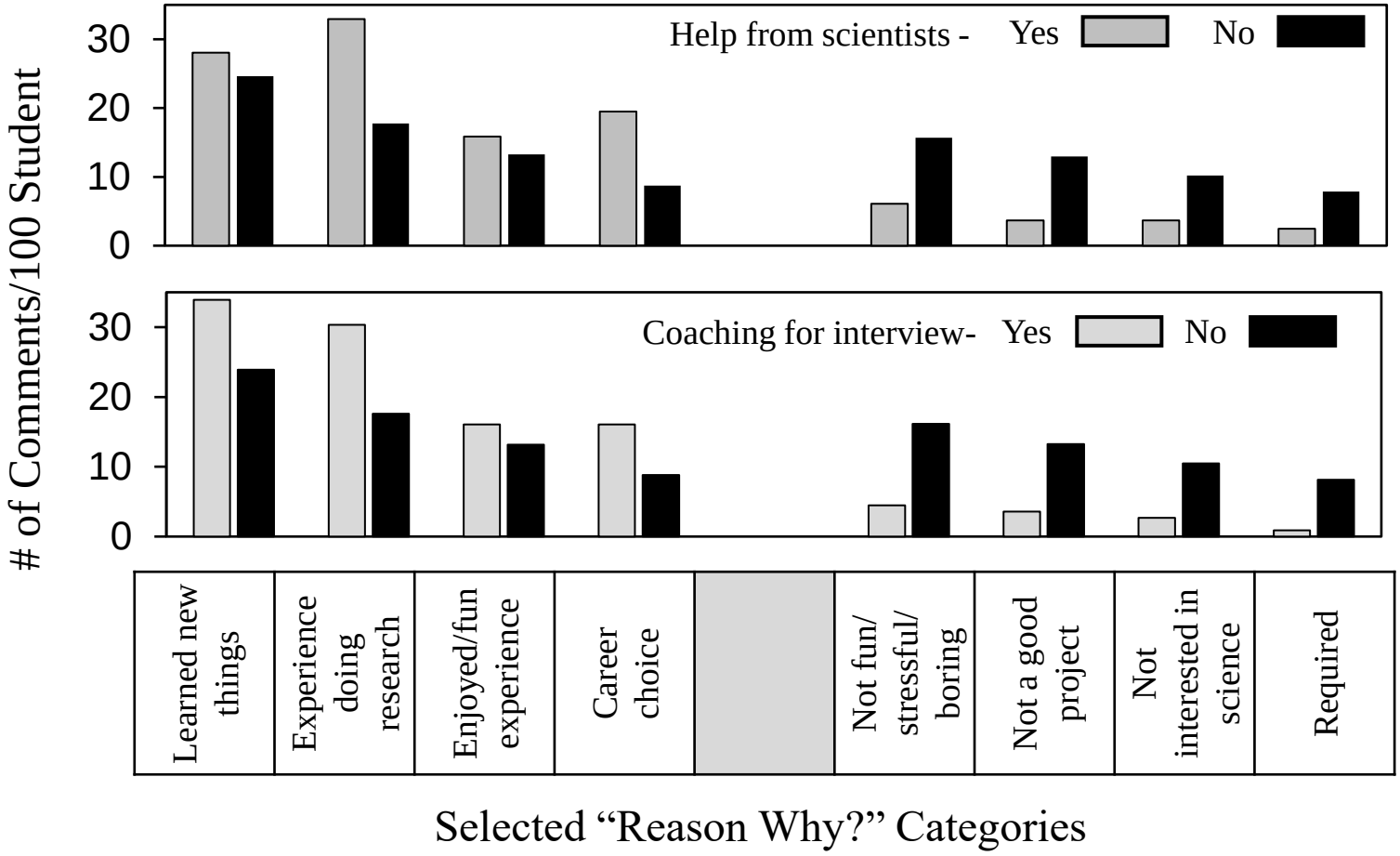


Figure 6. Frequency and distribution of students' comments depending on SEF competition level

Survey question	Survey answer	# (%) Students	Comments	
			Positive # (%)	Negative # (%)
Competition level	Beyond school	491 (41.1)	739 (84.5)	145 (16.4)
	School only	551 (46.3)	432 (44.7)	530 (55.1)

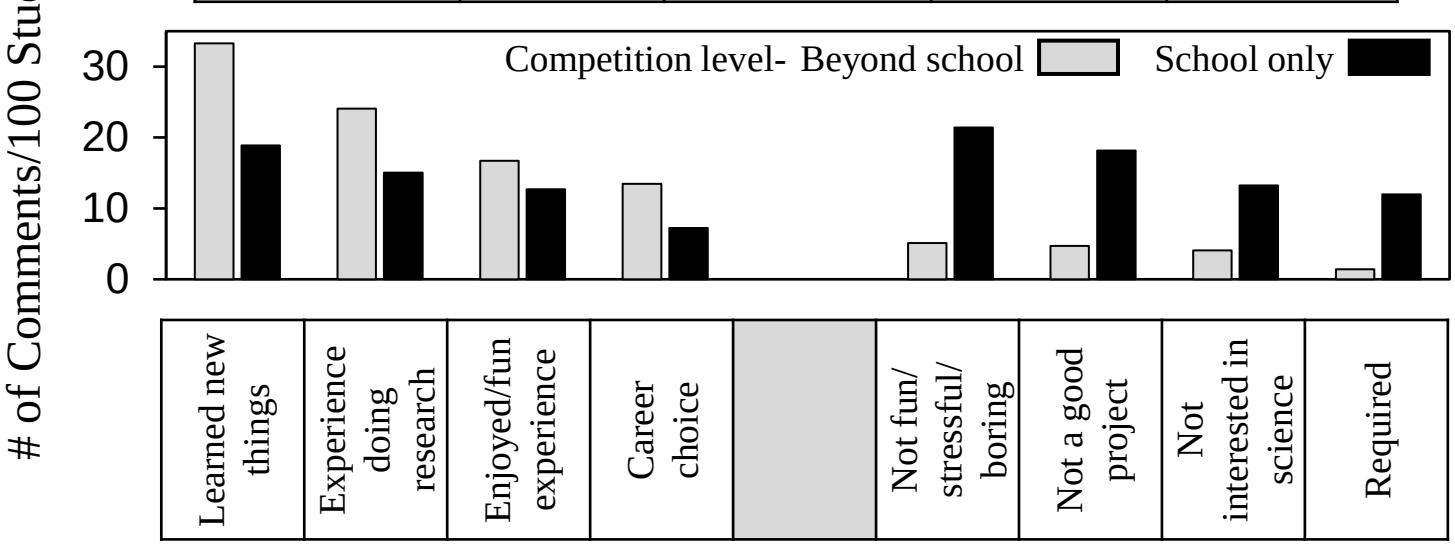


Figure 7. Frequency and distribution students' comments depending on student grade.

Survey question	Survey answer	# (%) Students	Comments	
			Positive # (%)	Negative # (%)
Grade in which students participated in SEFs	9	509 (42.8)	563 (62.5)	338 (37.5)
	10	369 (31.0)	338 (51.4)	319 (48.6)
	11	224 (18.8)	281 (67.7)	134 (32.3)
	12	88 (7.4)	132 (81.5)	30 (18.5)

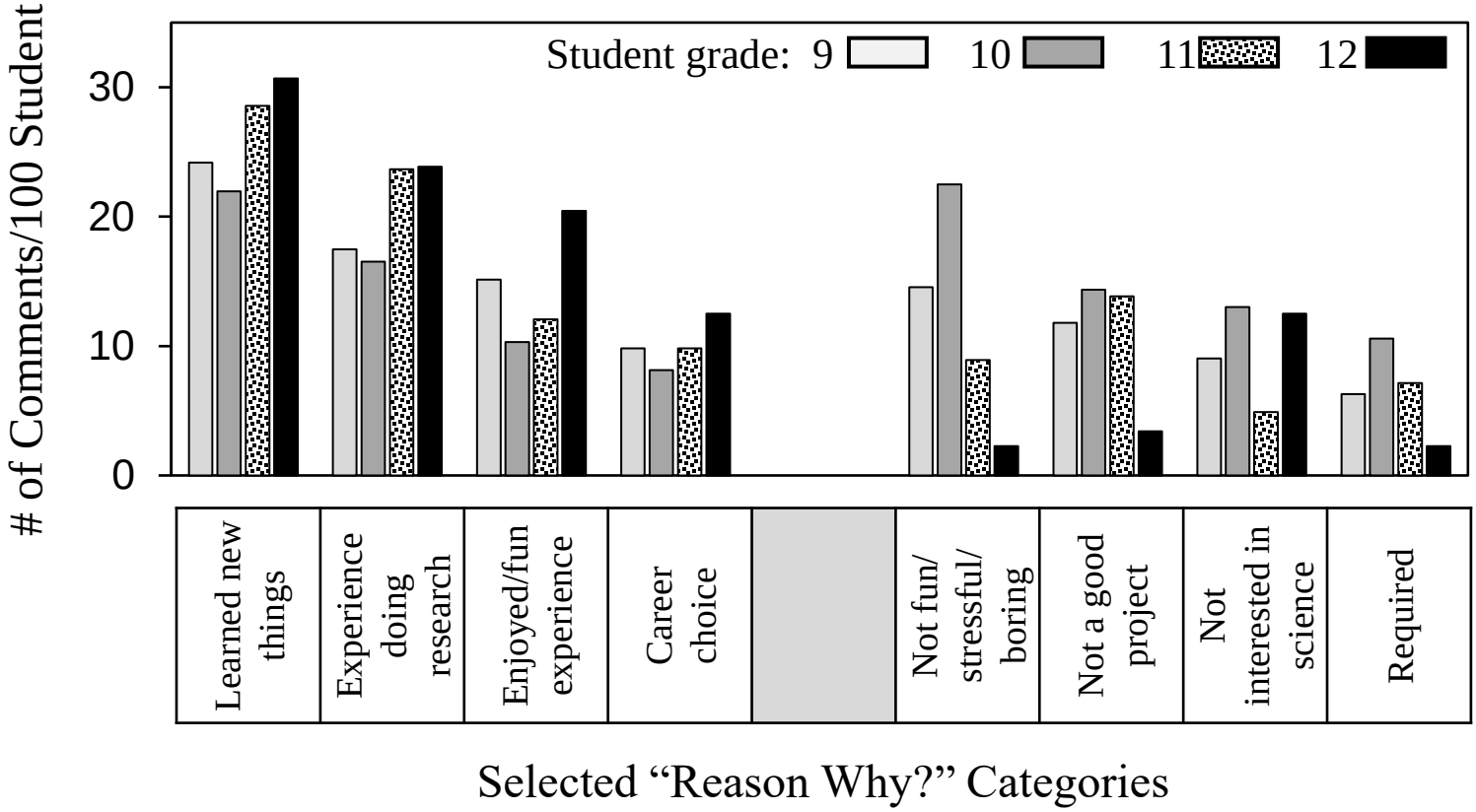
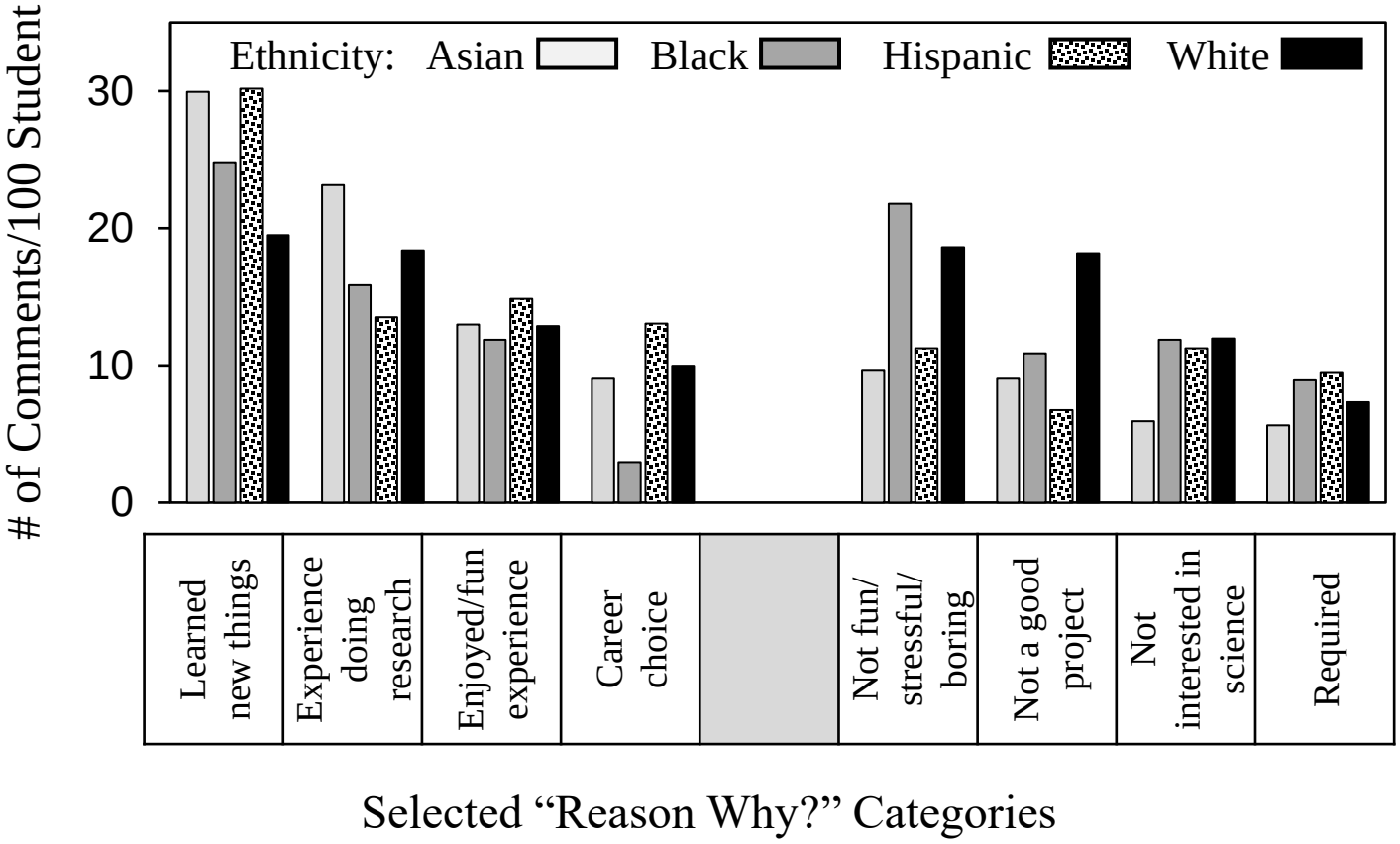
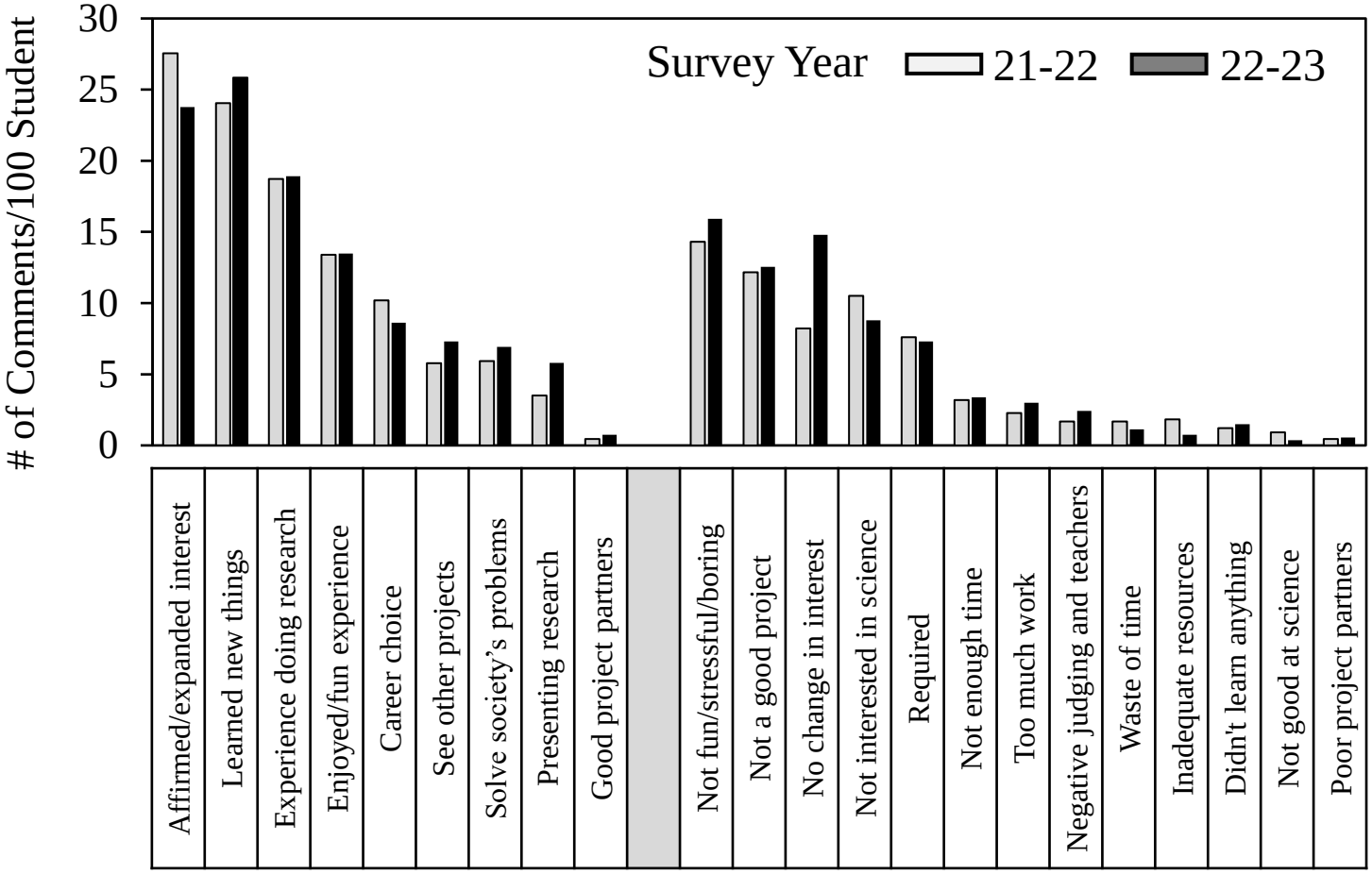


Figure 8. Frequency and distribution of students' comments depending student ethnicity.

Survey question	Survey answer	# (%) Students	Comments	
			Positive # (%)	Negative # (%)
Student ethnicity	Asian	354 (31.4)	472 (72.6)	178 (27.4)
	Black	101 (9.0)	98 (54.7)	81 (45.3)
	Hispanic	222 (19.7)	263 (69.0)	118 (31.0)
	White	451 (40.0)	418 (51.6)	392 (48.4)



S1 Figure. Distribution of students' comments in answer to the *Reason Why?* question year by year.



S1 Table. Quantitative student responses to the SEF survey year by year. Questions 1-11

SEF Survey Questions and Answers		% Students	
Questions	Answers	(21-22) 657*	(22-23) 534**
1. What grade are you in?	9	43.3	41.9
	10	30.2	32.0
	11	17.6	20.2
	12	8.7	5.8
2. Location of high school?	Urban	20.8	27.0
	Suburban	72.8	66.9
	Rural	3.6	3.7
2A. Type of high school? (22-23 only)	Public	NA	85.8
	Private	NA	7.1
	Charter	NA	6.2
3. Gender?	Female	52.4	55.4
	Male	45.4	43.4
4. Ethnicity most identified with?	Asian	30.4	29.0
	Black	7.9	9.2
	Hispanic	17.6	19.9
	White	38.9	36.5
	Other*	3.5	3.4
	Specify	-	-
5. During high school have you carried out science fair more than once?	Once	67.3	67.4
	> Once	32.4	31.8
6. In which science fair competitions did you compete this year (could be more than one)?	School	71.7	70.0
	District	32.4	27.0
	Region	24.5	30.3
	State	2.6	2.6
7. Was your science fair project team or individual?	Individual	65.5	61.0
	Team	32.5	34.6
8. Was the science fair project required by your school?	Required	64.9	59.2
	Optional	16.4	21.9
	Project	16.6	14.8
9. Do you think science fair projects should be optional or required?	Optional	72.8	75.7
	Required	26.6	22.7
10. Do you think science fair projects for competition should be optional or required?	Optional	87.4	85.4
	Required	12.2	12.9
11. Who helped you with your science fair project?	Parents	51.5	53.0
	Siblings	14.0	11.0
	Other family members	5.6	6.6
	Teachers	54.9	54.9
	Other students	32.2	30.3
	Scientists	5.9	8.1

S1 Table continued. Questions 11-17

Questions	Optional	(21-22) 657*	(22-23) 534**
11. Who helped you with your science fair project (continued)?	A paid mentor	1.1	0.9
	Articles on the Internet	55.8	53.7
	Articles in books or magazines	18.5	18.0
	Other	3.0	6.6
	Specify:	-	-
12. What kind of help did you actually receive?	Being given the main idea	10.9	11.2
	Development of the idea	30.5	28.3
	Gathering background research information, or finding a research site or participants	46.8	41.0
	Performing the experiments	38.8	38.6
	Writing the report	13.8	11.0
	Fine tuning the report after it is written	28.7	29.8
	Designing the poster board and presentation	21.3	21.5
	Producing charts or graphs	17.5	16.3
	Coaching for the interview with judges	9.9	8.8
	Copying the project from someone else	0.8	0.2
	Other	5.9	9.2
	Specify:	-	-
13. Did you get the kind of help you wanted from teachers?	Yes	84.3	80.1
	No	14.1	17.4
14. Was there some kind of help that you would have liked but did not receive?	Specify:	-	-
16. What types of communication and presentation skills did you use in your science fair project?	Written report	51.5	57.9
	Literature review	15.3	19.5
	Research notebook	29.5	32.8
	Poster board preparation	62.2	78.5
	Powerpoint presentation	44.7	27.2
	Software to prepare tables, graphs, or images	46.0	52.1
	Presentation to other students	0.0	42.9
	Interview with the judges	43.0	50.4
	Other	2.4	0.9
	Specify?	-	-
17. What obstacles did you face?	Coming up with the main idea	46.7	43.3
	Getting motivated to do the project	48.8	42.1
	Becoming disappointed with the project	24.0	26.8
	Limited resources	33.1	37.5
	Limited knowledge	26.0	28.5
	Limited skills	18.2	21.3
	Limited cooperation	12.8	11.0

S1 Table continued. Questions 17-20 and *,** Notes

Questions	Answers	(21-22) 657*	(22-23) 534**
17. What obstacles did you face (continued?	Getting organized	26.9	25.3
	Time pressure	60.5	59.2
	Not enough money	9.7	11.8
	Results not as expected	24.9	24.7
	Other	4.0	3.9
	Specify?	-	-
18. How did you overcome the obstacles you encountered?	Used someone elses main idea	1.5	1.7
	Picked a familiar/interesting topic	34.3	31.1
	Did more background research	48.8	50.2
	Stopped working on the project for a while	19.6	17.0
	Made a timeline to follow	27.1	26.6
	Perseverance and self-discipline	50.8	50.7
	Had someone else to keep me on track	15.0	16.7
	Had someone else do the math	0.3	0.2
	Changed the research plan	18.4	15.7
	Collected more data	28.0	23.6
	Had someone else collect the data	1.4	1.5
	Used someone elses data	0.6	0.2
	Made up the data	1.1	1.3
	Changed the hypothesis to fit the data	3.2	5.6
	Changed the data to fit the hypothesis	1.2	0.2
	Other	5.2	6.7
19. Are you interested in a career in the sciences or engineering?	Yes	58.1	62.0
	Not sure	27.2	22.7
	No	14.7	14.8
20. Did your science fair experience increase your interest in the sciences or engineering?	Yes	56.1	56.0
	No	43.8	44.0
20A. "Reason why?	-	-	-

*Students who answered 20A "Reason Why?" question (977 students total completed surveys)

**Students who answered 20A "Reason Why?" question (813 students total completed surveys)

S2 Table. Summary of quantitative student responses about the effects of SEF participation on their interests in S&E

Survey			SEF participation increased my interest in S&E			Chi Square (p Value)
Question	Answer	# Students	# Yes	# No	% Yes	
All Students		1191	668	523	56.1	
Grade	9	509	295	214	58.0	<.001
	10	369	165	204	44.7	
	11	224	142	82	63.4	
	12	88	65	23	73.9	
Ethnicity	Asian	355	238	117	67.0	<.001
	Black	101	49	52	48.5	
	Hispanic	222	141	81	63.5	
	White	451	205	246	45.5	
Gender	Female	641	356	285	55.5	NS
	Male	530	303	227	57.2	
Interest in career in S&E	Yes	712	498	214	69.9	<.001
	Not sure	300	139	161	46.3	
	No	176	30	146	17.0	
SEF requirement	Required	743	352	391	47.4	<.001
	Optional	224	190	34	84.8	
	Project Required	188	114	74	60.6	
Level of Competition	Beyond school	710	578	132	81.4	<.001
	School only	551	452	394	53.4	
Type of help	Received coaching for the interview	112	96	16	85.7	<.001
Who helped	Scientists	82	65	17	79.3	<.001
	Teachers	653	398	255	60.9	.043
	Parents	622	348	274	55.9	NS

S3 Table. Distribution of students' positive and negative comments in relationship to student demographics and SEF experiences

Survey Question		# of Comments/100 Student								
SEF participation increased my interest in S&E	Yes	42.4	30.1	21.9	13.8		0.6	0.3	0.1	0.4
	No	2.5	4.4	2.7	4.0		33.5	27.7	22.0	16.4
Interest in a career in S&E	Yes	30.2	23.3	13.6	12.2		8.0	13.5	1.7	4.2
	No	7.4	6.8	8.0	3.4		33.0	5.7	46.0	17.6
	Unsure	22.7	15.0	16.3	6.3		21.0	13.7	7.3	9.3
Science fair requirement	Optional	33.0	27.7	17.4	11.2		2.2	3.6	1.8	0.9
	Required	22.3	16.0	11.7	8.9		18.4	15.1	12.4	10.0
	Project	25.0	21.3	18.1	10.6		12.8	11.7	8.5	5.9
Help from scientists	Yes	28.0	32.9	15.9	19.5		6.1	3.7	3.7	2.4
	No	24.6	17.8	13.3	8.7		15.7	13.0	10.2	7.8
Received coaching for interview	Yes	33.9	30.4	16.1	16.1		4.5	3.6	2.7	0.9
	No	23.9	17.6	13.2	8.8		16.1	13.3	10.5	8.2
Competition level	Beyond school	33.3	24.1	16.7	13.5		5.1	4.7	4.1	1.4
	School only	18.9	15.1	12.7	7.3		21.4	18.1	13.2	12.0
Grade in which students participated in SEFs	9	24.2	17.5	15.1	9.8		14.5	11.8	9.0	6.3
	10	22.0	16.5	10.3	8.1		22.5	14.4	13.0	10.6
	11	28.6	23.7	12.1	9.8		8.9	13.8	4.9	7.1
	12	30.7	23.9	20.5	12.5		2.3	3.4	12.5	2.3
Student ethnicity	Asian	29.9	23.2	13.0	9.0		9.6	9.0	5.9	5.6
	Black	24.8	15.8	11.9	3.0		21.8	10.9	11.9	8.9
	Hispanic	30.2	13.5	14.9	13.1		11.3	6.8	11.3	9.5
	White	19.5	18.4	12.9	10.0		18.6	18.2	12.0	7.3
Selected "Reason Why?" Categories		Learned new things	Experience doing research	Enjoyed/fun experience	Career choice		Not fun/ stressful/ boring	Not a good project	Not interested in science	Required