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The "Air Toxics Under the Big Sky" program developed by The University of Montana in 2003 was designed to bring student-based scientific inquiry into the high school classroom, to give students real-world experience in air pollution problems relevant to their communities, and to encourage young people to seek further education and careers in environmental and biomedical sciences *(1)*. As part of the program, high school teachers receive training, curriculum, and air-sampling equipment via workshop participation under the guidance of University of Montana researchers. The teachers then integrated the material into their science classes, enabling students to design research projects, collect data, analyze their results, and finally prove or disprove their original hypotheses. Students complete the scientific process by presenting their findings at various culminating events (e.g., science fairs, school open houses, etc.), thereby gaining experience with communicating scientific findings while strengthening their oral and written communication skills.

The main components of the Air Toxics Under the Big Sky Program have been presented and discussed in previous publications *(2–4)*. Briefly, the program begins early in the school year when a visiting researcher from The University of Montana provides an overview of air pollution issues (both indoor and outdoor) in the western United States and how they link with respiratory diseases such as asthma. This cross-disciplinary presentation on air quality and environmental health sets the stage for students to conduct their own investigations and comparative studies developed during their individual yearlong sampling programs. The classroom is provided with an air sampler along with comprehensive training. The students then use the air sampler to collect data in support of their hypothesis-driven projects throughout the school year.

Students are provided with a questionnaire template designed to stimulate critical thinking about their research design of experiments, identifying potential sources of indoor pollutants and ways of mitigating these sources within their homes or school environments. After data collection (and at the conclusion of the school year), students devise ways to share their findings with others via posters, community reports, or participation in the annual Air Toxics Under the Big Sky Symposium on The University of Montana campus.

When we first reported on the Air Toxics Under the Big Sky program in this *Journal (2)*, the program was in its third year of implementation. Today, the program has evolved dramatically to meet the changing needs of our network of teachers and students. New technologies and instructional strategies have been incorporated in response to the program's growth, with our participating teachers playing a valued role in the design and implementation of materials and strategies. The program has now reached over 1000 students within 14 high schools, two Native tribal colleges, a college-level chemistry class, and two junior high schools located throughout Montana, Idaho, and Alaska. In this article, we provide an update on the program and highlight some of the major components of the program that have been revised and developed to date.

Focus on Indoor Particulate Matter Air Pollution

For the first few years, the Air Toxics Under the Big Sky program had a focus on measuring the levels of volatile organic compounds (VOCs) within and directly outside the homes of the participating students. VOCs are a class of common airborne pollutants and have been shown to cause adverse health effects at elevated levels. Today, for a variety of reasons, we have shifted away from VOCs and focused on a more relevant class of air pollution called $PM_{2.5}$ (particulate matter $\leq 2.5\ \mu m$ in aerodynamic diameter).

Generating VOC data relied heavily on research instrumentation capacity at The University of Montana (i.e., a gas chromatograph-mass spectrometry GC-MS) and took an incredible amount of staff and researcher time to analyze the samples that the students collected. When GC–MS problems occurred, analytical results were not provided to the students in a timely fashion. Sometimes, it would be months before students would see their data. Students are now able to collect samples and see their results in real time with the program's adoption of the TSI DustTrak continuous $PM_{2.5}$ air sampler. This instrument is easy-to-use, gives real-time measurements of $PM_{2.5}$, is programmable, and allows for the easy downloading of data from the instrument onto a computer. Training has also been facilitated through the development of air-sampling training videos focused on the DustTrak air samplers.

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It is also important to note that VOCs are more of an urban-airshed (i.e., Los Angeles, Houston, Atlanta) problem and not as relevant to the outdoor environments of many rural western U.S. communities. However, $PM_{2.5}$ is the major air pollutant in Montana, as well as in other rural communities throughout Idaho and Alaska. Residential woodstoves have been shown to be the predominant source of $PM_{2.5}$ within many regional communities *(5, 6)*, with impacts to both the outdoor and indoor environments. This indoor component is critical, as it is estimated that most people spend as much as 90% of their time indoors on a daily basis. $PM_{2.5}$ also has been linked to many adverse health effects such as respiratory and cardiovascular diseases *(7−9)*, with elevated $PM_{2.5}$ levels correlating directly with higher morbidity and mortality rates *(10, 11)*. Incorporating the continuous $PM_{2.5}$ monitor into the program has allowed the students to focus on community-specific air quality issues of importance within their respective communities and generate data quickly and efficiently.

Using the Program To Measure Different Types of Indoor Air Pollutants

Although the Air Toxics program has in the past focused on educating students about VOCs and $PM_{2.5}$, there is often an interest within the classrooms to measure (and therefore become educated about) other types of air pollutants. For example, over the past few years, we have expanded the program to sample for carbon monoxide (CO) and carbon dioxide (CO_2). CO is of interest (especially during the winter months) as it has all too often been linked with asphyxiation deaths in enclosed areas. In one of the schools, students used a portable CO monitor to determine the levels present within their homes, providing important information to not only the students, but to their families. In another school, a CO_2 instrument has been used to address indoor ventilation issues within the school and has been used in support of global warming lesson plans within the classroom. In the future, we plan to purchase radon kits to distribute to classes, providing students with the opportunity to test for radon levels, while also learning about the harmful impacts radon can have at elevated levels within their homes.

Program Expansion into Rural, Underserved Areas

The program began in Missoula, the second largest city in Montana (population of ∼80,000). One thing that has become evident as the Air Toxics Under the Big Sky program has evolved is that the program is a natural fit for those with schools located in rural and underserved communities. This is evidenced by our expansion into smaller communities throughout western Montana (i.e., Whitefish with less than 10,000 inhabitants; Libby and Corvallis with less than 5000 inhabitants), the Nez Perce Reservation (both Lapwai and Kamiah with populations of less than 1000), and rural communities in Alaska. In fact, some of the communities in Alaska have populations of less than 500 inhabitants. Not only does the program allow for students to research air pollution issues of importance to their communities (i.e., $PM_{2.5}$ woodsmoke), we feel that this program provides educational opportunities to these underserved schools and communities that might not otherwise be possible because of their geographic location and demographics.

Expansion into Different Grades, Including Middle Schools and a College-Level Chemistry Class

The Air Toxics Under the Big Sky program has demonstrated that certain features of the program are effective for integrating science learning with community engagement outside of its original conceptual framework as a high school science module. On the basis of positive evaluation results and teacher input, materials have been modified to correlate with other courses (e.g., environmental science and biology) and have been successfully integrated. The program has traditionally been focused on educating chemistry students in grades 10−12. However, our program has recently expanded into different grade levels, including two middle schools in Alaska, as well as a college-level chemistry class at The University of Montana.

Middle Schools

New curriculum has been developed for use at the middle-school level. The strategy is to have the class work as a whole while conducting a study of indoor air quality (e.g., "Which room in the school has the lowest levels of $PM_{2.5}$?"). There is much more guidance and contact time with the teacher to ensure that these younger students are walked through the steps of the scientific process early on in their school careers. Purposeful guidance from the teacher increases the likelihood that these younger students will meet with success as they experience the scientific process and also ensures that the air sampling equipment will be properly used and safeguarded.

College-Level Chemistry Class

The Air Toxics Under the Big Sky program was introduced into a University of Montana nonmajor chemistry class during the summer of 2009. The University of Montana, as many other colleges, offers a chemistry course designed for students who have never taken a university-level science class. Historically, this class has been taught in the traditional manner with separate lecture and laboratory sessions. The laboratory session included routine labs where students simply go through a set of instructions and do some preset calculations. These students have had little opportunity to experience scientific research: the process of asking a question and seeking out their own conclusions.

Within the college class, pairs of students worked together to formulate their research question, hypothesis, and experimental method and then implemented their sampling experiments in their homes (including university dorm rooms) and workplaces (daycares, elementary schools, malls, restaurants, and bars). After a week of performing their experiments, students met to discuss their results, as well as any experimental problems that may have occurred. They were then allowed time to repeat their experiments. Students later formerly reported their results and had the opportunity to explain and decipher their experimental data, explain variables and mishaps in their data collection, and draw conclusions from their results on the strength of their original hypothesis.

An internal qualitative assessment was given to the students after their two-week experience in the guided-inquiry lab. Consistent with the feedback from the high-school program, college students commented that they enjoyed being part of an experimental process of collecting data with a real scientific instrument and having the opportunity to study a "real-world" environmental problem in their community. Students learned the importance of keeping track of experimental details, controls, taking careful notes, and defining a hypothesis. Also many stated that after performing their experiments they had new questions or variables they would like to test. This type of class has great potential to evolve into a college-level service-learning course whereby student groups could work with community organizations or private residences in testing air quality.

Using the Air Toxics Under the Big Sky Program To Investigate Real-World Issues

We have encouraged the students to utilize the program within their schools to investigate air pollution issues specific to their homes, schools, and communities. In addition to the "traditional" yearlong programs within the schools, some students have engaged in more controlled research projects in collaboration with The University of Montana and external funding agencies. Following are two examples of these more applied research applications.

Nez Perce Woodstove Changeout Study

During the winters of 2006–2007, 2007–2008, and 2008–2009, a woodstove changeout program was conducted in Kamiah and Lapwai, Idaho on the Nez Perce Reservation. In addition to the replacement of old stoves with EPA-certified stoves, air sampling was conducted within 16 homes to measure the improvement in air quality before and after the changeouts on a home-by-home basis. A second objective of this project was to educate participating households on the health effects of being exposed to smoke from wood burning stoves and how to operate the new stoves most efficiently.

Using air samplers and protocols provided by The University of Montana, students collected $PM_{2.5}$ samples within the common area (rooms where the stoves were located) of 16 homes both before and after the installation of the cleaner burning EPA-certified stoves. Results of the program showed that there was an overall average of 52% reduction in indoor $PM_{2.5}$ (including a 60% reduction in $PM_{2.5}$ spikes) when the old stoves were replaced with EP-certified stoves. This project was carried out by students from Kamiah high school and from the Distance Learning Center (satellite campus of the Northwest Indian College in Bellingham, WA) in collaboration with the Nez Perce Tribe's Environmental Restoration and Waste Management (ERWM) Air Quality Program. Funding from the program was provided by Region 10 of the Environmental Protection Agency.

Residential Air Filtration Unit Study

During the winters of 2006–2007 and 2007–2008, students from multiple high schools throughout western Montana participated in a project to determine the effectiveness of 3M air filtration units in homes. Student researchers identified homes for sample collection, and followed a sampling protocol designed by both The University of Montana and 3M Corporation scientists. $PM_{2.5}$ samples were collected before and after a filtration unit was installed within homes. Final results of the program showed that using a filtration unit within a residential setting can have a dramatic impact on improving indoor air quality, reducing indoor $PM_{2.5}$ levels by 50–75%. This program (which was partially funded by the 3M Corporation) turned out to be an effective strategy for educating students on indoor air quality and measures that can be taken to improve air quality within their homes.

Development of New Products

As the Air Toxics Under the Big Sky program has evolved, we have had the opportunity to observe what components of the program work, and more importantly, what does not work within the schools. Much of our effort has been geared toward developing new products or services that enhance and complement the existing program. These new products include air sampling training videos and new curriculum modules focused on air quality and respiratory health.

Sampling Videos

At the beginning of each school year, air sampler training is provided within the schools. The goal of this training is to educate the students on how to operate the air samplers, where to collect samples, how to calibrate the air sampler, maintenance activities, and so forth. Frequently after the training, students forget what was presented. In an effort to provide supplemental training, air-sampling videos have been developed and posted on the Web *(12)*.[1] These videos display step-by-step procedures, showing them everything they need to know to successfully collect air samples as part of their program.

New Curriculum Modules Focused on Air Quality and Respiratory Health

Our team developed a curriculum that supports the Air Toxics Under the Big Sky program within the schools. The program curriculum consists of 10 lesson plans (with accompanying PowerPoint presentations, overhead transparencies, interactive games, and student handouts) specifically designed to incorporate the scientific process into existing high school science courses within the schools.[2] Following are the 10 modules that have been developed to date:

Lesson 1: Particulate Matter Matters
Lesson 2: Air Quality and Respiratory Health
Lesson 3: Understanding the Respiratory System
Lesson 4: Regional Air Quality Issues
Lesson 5: Operating Air Monitoring Equipment
Lesson 6: Conducting a Successful Research Project
Lesson 7: Using GPS/GIS in Research Projects
Lesson 8: Small Scale Chemistry Lab: Simulations of Acid Deposition
Lesson 9: Sharing Findings with Others
Lesson 10: Identifying Interventions

The curriculum introduces students to new scientific equipment and technologies that would not normally be available to them as part of their secondary science classes and labs. For the middle school, we have adapted some of our modules to include a board game where students solve human health and indoor air quality mysteries, a scavenger hunt to introduce GPS–GIS, and electronic games to review content.

Virtual and Alternative Symposia

Implementing an annual symposium as the culminating event has proved to be a critical and valuable component of the program.

It has been our experience that the final step of the scientific process—sharing research findings with others—is often overlooked. Instituting a capstone experience as an integral part of their yearlong research project provides a strong incentive for junior researchers to hone their research methods as well as communication skills. For this program, the signature event takes place on The University of Montana campus every May, bringing together students, teachers, community members, public officials, faculty, and researchers in one of the largest lecture halls on campus.

As the program has expanded to wider geographical sites, it has become more difficult to hold a single, synchronous symposium to encompass all the participating schools. Once again our strong working relationship with the schools has allowed us to expand by identifying alternative, and more local, events: science fairs, school assemblies, open houses, poster displays, community health fairs, and virtual symposia using remote learning capabilities. This latter option was piloted in May 2009, using videoconferencing technology interface to connect The University of Montana researchers with students from high schools in Hoonah and Wasilla, Alaska.

Researchers in the Schools

A campus-to-community project, known as "Researchers in the Schools", integrates well with the Air Toxics Under the Big Sky program and serves as another example of our evolution *(13)*. To present a bigger picture of the various approaches to a problem such as air pollution, researchers (faculty, postdocs, and graduate students) from different disciplines volunteer to go into the schools and present lectures on areas of research being conducted at The University of Montana. An environmental epidemiologist might visit one of the high schools to talk about the health effects of air pollution exposure, whereas an immunologist can address how pollutants impact the body at the cellular level. The University of Montana's Researchers in the Schools program is now open to educators throughout Montana, Idaho, and Alaska, covering topics from cell structure to systems of the body. The goals of this program are to (i) familiarize students with current scientific research, (ii) demonstrate how research relates to current problems, and (iii) provide role models and mentors for our youth.

Conclusion

A growing number of outreach programs effectively bridge university research initiatives into broader social context by engaging high school students in authentic scientific research *(14–17)*. These programs directly benefit science learning in the participating schools and can extend scientific research into community settings. The Air Toxics Under the Big Sky program continues to evolve as more schools from different states join the program. However, the program has maintained its four components of project based learning (PBL) *(18)*. First, the Air Toxics program focuses on a real and important environmental health concern (i.e., reducing levels of $PM_{2.5}$ in the western United States). Second, students have an opportunity to collaborate on projects in research teams and interact with university researchers, environmental-health professionals, and public-policy officials. Third, the program has created new teaching materials and training modules. This includes instrument training videos, environmental lesson plans, experiments, and professional development workshops for science teachers. In the future, data set lessons on graphing techniques and analysis of "real" experimental data will also be available as an option for schools (in lieu of purchasing a $PM_{2.5}$ air sampler). The final component of the PBL model is the use of cognitive tools to support the process of research and promote inquiry. Students are doing science and interpreting the results in the context of their indoor living environment, which tends to reinforce learning by making it personally meaningful.

The Air Toxics Under the Big Sky program has made an impact by using a collaborative approach to studying subject matter pertinent and tangible to *all* students, not just those who stand out and excel as science super-achievers. Environmental health intersects many different scientific fields: chemistry, earth science, epidemiology, genetics, botany, and health. This means young students are exposed to a wide range of possible science career paths to help them identify their own interests and guide their transition from high school to college. As the program expands further, we will continue to modify the program to meet the needs of the network of teachers and students. We will also encourage the students to take the next step in the program by translating findings back to the community. We strongly feel that the results of the mini-research projects conducted by the students can influence change within their communities, thereby improving overall community health.

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Notes

1. The videos have been posted on both YouTube and TeacherTube.
2. The authors are in the process of dedicating a server where teachers can download pdfs of the modules and other resources. The URL will be available on the home page listed in ref *(1)*.

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