A "Reverse Science Fair" that Connects High School Students with University Researchers

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Abstract

Many university science outreach programs involve presentations of research projects to high school students. These presentations often focus more on exciting scientific content and less on fostering direct relationships between high school students and scientists. Such interactions are important for sustaining student interest in science throughout high school and into college. The Reverse Science Fair seeks to build relationships between high school students and graduate student researchers by swapping the roles that each play during a traditional science fair. Graduate student researchers are introduced as young scientists devoted to asking their own research questions and finding their own answers. This facilitates discussion not only about the scientific method and the research being presented but also about researchers' personal experiences in the laboratory. Graduate students from Tufts University (Medford, MA), in October 2015 and February 2016, first exhibit and discuss their own research at poster presentations located at Medford High School. Then, the high school students have the opportunity to discuss their own science fair projects at a school-wide fair with the graduate students. Data from surveys and observer reports show that high school students benefited from discussing science with relatable role models who are enthusiastic about science. The majority of high school students indicated that they had an increased understanding of different applications of the scientific method as well as an increased interest in doing scientific research. Graduate students reported that they gained valuable experience from presenting to a new audience.

Key Words
High School/Introductory Chemistry, Graduate Education/Research, Interdisciplinary/Multidisciplinary, Public Understanding/Outreach, Communication/Writing

Introduction

The science fair, or a similar self-guided inquiry project, is an important part of many high school science classes. These projects teach students to use the scientific method in order to answer a question or solve a problem that is relevant to them. This type of logical thinking, planning, and problem solving is an essential part of any career in science, technology, engineering, and math (STEM), and can also be a powerful tool outside these fields. Despite the importance of carrying out an independent scientific exploration, the science fair project is often met by strong resistance or anxiety from the students.[1] The Reverse Science Fair (RSF) was developed in order to motivate high school students to engage in science by initiating informal conversations with graduate student researchers. The researchers serve as role models who can explain how science is carried out and what excites them to do their research.

Other types of "Flipped-Fairs" and "Reverse Science Fairs" assemble graduate and undergraduate student researchers with K-12 students. In many of these programs, K-12 students interact with the university students as they complete demonstrations or short science experiments. Such programs include Brain Rules, in which neuroscientists teach short lessons to middle school students, and the NSF Division of Environmental Biology's Reverse Science Fair, in which researchers do short science activities with middle school students.[2-6] These programs typically focus on a specific scientific concept and experiment as opposed to showing students how the scientific method is applied to a wide variety of research questions and allowing students to engage in conversations about projects that are of specific interest. In other reversed fair programs, high school students are selected to do research projects with the guidance of graduate or undergraduate mentors or using university laboratories and equipment.[7-9] Such research programs provide in-depth research experiences for students but can only serve a small number of students. In the RSF described here — sponsored by the National Science Foundation and Department of Chemistry at Tufts University and hosted by Medford High School — the focus is shifted away from content-based learning and towards the application of the scientific method. High School students see how different researchers develop a research question through methods such as observation, journal research, and results from previous experiments. The researchers then describe how they designed experiments that lead towards answering these research questions and how data analysis is used to support or reject the hypothesis and may also lead to more questions. This is achieved through presentation and facilitated discussion of a wide variety of current, graduate-level research. High school students of all levels not only learn about science content, but also how different scientists think about their chosen research problems. Through informal conversations, the high school students learn how science is carried out in a research setting, and hear about the personal experiences of graduate student researchers. Because the graduate student researchers are only 5-10 years older than the high school students and come from a wide range of cultural backgrounds, the high school students are able to see themselves in the role of a scientist, thereby connecting to the researcher and their experiences in the laboratory. The high school students are able to gain an appreciation that young people, just like themselves, are doing cutting-edge science locally using the same scientific method that they will use in their science fair projects.

Methodology

The first stage of the RSF was set up analogous to poster sessions at national research conferences. In order to expose high school students to a broad range of scientific research, graduate student researchers from multiple science departments at Tufts University were asked to

volunteer. Departments that have been involved include chemistry, biology, biomedical engineering, and chemical engineering. Graduate student researchers were asked to either bring a poster that they created for a recent presentation or conference, or create a slightly more simplified version. In order to involve as many students as possible in informal conversations with the researchers, the fair was held over the course of two days. Each day, 7-10 researchers displayed their posters around a large multipurpose room for small groups of high school students. Rather than more formal presentations to larger audiences, this setup allowed the students to spread out among the different presenters in groups of about 5-8 high school students. This encouraged back-and-forth dialog between students and scientists, as opposed to a one-way, lecture-style presentation.[10] Before attending the RSF, high school students were given a list of the graduate students' research topics to help them to decide which projects they wanted to learn more about. High school students were also given an interview guide to be filled out during the RSF. This guide is included in the Supporting Information. The questions were designed as a scaffolding strategy to encourage the high school students to initiate two-way conversations with the graduate student researchers. These questions also served as a guide to learn about the scientific method and the process of performing research. The high school students asked questions to the researchers similar to those that would be asked of them about their own projects later in the year. In this way, the students got a preview of the types of questions asked during judging, and an introduction to the judges of their school fair. This was designed to ease the high school students' anxiety about taking on their own science fair projects.

In order to facilitate more personal interactions between the high school students and the researchers, the number of high school students at the event was limited to fewer than 30 students at any given time. 11^{th} and 12^{th} grade science classes were given priority, with other classes signing up for the remaining time slots. Most classes that visited the fair were scheduled for about 30 minutes, and advanced placement classes stayed for around 60 minutes. The students in advanced placement courses were given the additional time as many of them want to study science in college and expressed interest in speaking to as many of the graduate students as possible about their research projects and their college science experiences. Students in a broad range of science classes attended the fair, including standard, honors and AP levels of physics, biology, and chemistry, biotechnology, sheltered English immersion sciences, and special education science classes. In 2015, just over 300 high school students participated in the fair (approximately 50% of Medford High School's 11^{th} and 12^{th} grade students) over the course of two days. High school students at the RSF were encouraged to talk to at least 2-3 graduate student researchers based on the projects that interested them the most.

In a 2007 study, Laursen et al. observed the positive and negative aspects of postsecondary student presentations in a K-12 setting. The authors noted that students did not connect with the presenters as role models due to the short amount of time available to meet with each presenter, as well as difficulty in scheduling classes to view presentations of interest.[10] The RSF seeks to alleviate these problems by giving students a choice of projects to view and maintaining small groups around each poster in order to promote conversations and connections.

After attending the RSF, high school students began their own science fair projects. Once the projects were finished, some were presented at the school-wide science fair. As the second phase of the RSF, the same graduate students researchers were among the judges for the school-wide science fair, swapping the roles of the groups. The judges asked similar questions to those asked of them during the first phase of the RSF, focusing on how the high school students utilized the different parts of the scientific method in their own research projects

Assessment

In order to assess the effectiveness of the RSF on student learning and attitudes towards science and the science fair, surveys were given to the high school students and researchers after the poster presentation in 2015. It has been demonstrated that the disadvantages of using all positive questions in terms of bias are outweighed by the errors that survey takers experience due to confusion between positive and negative statements.[12] Therefore, questions on the surveys and observation forms were written uniformly as positive statements to avoid confusion for those answering the questions. The questionnaires, administered as an online survey, are included in the Supporting Information. For ease of analysis, survey responses of "strongly agree" and "agree" were collapsed into a "positive" category, and the categories of "disagree" and "strongly disagree" were collapsed into a "negative" category. Additionally, observers from Tufts University— a Program & Outreach Specialist, a postdoctoral scholar, and a graduate student (former presenter in 2014)— collected data on student attentiveness and engagement during the event. The lead observer, the Program & Outreach Specialist, who has prior high school teaching experience and Responsible Conduct of Research (RCR) training, discussed the physical cues to note and the observation checklist with the other observers prior to the event. The observation checklist is provided in the Supporting Information.

Results and Discussion

The results of the surveys and observation checklists mirror the data found by Laursen et al. in that high school students showed increased enthusiasm for research and viewed the researchers as relatable.[11] Overall, observers noted that the majority of students (97%) were attentive. The high school students nodded, kept eye-contact, and/or wrote down responses in 29 of the 30 observations recorded during the event. Graduate researchers reported in the survey that most of the students were engaged throughout the RSF and that aspects of the scientific method, such as choosing variables, designing experiments, and data analysis were discussed more than 62% of the time. Interestingly, only 38% of the researchers discussed sources of error within their experiment. This is a topic with which the high school students generally struggle, which may indicate why fewer questions were asked about the topic. In all, 62% of the graduate researchers reported that the questions of the high school students demonstrated an understanding of how the scientific method was connected to their research projects.

The data confirm that discussions focused not only on the scientific process of research, but also on the more personal and behind-the-scenes aspects. 54% of researchers reported that students expressed an interest in their personal experiences with research and 31% said that most of the students asked about college and graduate school. A topic that was not discussed as much as expected was careers in science; only 8% of researchers reported that students asked about careers in science. Focus on this important topic may be increased next year by modifying the guiding questions. A summary table of the graduate student survey data is in Table 1.

Table 1. Summary of Graduate Student Survey Data Collected in October 2015

Survey Statements for Response[a]	Responses, % (N = 13)		
	Negative Response	Neutral Response	Positive Response
The high school students were engaged during my conversations with them.	0%	0%	100%
I was asked relevant questions of where the topic of my research originated.	8%	23%	70%
The high school students indicated interest in completing a science fair project this year.	46%	46%	8%
The students expressed an understanding for how the scientific method is linked to my research.	23%	15%	62%
The high school students were interested in my personal experiences in doing research.	23%	8%	69%
During my conversations, I was asked questions about college and/or graduate school.	46%	23%	31%
The high school students asked me questions about a future career option in science or engineering.	69%	23%	8%

[a] Graduate students also reported that they discussed these topics with high school students (students reporting choice count) variables and controls in your experiment (10); organizing the data (9); measuring data (11); data analysis (8); conclusions drawn from data (13); sources of error (5); future steps in your experiments (13); and significance of research (12).

The survey results from the high school students verified that these students made strong connections between the research projects and the scientific method. 70-80% of students indicated that they agreed or strongly agreed that the experience increased their understanding of the scientific process, including: how to effectively communicate their projects, how to develop an original research question, the importance of representing data in different ways, and how to draw conclusions from data. 76% of the high school students agreed or strongly agreed that they learned the importance of collaboration with others for a research project and 70% agreed or strongly agreed that the RSF taught them more about the scientific method.

The RSF fostered the high school students' interest in doing science. 40% of the high school students reported an increased interest in doing a science fair project and approximately 50% of students expressed an increased interest in doing laboratory research. A summary table of the high school student survey data is in Table 2.

Table 2. Summary of High School Student Survey Data Received in October 2015

Survey Statements for Response[b]	Responses, % (N= 306)		
	Negative Response	Neutral Response	Positive Response
The graduate student conversations were clear and easy to understand.	10%	16%	75%
These conversations taught me more about the scientific method.	10%	20%	70%
Conversations with the graduate students provided me with the opportunity to see the scientific method applied to real research.	3%	10%	87%
The graduate student conversations provided me with examples of effective ways to communicate my science fair project this year.	9%	21%	71%
The conversations I had with the graduate students increased my interest in completing a science fair project this year.	28%	27%	46%
The graduate student conversations helped me to feel more confident in my own ability to perform research for a science fair project.	20%	35%	47%
The conversations I had with the graduate students increased my understanding for how long a research project may take.	5%	9%	86%
These conversations taught me the significance of developing my own question.	11%	22%	66%
The graduate student conversations helped me determine a way to record and organize the data for my future science fair project.	13%	23%	64%
Conversations with the graduate students taught me the significance of visually representing data analysis in a chart, graph, or image.	4%	16%	80%
These conversations provided me with examples of appropriate conclusions to draw from data.	4%	17%	79%
The graduate student conversations taught me about the significance of collaborating in research.	7%	17%	76%
The conversations I had with the graduate students made engineering and science sound exciting and a possible future career option.	19%	24%	57%
Conversations with the graduate students increased my interest in completing laboratory research in the future.	25%	24%	61%
These conversations increased my understanding of the school required to pursue a career in research.	16%	25%	60%

[b] High school students also reported that 88% of them intended to complete a science fair project this year and 12% did not intend to complete a science fair project.

Observers recorded that high school students showed an overall excitement for the RSF. There were several instances of these students, after attending the event, telling their peers about posters they should see during their visit. Teachers reported that students, upon returning to the classroom, wanted to ask a lot of questions about the research topics and researchers. Several high school students, especially in the upper-level classes, asked to return to the fair for the

second half of the class period or during another science class. The following are a few quotes from high school students that were collected through the online survey:

> *"This event was very educational and beneficial. It gave me a glimpse of the type(s) of research I will conduct during the undergrad and graduate years in college."*
>
> *"While some of the material went over my head, I thoroughly enjoyed listening to the presentations. It inspired me to make a better science fair in my senior year."*
>
> *"A lot of the interaction felt forced and felt geared towards AP students. As an honors student it was difficult to understand a lot of the material. Also I did not feel very engaged or encouraged to ask questions to the student speakers."*
>
> *"When speaking to people who don't know much about chemistry, they should try to use simpler vocab so we can try to wrap around the idea of what they are trying to do."*
>
> *"It was an experience that I felt was very important and I believe provides insight on what a science fair should/could look like if enough work and effort is put into it."*
>
> *"The lady who presented the bee project, the one with dirty water, made it accessible to individuals who did not have an extensive background in their field of research, accessibility made it more tangible and understandable for the students and hypothetical layman."*

These quotes illustrate the interest and excitement that the high school students had for the fair and also indicate one of the areas that will need improvement in Reverse Science Fairs in subsequent years. Although students were interested in learning about the projects and the more personal aspects of what research is like, they reported that they were overwhelmed by some of concepts and vocabulary. Researchers sometimes fell into the trap of using jargon and referring to techniques that would not be familiar to someone outside of their field. Some high school students were comfortable enough to ask clarifying questions and learn what these terms meant, but many of the students did not feel comfortable doing this, especially when it meant interrupting the graduate student to ask the question. Some graduate student researchers also tended to get on "auto-pilot" by presenting their projects as they would to someone in their field, contributing to the lack of student comprehension. Modifications to the event that will assist all students to become more involved in the RSF are discussed below.

Benefits for High School Students

Throughout K-12 education most students only experience science in a classroom setting. Despite outside speakers and other resources, K-12 students often picture real-world scientists as people with super-human intellect, wearing white coats and locked in a laboratory.[13] The RSF serves as informal exchange that provides high school students with an opportunity to speak with practicing researchers in a low-pressure situation, so they can view scientists as regular people who have a passion for discovering answers to unsolved questions. Unlike the standard science

fair in which the students are only judged by researchers, the first part of the RSF allowed the high school students to learn from the graduate student researchers without the stress of presenting a project. High school students perceived the graduate students as peers at a similar age range, making them more comfortable in carrying out a conversation. They also recognized that, like the high school students themselves, the graduate students came from diverse cultural backgrounds. By choosing which researchers they wanted to engage in conversation, the high school students were able to find someone with whom they could relate or an area of science that interested them. As stated by one student after attending the RSF:

> "*This event made me much more interested in STEM. It's not all just boring stuff with a bunch of old professors! Young people locally can achieve amazing things by just asking a question and putting themselves out there. This truly reversed my understanding of higher level sciences. They all looked so intrigued and genuinely in love with [their] projects, which rubbed off on me. The students taught me that changing the world with science can start in my own backyard, I just need the confidence to get out there!"*

Once high school students observed that the researchers, like themselves, come from diverse backgrounds and are relatable, the next goal was to provide real-world examples of the scientific method being applied in research. During the presentations of the graduate students' research, high school students learned that the process of asking a question, doing background research, crafting a hypothesis, planning and carrying out an experiment, and drawing conclusions, applies to doing research outside of the school environment. At the 2015 RSF, high school students learned how these processes were applied to everything from discovering cures to diseases to studying honey bee health. In this way, students were given real world models for how the scientific method is applied outside of the classroom.

In addition to learning about how the steps of the scientific method are used, the guiding questions prompted the high school students to ask about what doing real-world research is really like from the perspective of the scientist. They learned that it takes time to develop a question, to design experiments that will have clear results, to finish a project once the initial results show something unexpected or interesting, how new questions invariably stem from initial experiments, and the importance of collaboration with other researchers during the entire process. Speaking with the graduate student researchers also gave the high school students practice discussing something that was, at least initially, very unfamiliar to them. These communication skills are direct practice for the school science fair, when high school students must present their own research to a broad audience who may not be familiar with the subject area that they are presenting.

The RSF also improved high school student experiences at the school-wide science fair later in the year. In previous years, when graduate students were judges for the school fair, they had never been to the high school before and were perceived as complete strangers. The RSF established a rapport between the graduate student researchers and the high school students. The judges were less intimidating, making it less stressful for the high school students to explain their own projects and answer questions. This benefit was confirmed after the school-wide science fair in 2015, when several high school students commented that they recognized some of the judges and felt much more comfortable presenting their own projects having seen the judge present earlier in the year.

Benefits for Graduate Students

Communication is a key aspect of scientific research. Scientists are expected to disseminate their research by writing a publication for a scientific journal or presenting at a professional conference. Since graduate students become very specialized in one particular aspect of their field, it can be difficult for them to present their experiments and results to the general public, or even to other scientists outside of their field. The RSF provides the opportunity for the graduate student researchers to practice presenting their research to a general audience. The RSF challenged them to present their work in a clear, concise and jargon-free manner. Since the researchers had to give multiple poster presentations to different groups throughout the day, they were able to adjust their language as they experienced firsthand what was or was not understood by the high school students, teachers, and administrators. A few of the researchers that presented in 2014 made adjustments prior to returning in 2015. These graduate student researchers, who were studying computational chemistry, stated they previously had difficulty getting the idea across that their research was conducted using computers, as opposed to the wet chemistry more common in high school laboratory experiments. In 2015, these researchers brought a computer and ran a simulation as part of their presentations. This greatly improved the effectiveness of these researchers' presentations.

The RSF also allowed the graduate student researchers to hear how members of the general public perceive their research. Because the RSF was set up as a discussion, the high school students, teachers and administrators were able to ask as many questions as they wanted about the research and its significance. After the RSF, researchers commented that it gave them a chance to reflect on the "big picture" motivation for their research, and how to get others excited about it. Observers at the event noted that graduate students responded to the high school students' excitement with their own enthusiasm as they explained their projects to this new audience. One graduate student remarked that these presentations were great practice for an upcoming poster session at a conference that she was going to attend.

The graduate student researchers reported an additional, unexpected benefit during the RSF. Because volunteers were recruited from multiple departments from Tufts University, the RSF gathered together many researchers who ordinarily have little interaction. These researchers found connections between their research projects that provided them new perspectives, and uncovered potential collaborations with similar projects in other fields.

The RSF also better prepared the graduate student researchers for the high school science fair later in the year. When the graduate students returned to judge the school fair, they already had experience communicating effectively with the high school students and could better evaluate how clearly the high school students convey their experimental design, scientific findings and knowledge of their topic. Furthermore, graduate student researchers indicated that they enjoyed teaching and having discussions with the high school students and expressed that they would like to participate in future outreach programs to continue the relationship.

Benefits for High School Teachers

In order to make science classes relevant to the students, high school teachers must find ways to apply the content to current events and problems.[14] The graduate student researchers at the RSF presented cutting-edge research that applied many of the concepts that are taught at the high school level. These presentations gave the teachers new examples and experimental techniques that they could integrate into their courses. Since the high school students were able to speak directly with the researchers, the students had a personal connection to the research.

Integration of the research thus combined the students' knowledge and their personal discussions with the researchers.

During the RSF, many teachers joined groups of students at each of the posters. The teachers asked questions to increase their own understanding of new research areas, as well as that of the students. The teachers modeled how they themselves are excited to learn new concepts and how to ask questions to gain understanding of an unfamiliar topic. Modeling this behavior for the high school students helped the students to feel more comfortable asking their own questions as they observed that their teachers do not know everything about the project right away. The teachers' excitement also demonstrated to students how important and interesting these projects were, and this enthusiasm transferred to the high school students as they participated in the conversations.

Improvements for Future RSFs

Three improvements will be implemented in order to help make the RSF more conversational and accessible, especially for students that are not in AP and honors classes. First, a meeting will be held with the high school teachers or at least clear communication will be used to provide the volunteer graduate student researchers precise presentation expectations before the Reverse Science Fair. Graduate students will specifically be asked to remove jargon or overcomplicated explanations that will not be understood by the high school students. Past RSF volunteers will be encouraged to share, either at the meeting or another opportunity prior to the poster session, what they have learned about presenting to the high school students, since their own presentations improved noticeably as the event continued. This communication will encourage graduate student researchers to focus less on exact details, and more on their scientific approach and on the daily challenges of doing research. They will also be encouraged to describe personal experiences in the lab, in college or in graduate school, and their future plans, thereby encouraging high school students to ask more about science-related career paths. In this way, even if the high school students do not learn all the details of the project, they will get a sense of how real-world research is performed.

Another way to make the projects easier for students to understand will be to provide simple summaries of the projects and keywords to the high school students and teachers in advance. The high school students will select a few abstracts and/or keywords that seem interesting to them, and will be encouraged to learn about any terms or concepts that are unfamiliar, using the Internet, textbooks, and their teachers as resources. High school students and teachers will then come into the event excited to speak with specific researchers, and ready with questions from their readings.

We also recommend that the observation checklist be revised. "High school students express an understanding of the design of the project" should be reworded as: "High school students express an understanding of specific aspects of the design of the project" and room should be provided for observers to note down any specifics. Additionally, "High school students express a comprehension of how the scientific method is applied to real research" should be removed as it is difficult to evaluate just by observations. A revised observation checklist is provided in the Supporting Information. With the modifications described, the Reverse Science Fair should become even more effective in providing high school students with role models that demonstrate how to pursue science now and in their future endeavors.

Summary

The Reverse Science Fair was successful in engaging high school students and teachers in conversations with graduate researchers in a low-pressure environment. High school students were engaged in conversations with practicing young scientists about current research and the process of doing science. These conversations gave the students a realistic and engaging model for designing their own science fair projects. The graduate student researchers gained experience presenting their projects to a new audience. Due to the two-day schedule of the fair, graduate student researchers were able to practice their presentations multiple times in front of different groups, and learned how to more effectively explain their project to a general audience. High school teachers were exposed to real-world research that connect to their content areas. While it requires some additional preparation beyond traditional science fairs, the Reverse Science Fair is relatively straightforward to implement and provides unique benefits for all participants. Universities and high schools that wish to collaborate in STEM projects should consider using the RSF as an effective way of increasing student engagement and promoting students' perception that they themselves can conduct independent scientific experiments.

ASSOCIATED CONTENT

Supporting Information
The first item is the handout that was given to students during the Reverse Science Fair. Students were expected to use the questions as a guide for initiating conversations with the researchers.

The second item is the questionnaire graduate students were asked to complete as an online survey after their poster presentation at the high school.

The third item is the questionnaire high school students were asked to complete as an online survey after they attended the poster presentation at their high school.

The fourth item is the observation checklist used during the poster session.

The fifth item is a revised version of the observation checklist that would recommend for future use.

The sixth item is the form used by the graduate researchers and other community members when they judge the high school science fair projects.

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