The Big Sky Inside

Measuring rural indoor air quality and its impact on the community

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Science taught through authentic and relevant scientific investigation provides a valuable and long-lasting learning experience for students (Donovan and Bransford 2005; Wilkinson 2003; Zaikowski and Lichtman 2007). When students pose their own research questions and collect the data needed to answer them, they discover firsthand how to directly apply concepts covered in the classroom. Many science educators seek models to engage students in relevant scientific research that use local resources and link students to their communities (Sedlacek et al. 2005; Stone 2007; Zaikowski and Lichtman 2007; Tompkins 2005; Walters et al. 1998).

To address this need, the University of Montana (UM)–Missoula has implemented a problem-based program in which students perform scientific research focused on indoor air pollution. The Air Toxics Under the Big Sky program (Jones et al. 2007; Adams et al. 2008; Ward et al. 2008) provides a community-based framework for understanding the complex relationship between poor air quality and respiratory health outcomes by teaching students chemical, physical, and health concepts in the classroom setting. In addition to designing controlled experiments, students are guided through the process for conducting independent research projects to explore a real-world issue in their communities.

Program overview

Developed in 2003, the Air Toxics Under the Big Sky program is a collaborative endeavor among high school science teachers and scientists at UM's Center for Environmental Health Sciences (CEHS) and Department of Chemistry. It began when a local chemistry teacher sought the assistance of UM researchers to address a student's curiosity about air toxics.

Through the collaboration, high school science students are guided through independent research projects that involve rural indoor air quality—an environmental "problem" in their communities. As word of the program has spread, so has interest in participation. One key criterion for accepting teachers is whether air pollution levels in their communities persistently exceed the national ambient air quality standards set by the Environmental Protection Agency (EPA) (see "About particulate matter," p. 42). To date, over 400 students across seven counties, two states, and two American Indian

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reservations have completed the curriculum and conducted indoor air quality research that has resulted in an overall heightened awareness of its impact on our health.

DustTraks

Each school participating in the program is issued a DustTrak, a portable, laser photometer with real-time mass concentration readout and data-logging capability. These units are battery operated and can record data over a 24-hour period at a rate of 1 reading/min. Student researchers collect indoor particulate matter ($PM_{2.5}$) measurements, download the data to a computer, and immediately analyze and interpret their data by viewing average, maximum, and minimum concentrations. Students use these DustTraks to compile and analyze the data used in their independent research projects. The results help them address the "problem" of indoor air quality in this problem-based project.

Although DustTraks cost a little over $5,000, we have not found the purchase price to be a stumbling block, as both UM researchers and participating teachers have been successful in securing funding from private foundations (see "Acknowledgments," p. 45). It should also be noted that the DustTrak requires no additional expenses, such as shipping samples off for lab processing. If cost does at some point become a consideration, program participants can use databases of $PM_{2.5}$ levels recorded by others in the program. In addition, teachers have shared the equipment with science classrooms at other schools, which enhances the collaborative, integrative nature of the research program.

Teacher workshops

The program takes a systematic approach to professional development as a way to expose teachers to inquiry-based learning and to familiarize them with curriculum, equipment, and auxiliary materials. Program teachers are invited to attend two summer workshops at UM. In these workshops, CEHS researchers provide information regarding indoor air quality and its relation to respiratory health and model the integration of the program into the regular chemistry curriculum. Teachers also receive hands-on experience with smallscale chemistry and geographic positioning system labs. Both workshops include assessment sessions in which teachers discuss various assessment tools—both formative and summative—that best match program objectives.

Following the summer workshop, the academic year begins with a program description that is sent from the teacher to students' homes. This is followed by comprehensive training provided by UM researchers within the schools on how to operate the DustTrak. Students are provided with step-by-step protocols not only on how to collect samples but also on where to collect samples, how to clean the instrument, and how to zero/calibrate the instrument. All of the quality assurance and quality control steps are included in the protocols to ensure that students collect high-quality data following UM-approved methodologies.

In the community

Families continue to be involved in the program throughout the year as their children bring home the DustTrak, review the protocol, monitor indoor air quality, complete activity sheets, answer questions, and lead discussions. Since the ultimate goal of the Air Toxics Under the Big Sky program is to improve respiratory health, students are encouraged to share their findings with members of their communities. This is accomplished at the end of the academic year, when students present their results at the annual UM symposium. At this event, students from multiple schools present their research before their peers, teachers, university scientists, industrial representatives, and members of county, state, and federal government. Crews from the local television stations are on hand to film the event for later airing and broader community access.

Although the program's purposeful inclusion of the community has proved to be a successful way to address our overarching mission, it has also been our experience that individual schools have devised innovative and effective ways to further augment the public take-home message for their communities. A few examples are provided in the "Case studies" section.

Student safety

Safety standards for this project are set through the school and UM Institutional Review Board processes to clarify the aims of the research project and minimize any risk to participants. It is important to note that the DustTrak does not emit a laser light during operation. The light-scattering laser photometer is enclosed inside the DustTrak, so there is no risk of exposure to the laser. See "Safety notes" for more on student safety and teacher responsibility.

Case studies

The following case studies provide examples of independent student research projects. The results of these projects were shared with the class, school, and community through the UM symposium.

Case study 1: Home heating systems compared

One student research group sampled three different heat sources in the home—pellet, propane, and woodstoves—to determine which produced higher levels of $PM_{2.5}$. The experimental controls included sampling at varying distances from the heating source and controlling for time and temperature. Findings supported the group's hypothesis that, of the three, the propane stove produced the least amount of $PM_{2.5}$. This proved to be an effective learning experience for the students regarding indoor air

About particulate matter.

Due to their topographic characteristics, communities throughout Montana and Idaho often experience elevated concentrations of particulate matter ($PM_{2.5}$) during the winter and early spring as a result of temperature changes and residential woodstove use. $PM_{2.5}$ refers to airborne particles that are ≤ 2.5 microns in aerodynamic diameter and therefore most likely to pass into the lungs and potentially cause respiratory problems. Additionally, a new trend of elevated $PM_{2.5}$ levels in summer months has been observed over the last decade due to the growing frequency of catastrophic forest fires.

Although $PM_{2.5}$ measurements are routinely made in the outdoor environment, little information exists on the concentrations of indoor $PM_{2.5}$ in this region of the country during these seasonal periods. The information that does exist shows that elevated concentrations of $PM_{2.5}$ can lead to adverse health effects (Dockery et al. 1993; Heath, Pope, and Thun 1995; Pope, Dockery, and Schwartz 1995; Pope et al. 1995; Schwartz, Dockery, and Neas 1996; Laden et al. 2000; Pope 2000). However, these studies have mostly been conducted in urban settings. The Air Toxics Under the Big Sky program is unique in that indoor air data is evaluated in rural communities with the hope of creating changes that will improve respiratory health. The major focus has been in rural areas for two reasons: The majority of communities in Idaho and Montana are rural communities, and there has been little research accomplished in monitoring levels of $PM_{2.5}$ in these communities.

Safety notes.

CAUTION

Any science activities requiring work out of the school instructional site (e.g., science classroom)—such as the home or another classroom—assigned by the teacher carries a "duty of care" legal responsibility. The teacher should provide written communication about the activity and possible safety issues or concerns, along with proper operation protocols for the supervising adult (i.e., parent, another teacher). If students are hurt while carrying out an activity that proves to be unsafe, the teacher may be liable should there be legal implications. For example, if a student is burned while working near a woodstove in carrying out the science activity, this is not only a safety issue but also a legal one.

quality, as they began to understand how their data were influenced by other factors they had not considered before designing their research projects (e.g., small sample size, age of the tested homes).

The class devised ways to let area residents learn about indoor air quality through multiple newspaper features and an evening open house at which students presented their research to their families and other residents of the rural community. A side benefit of the students' efforts was that a prominent environmental health scientist from Mount Sinai Hospital in New York learned of their studies and made a special visit to their class, where he discussed recent research concerning asbestos-related diseases.

Case study 2: School heating, venting, and air conditioning practices improved

Another group of student researchers decided to investigate their school's wood and metal shop to determine if it contained high $PM_{2.5}$ concentrations and if levels varied throughout the day. Air samplers were mounted at various locations and heights around the shop to measure $PM_{2.5}$ concentrations in different areas. The units indicated where concentrations were highest, when those levels dropped during less active hours of the day, as well as when filters for the room's filtration system were cleaned or replaced. The school principal acted on this information to institute a more rigorous maintenance schedule for changing the school shop's air filters.

Case study 3: Air filtration in homes

Multiple groups of students enrolled in two different schools studied the efficiency of a commercial air filter in households and whether it decreased $PM_{2.5}$ concentration levels in the home over a 24-hour period. Their collected data suggested that a commercial air filter decreased $PM_{2.5}$ concentrations by up to 50% in the household. From their studies, they also concluded that including more sampling days, varying the location of the air filter, and testing homes with different heating sources would produce more robust data for longer-term analysis.

Peers, parents, teachers, community members, and school officials learned of this research when students presented their results as part of the senior project program at each school and at the Annual Northwest Regional High School Science Symposium in Utah.

Case study 4: Air quality comparisons in school

Another student research group studied the amount of $PM_{2.5}$ in the air inside various school classrooms by monitoring the $PM_{2.5}$ concentrations over a 24-hour period in a chemistry lab, a general science classroom, two math rooms, and two history rooms. While students did measure for $PM_{2.5}$ indoors, they compared their results with EPA standards for outdoor or "ambient" air because there is no indoor $PM_{2.5}$ standard. Students found that concentrations in all the rooms did not exceed EPA outdoor standards and that the ventilation in the school was adequate.

Case study 5: Asthma and wood smoke on the Nez Perce reservation

Although schools currently participating in the Air Toxics Under the Big Sky program measure particulates using DustTraks, the program initially sampled for volatile organic compounds (VOCs). In one of these original projects, students from two high schools on the Nez Perce American Indian Reservation conducted sampling for VOCs within their homes throughout the school year. As a result, two articles summarizing their involvement with the program were published in the tribal newspaper that is distributed throughout the community of 1,800 citizens. One student group presented their results to a tribal panel and others presented at an open poster session for the community in their school. A key student research leader with the project gave a presentation to 200 elementary students on air quality in their homes. In these earlier projects, VOC analysis proved to be both expensive and prohibitive, so the program switched to using the more "user-friendly" DustTrak unit to measure particulates instead of VOCs.

These case studies serve as clear examples of how students can investigate local air-quality issues and generate scientifically sound data that educate and impact the community.

Student response

When students present their data at the end-of-the-year symposium, they describe how they problem solved to overcome any challenges encountered as their research progressed. Many discovered their hypotheses were disproved due to the presence of multiple variables or unexpected outcomes, which led them to collect more data by repeating the experiment or modifying their hypothesis. These are the same thought processes scientists must use in a research environment: designing, implementing, and interpreting their experimental results.

Depending on class size, students usually work collaboratively in teams of anywhere from two to six people, which requires good interpersonal skills to schedule and organize tasks and effectively communicate the results through posters or oral presentations. Student comments have shown that they appreciate the opportunity to conduct relevant research for themselves and to go through the process of problem solving, correcting mistakes, processing their results, and drawing a conclusion (see "Student comments," p. 44).

Program evaluation

The effectiveness of the Air Toxics Under the Big Sky program was tested through a careful comparison study. The treatment group of 130 students participating in the program was statistically matched to a comparison group of 148 students that did not participate. Students serving as the treatment group were enrolled in classes taught by teachers who had been trained in the program workshops. To serve as the comparison group, these treatment teachers chose the students of colleagues teaching science courses at similar levels in their respective schools. Students in both groups were from five high schools in northwestern Montana and all completed the same end-of-program content assessment.

The treatment students scored significantly higher (65% correct) on the assessment than the comparison students (43% correct). They were also much more knowledgeable about air pollution and respiratory health and were better able to deal with research issues such as outlier data and the importance of keeping field notes.

Additionally, treatment students provided feedback about their experience in the program at the conclusion of the symposium. Eighty-eight percent indicated that their time during the symposium was either good or excellent. Forty-six percent of participating students expressed an "extreme interest" in science, and of these, almost half reported that the experience made them more interested in science. Similarly, about 40% of students indicated that they were "extremely interested" in a science career and of these, almost two-thirds said that the program made them more interested in becoming a scientist some day.

Evaluation results provide strong evidence that the program increases and sustains interest in science and science careers and results in knowledge gains. In particular, students acquire valuable content knowledge to which they otherwise would not typically have access. The program's strong research emphasis also meets Montana state standards with required components, such as generating a hypothesis, data gathering and analysis, graphical and mathematical processes, scientific investigation, and the review and defending of results (see "Addressing the Standards").

Teachers who are interested in conducting an indoor air quality project may contact the CEHS at the University of Montana to find out more about initiating such programs in their classes.

Conclusion

The Air Toxics Under the Big Sky program is an effective way to educate students on the importance of good air quality and the health impacts of exposure to poor air quality. One of the strongest outcomes of this program is that students are encouraged to design controlled experiments and test their own hypotheses while investigating air pollution issues of interest to them. Finally, in addition to being an outreach and education project, the Air Toxics Under the Big Sky program generates high-quality technical data that are being used to investigate indoor air quality issues—placing student research in the greater scientific world. ■

Student research assessment milestones.

First quarter: Students turn in the question, hypothesis, and list of variables for their indoor air quality research project. The instructor reviews and provides any necessary guidance.

Question examples: Does the heating system of the house affect its air quality? How does the age of the house relate to $PM_{2.5}$ levels? What classroom in the school contains the most $PM_{2.5}$? Does the type of flooring material affect the amount of $PM_{2.5}$ found in the building? Does it make a difference in air quality when using an EPA-certified woodstove versus a noncertified model?

Second quarter: Students turn in a written report discussing the data collected to date. The data is reviewed by fellow students who provide suggestions to enrich the research.

Third quarter: Students complete their data collection and provide the teacher with a written report.

Fourth quarter: Students present their findings via PowerPoint presentations or posters to community members at the school or at the annual symposium. The symposium judges' scores are averaged into students' chemistry grades.

Visit *www.nsta.org/highschool/connections.aspx* for UM judges' scoring rubrics.

Student comments.

The following student comments are from end-of-the-year evaluations:

- "The most important thing I learned is that there are many possibilities for projects, but you need to think the experiment all the way through to be successful."
- "The most important thing I learned as a result of giving my presentation is that communicating results is a key skill in science."
- "I learned how important—and fun—science is and that projects like these have a huge impact within the science field and possibly impact the world."
- "The thing that had the greatest impact on me is that all the people who are interested and work in the fields of chemistry and biology seem to love it."
- "I learned that it is okay if your hypothesis is wrong; it actually provides valuable information and the opportunity for further investigation."

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Addressing the Standards.

Montana's science standards are highly consistent with the *National Science Education Standards* (NRC 1996) and *Benchmarks for Science Literacy* (AAAS 1993), with most containing the phrase "through the inquiry process." For example, one standard reads: "Students, through the inquiry process, demonstrate the ability to design, conduct, evaluate, and communicate results and reasonable conclusions of scientific investigations." This focus on inquiry-based learning requires activities specifically designed to meet that requirement. As one participating teacher reflected, "A major goal in my chemistry class is for students to learn the scientific process. I take many steps to achieve this goal, but the Air Toxics Under the Big Sky program takes kids from start to finish in an open-ended manner in a research project of their own design. Consequently, they learn the scientific process by doing it."

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References

Adams, E., T. Ward, D. Vanek, N. Marra, C. Noonan, G. Smith, D. Jones, M. Henthorn, and J. Striebel. 2008. Air Toxics Under The Big Sky: A real-world investigation to engage high school science students. *Journal of Chemical Education* 85 (22): 221–224.

American Association for the Advancement of Science (AAAS). *Benchmarks for science literacy.* New York: Oxford University Press.

Dockery, D.W., C.A. Pope III, X. Xu, J.D. Spengler, J.H. Ware, E.F. Martha, B.G. Ferris Jr., and F.E. Speizer. 1993. An association between air pollution and mortality in six U.S. cities. *New England Journal of Medicine* 329: 1753–1759.

Donovan, M.S., and J.D. Bransford, eds. 2005. *How students learn: Science in the classroom.* Washington, DC: National Academies Press.

Heath Jr., C.W., C.A. Pope III, and M.J. Thun. 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *American Journal of Respiratory and Critical Care Medicine* 151 (3): 669–674.

Jones, D., T. Ward., D. Vanek, N. Marra, C. Noonan, G. Smith, and A. Adams. 2007. Air Toxics Under The Big Sky: A high school science teaching tool. *Science Education and Civic Engagement: An International Journal* 1 (2): 51–55.

Laden, F., L.M. Neas, D.W. Dockery, and J. Schwartz. 2000. Association of fine particulate matter from different sources with daily mortality in six U.S. cities. *Environmental Health Perspectives* 108 (10): 941–946.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academy Press.

Pope III, C.A. 2000. Epidemiology of fine particulate air pollution and human health: Biologic mechanisms and who's at risk? *Environmental Health Perspectives* 108 (4): 713–723.

Pope III, C.A., D.W. Dockery, and J. Schwartz. 1995. Review of epidemiological evidence of health effects of particulate air pollution. *Inhalation Toxicology* 7: 1–18.

Pope III, C.A., M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath, Jr. 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *American Journal of Respiratory and Critical Care Medicine* 151: 669–674.

Schwartz, J., D.W. Dockery, and L.M. Neas. 1996. Is daily mortality associated specifically with fine particles? *Journal of the Air and Waste Management Association* 46: 927–939.

Sedlacek, N., J.A. Young, C. Acharya, D. Botta, and T.M. Burbacher. 2005. Linking the classroom to the community. *The Science Teacher* 72 (4): 44–45.

Stone, J. 2007. Accomplishing multiple goals through community connections. *The Science Teacher* 74(4): 28–32.

Tompkins, L.J. 2005. A case for community-based education. *The Science Teacher* 72 (4): 34–36.

Walters, E.A., T. Micciulla, A. Parada, and N. Pellegrino. 1998. Environmental activism, researching trash alternatives for New York City. *The Science Teacher* 65 (5): 48–49.

Ward, T.J., D. Vanek, N. Marra, A. Holian, E. Adams, D. Jones, and R. Knuth. 2008. The big sky model: A regional collaboration for participatory research on environmental health in the rural West. *Journal of Higher Education Outreach & Engagement* 12 (3): 103–115.

Wilkinson, S.L. 2003. Creative boost: High school and college teachers empower students to do consequential science projects. *Chemical and Engineering News* 81 (38): 34–35.

Zaikowski, L., and P. Lichtman. 2007. Environmental research put into action. *The Science Teacher* 74 (4): 47–51.