Engaging Students in Atmospheric Science: A University-High School Collaboration in British Columbia, Canada

K.E. Sinclair[1,2], S.J. Marshall[1,3]

ABSTRACT

Five high schools in British Columbia, Canada, participated in an atmospheric sciences project during the winter of 2006-07 established by researchers at the University of Calgary. Precipitation gauges and temperature and relative humidity probes were installed at each school and students were asked to collect a water sample each day that precipitation accumulated. These samples were used to trace the evolution of stable water isotopes across southwestern Canada. Researchers visited schools to talk about water resources and climate change, and data were collated and given to teachers to use in an atmospheric science project. The participatory nature of this project gave students exposure to data collection and basic analytical techniques used in atmospheric sciences. This was a first attempt at collaboration between our research group and secondary schools, and we point out a number of issues that arose in our study with respect to a successful two-way engagement between researchers and students. These include school engagement, the geographic distribution of the participating schools, the time span of the project, and the time available to schools. There are also a number of data quality considerations, but we were successful overall in acquiring a unique, high-quality dataset that satisfies our research objectives.

INTRODUCTION

While it is common for research scientists to involve undergraduate students in data collection and analysis (e.g. Woltemande and Stanitski-Martin, 2002), it is comparatively rare for the university research community to extend their activities into high schools, despite the obvious advantages associated with students engaging in 'hands on' scientific activities (Ledley et al., 2003). Part of the difficulty in collaborating with high schools is due to the technical nature of most physically-based research. The logistics associated with measuring environmental variables are often too time-consuming and specialized to be of use to high school classes, and scientific research results are typically unavailable until many months, or even years, after the initial data collection. This makes it difficult to fully engage high school students and provide a rewarding return on their time investment. In addition, from a researcher's standpoint, the amount of time and training needed to set up a project in high schools often outweighs the value of the data collected.

Despite these limitations, researchers who have undertaken collaborative projects with high schools have found the process personally rewarding and valuable to their research (e.g. Hobson et al., 1999; Denzais et al., 2002; Klene et al., 2002; Calhoun et al., 2003). From an educational perspective, research projects expose students to scientific theory and practice, including different methods of data measurement and analysis, and collaboration between secondary schools and universities can result in successful learning initiatives (Morse and Sabelli, 1991; Jackson et al., 1997). However, as Ledley et al. (2003) argue, the main requirement for a successful student-teacher-scientist partnership is that all involved benefit from the collaboration.

This paper describes a university-high school collaboration that was designed to introduce students to techniques used in atmospheric sciences. As researchers at the University of Calgary, we needed to find a way to collect rain and snow samples from winter storm systems that traverse southern British Columbia from the Pacific Coast to the Rocky Mountains. This required the almost simultaneous collection of samples across an 800 km transect in southwestern Canada (Figure 1). These samples are being used in a research project that considers the effect of air mass trajectories and weather conditions on stable water isotopes in winter snowpacks in the Rocky Mountains. This is of interest because the isotopic character of the snowpack reflects the sources and pathways of moisture, and snowpack isotopes can be decoded to reveal the dominant weather systems and the meteorological controls of moisture for the region. Predictions of how these prevailing weather systems might be altered by climate change can then be translated to impacts for the mountain snowpack, glacier mass balance, and water resources in western Canada. By working with high schools to collect these samples, we were able to gather a unique and valuable dataset to further these research objectives.

We aimed to develop a strong two-way engagement and exchange of information with the teachers and students participating in this study. Simmons (2001) researched the extent to which urban high school students understand environmental issues and found that, while students had heard of most major issues, their understanding was shallow. Furthermore, Agelidou et al. (2001) found that junior high school students represented the relationships between water and contemporary society in a simplistic way, had a limited capability to construct causal relationships, and struggled to comprehend the complex environmental problems linked to water. In an era when climate change and water resource issues feature prominently in mainstream media, it is crucial that these multi-faceted issues are addressed and taught effectively in the high school environment (McBean and

[1] University of Calgary, Department of Geography, 2500 University Drive NW, Calgary, AB T2N1N4 Canada
[2] Now at GNS Science, 1 Fairway Drive, Lower Hutt 5010, Wellington, New Zealand; k.sinclair@gns.cr.nz
[3] shawn.marshall@ucalgary.ca

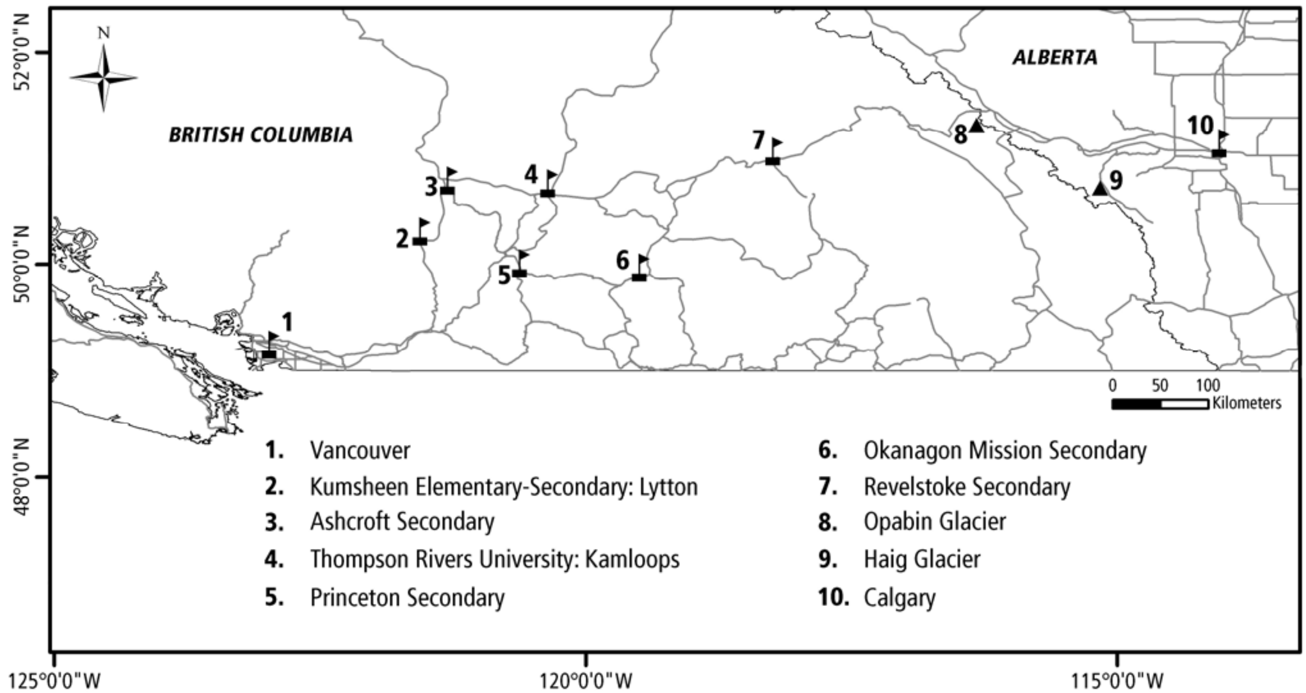

FIGURE 1. Map showing the geographical distribution of schools participating in this study. The locations of alpine field sites (the Opabin and Haig Glaciers) and the City of Calgary are also indicated. We sampled the precipitation isotopes ourselves at these sites.

Hengeveld, 2000), and we hoped to facilitate student learning via this project.

Our study region is geographically diverse but water, climate, and snowfall patterns have prominent impacts on the lives of students in the area. These impacts include recreational opportunities (e.g. skiing and water sports), frequent winter-time highway closures, the propensity for drought and recent fire hazards in semi-arid parts of interior British Columbia, and natural-resources based economic activities such as forestry, agriculture, and hydro-electric power generation, which are sensitive to climate change and water resource stress. We therefore anticipated that students in the region would have a natural engagement with climate and environmental issues. We designed this study as a vehicle to give students a better understanding of atmospheric processes and to encourage them to think critically about how global atmospheric change will affect their local climates. In addition, because students gain more by participating directly in 'real world' case studies (Orr, 1992; Meyers and Jones, 1993), this project was designed to give high school students exposure to data collection and some basic analytical techniques used by atmospheric scientists.

PROJECT DESIGN

The first task in designing this project was to determine if the study would fit within the curriculum for British Columbia high schools. Fortunately, the Canadian Earth Science 11 Atmospheric Science Curriculum (Evaporation, Precipitation and Weather) includes fieldwork and analysis as essential components. The rationale for this portion of the curriculum is to "encourage students to examine the impact of scientific knowledge on their lives, society, and the environment (B.C. Ministry of Education, 2006)." Our project was also considered to fall within the following prescribed learning outcomes of the curriculum:

- Identify and describe the forms of precipitation.
- Measure, record, and identify a variety of atmospheric data.
- Measure precipitation and devise a visual representation of the data.

Forty-one schools were initially identified using the B.C. Ministry of Education (2006) website to represent the areas that we were hoping to cover in our sampling transect. We mailed a cover letter and double-sided brochure outlining the project to the principals of these schools in June 2006 and asked that this information be distributed to Grade 11-12 science teachers. Five schools replied and indicated that they were interested in participating in this study, and a colleague at Thompson Rivers University offered to incorporate this project into her first-year Geography course. We contacted 15 Vancouver schools, but were not able to find a teacher willing to participate in this study. Because this city lies on the Pacific Coast, it receives the earliest rainfall from weather systems moving off the ocean, making it an important sampling location for our research. Eventually we approached a personal friend in North Vancouver who was willing to collect water samples, enabling us to complete our suite of sampling sites.

The geographic distribution of all sampling sites is shown in Figure 1, while Table 1 provides the names, locations, type and total enrollment of schools, along with the age group of participating students. The number of students involved in the sampling ranged from 20-34

TABLE 1. NAMES, LOCATIONS, SCHOOL TYPE AND ENROLLMENT, ALONG WITH THE AGE GROUP OF PARTICIPATING STUDENTS

School Name	Location	School Type	Enrollment[1]	Age group participating
Revelstoke Secondary	Revelstoke	Public (Grades 8-12)	536	Grade 12
Okanagan Mission Secondary	Kelowna	Public (Grades 8-12)	896	Grade 12
Thompson Rivers University	Kamloops	Tertiary		1st year (Geography)
Princeton Secondary	Princeton	Public (Grades 8-12)	225	Grade 11
Ashcroft Secondary	Ashcroft	Public (Grades 8-12)	254	Grades 10-12
Kumsheen Elementary-Secondary	Lytton	Public (Grades 7-12)	111	Grades 10-12

Notes:
[1] As of September 30, 2006.

students at the high schools, while the entire 1st year geography class was involved at Thompson Rivers University.

The meteorological instrumentation that we used in this study was chosen with several considerations in mind. The equipment needed to be able to withstand the vagaries of the winter climate of British Columbia and be left for a long period of time with little maintenance. Also, because we planned to establish the instruments in school yards, there were some concerns about security and vandalism. Conventional weather stations tend to have exposed wires which can be easily tampered with and the instruments are prone to human disturbance.

The suite of instruments that we finally selected included temperature and relative humidity probes with programmable, automatic dataloggers. These were set to record data at 20-minute intervals so that they had sufficient storage space to run for five months without being downloaded. The probes were housed in Stevenson Screens, which can be attached to either a pole or fence (Figure 2), and have the dual role of preventing solar radiation from directly affecting the temperature data,

FIGURE 2. A Stevenson screen at Thompson Rivers University, Kamloops, housing temperature and relative humidity probes and a data logger.

FIGURE 3. A rain gauge installed at Thompson Rivers University, Kamloops.

while protecting the instruments.

We also established precipitation gauges at each site to measure the amount of rain or snow and provide a water sample from each day of precipitation. In areas that generally receive precipitation as rain rather than snow, a standard non-recording gauge was the best solution (Figure 3). These attach to a pole or fence on a plastic mount and can be removed and taken inside each day for sample collection and, on occasion, de-icing and cleaning. These gauges are subject to sources of error that include water loss during strong winds (Nešpor and Sevruk, 1999); overflow and 'splashing' during very high rain events (Michelson, 2004), and observer error (WMO, 1983). Despite these sources of error, the gauges provide a simple and reasonably accurate way to measure liquid precipitation and are ideal for student projects. At two locations (Kelowna and Vancouver) we also installed a data-logging tipping bucket. These contain a pair of collection devices on a fulcrum that tips when it fills with water (Dingman, 2002). Each tip corresponds with 0.2 mm of water and is recorded on a datalogger so that the total precipitation over a given time period can be calculated.

Measuring snowfall is more problematic. Gauges that are commonly used by agencies such as Environment Canada were prohibitively expensive for this project. They also require regular maintenance and the personnel involved in data collection need training and expertise to ensure that the data is accurate. We opted for a simple solution and, in high-snowfall areas such as Revelstoke, a large plastic gauge was mounted on a pole near the ground. Students were asked to melt the accumulated snow and record the water equivalent for each day of precipitation. A summary of the sampling site elevations and locations along with the equipment installed at each site is given in Table 2.

PROJECT IMPLEMENTATION

The first school visits took place in mid-November (2006) to install equipment and meet with the students and teachers who would be responsible for this project. Given the spatial distribution of the schools and large geographical area involved (Figure 1), it was only possible to visit one school per day. The scheduling was also hampered by student availability (most earth science classes are only taught 2-3 times per week). We were, however, eventually able to meet with all classes to present the project and discuss the ways that this type of research fits within broader scale environmental concepts, such as the changing global hydrological cycle. During this visit, we were able to talk with teachers about the protocols for data collection and give then a brief overview of the equipment.

At most schools, students were able to help with the equipment installation and helped problem-solve in terms of where best to establish the instruments in the school grounds. All materials that were needed for data recording, such as clipboards, pens, flasks for measuring water and spare rain gauge parts, were provided in a labeled plastic box so that the students responsible for the measurements could easily locate this each day. A series of recording sheets were also provided and kept on the clipboards for the duration of the study. Students were asked to record the date and time, their name, and make notes about the weather conditions or any problems that occurred during sampling.

We helped teachers set up a class schedule so that one student was responsible for the equipment maintenance and data collection each week. This ensured that the rain gauge was checked each day (in principle). If precipitation had accumulated over the past 24 hours, the liquid water (or melted snow) was measured and recorded. Students also transferred a water sample for isotope analysis into a plastic bottle, which was labeled and refrigerated.

Throughout the winter, we were in contact with teachers regularly via email and questions that arose were generally dealt with online. We also joined the Okanagan Mission Secondary class on a two-day field trip in the Rocky Mountains to discuss mountain weather and snowpacks. We returned to all schools in late April (2007) to collect water samples, download data, dismantle equipment, and speak with students again. Teachers were provided with the weather data from the period of study at this time. The analysis of water samples at the University of Calgary Stable Isotopes Laboratory takes approximately three months, so these results could not be made available to the students that participated in the sampling. However, we are planning an additional visit to schools where the teachers expressed interest in hearing

TABLE 2. SAMPLING SITE ELEVATIONS, UTM POSITIONS AND SUMMARY OF EQUIPMENT INSTALLED

Location	Elevation[1]	UTM positions		Temperature/relative humidity	Rain/snow gauge (R/S)	Tipping bucket
		Easting	Northing			
Revelstoke	619	415628	6549578	Y	S	N
Kelowna	330	321233	5521648	Y	R	Y
Kamloops	498	686251	5616767	Y	R	N
Princeton	695	680886	5482445	Y	R	N
Ashcroft	332	622225	5621570	Y	S	N
Lytton	229	601572	5564342	Y	R	N
Vancouver	330	486682	5454795	Y	R	Y

Notes:
[1]meters above sea level

about the research outcomes with respect to the precipitation isotopes.

RESULTS AND KEY OUTCOMES

Isotope Samples

Most schools that participated in this study were able to maintain the project from the date that equipment was installed until the end of March 2007 (Table 3). The project was stalled at Revelstoke Secondary towards the end of winter due to a change in teaching staff. There were also a significant number of days that the gauges were not checked, such as weekends and public holidays, and we need to account for this in analysis of the data. A Monday morning water sample, for example, would generally include water from the previous weekend and would be more prone to evaporative effects, which alter the isotopic values.

A total of 245 water samples was collected at all locations (Table 3). The number of samples at each site varied considerably, depending on the local climate and the level of commitment of each school. Vancouver had the highest number of precipitation days (85), while only 22 samples were collected in Lytton. The Vancouver rain days generally produced a full bottle of water, but in drier areas such as Lytton and Kamloops, the rain gauge often did not collect enough precipitation for isotope analysis.

TABLE 3. NUMBER OF WATER SAMPLES COLLECTED AND SAMPLING DURATION

Location	Number of samples	Sampling Duration
Revelstoke	36	Nov. 16 2006 – Feb 22 2007
Kelowna	26	Nov 17 2006 – Mar 31 2007
Kamloops	24	Nov 22 2006 – Mar 31 2007
Princeton	27	Nov 17 2006 – Mar 31 2007
Ashcroft	25	Nov 21 2006 – Mar 31 2007
Lytton	22	Nov 21 2006 – Mar 31 2007
Vancouver	85	Nov 19 2006 – Mar 31 2007

The samples were analyzed at the University of Calgary Stable Isotopes Laboratory. The quality of the data was checked by plotting δD (the ratio of the heavy: light stable isotopes of hydrogen) against $\delta^{18}O$ (the ratio of heavy: light stable isotopes of oxygen). Overall, this returned very acceptable results; only 12 of the 245 samples were considered outliers. These outliers showed no bias to any particular sampling site and we will remove them from future analysis. Figure 4 shows the average $\delta^{18}O$ values from each of the sampling sites plotted against the distance from the Pacific Coast. These values reflect the loss of heavy stable isotopes in precipitation ($\delta^{18}O$ becomes more negative) as air masses move away from the coast and lose moisture. Ongoing research at the University of Calgary is directed towards modelling the isotopic evolution of precipitation from Pacific air masses, and samples from this transect will be used to assess the model.

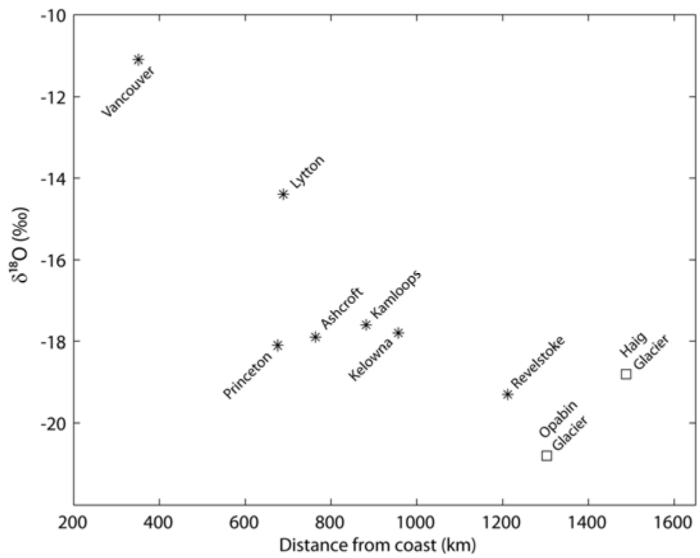

FIGURE 4. Average $\delta^{18}O$ values from each sampling site and from end-of-winter snow pits at alpine field sites in the Rocky Mountains. Distance from the coast is measured as the westerly distance to the nearest Pacific Coast (the west coast of Vancouver Island).

Atmospheric Sciences Project

Because sampling sites spanned a large longitude range, from the Pacific Coast through to the Rocky Mountains, this provided students with a good opportunity to learn about the way that precipitation and climatic conditions change across British Columbia. We compiled temperature and relative humidity data from each site into a spreadsheet and included, for each location, both the raw precipitation measurements made at the schools and precipitation data from nearby Environment Canada weather stations. Teachers were provided with the spreadsheet and an assignment that asked students to:

- Calculate the average temperature and relative humidities for each month of the study and compare this to another location in British Columbia;
- Produce a graph showing the temperature and relative humidity trends over the study period;
- Explain the seasonal trends in all data and comment on the reasons for any differences between sites. Students were asked to think here about factors such as differences in elevation, their location in relation to major mountain ranges, the presence of a large city, and their proximity to water;
- Compute and compare precipitation totals at different locations in British Columbia;
- Compare the tipping bucket totals in Vancouver with the Environment Canada climate 'normals' for the study month (Vancouver experienced an exceptionally wet winter and this made a good case study)
- Comment about possible sources of error in the different datasets that we collected, along with problems associated with comparing data from different types of instruments.

Evaluation of Project by Teachers

To gauge the thoughts of teachers upon project completion, an anonymous online survey was distributed to all schools in May 2007. Three responses to the survey

TABLE 4. SURVEY STATEMENTS AND TEACHER RESPONSES ON A SCALE OF 1 (STRONGLY DISAGREE) TO 5 (STRONGLY AGREE)

Statement	Teacher 1	Teacher 2	Teacher 3
This project was well organized and well managed	3	5	5
The instructions and sampling protocol for this project were clear to students and teachers	3	5	5
Students benefited from the initial visit and talk in November	3	5	5
The data collection and analysis taught the students valuable skills	4	5	5
The data collection and analysis will tie in well with the curriculum	5	5	5
The time commitment for teaching staff was reasonable	5	5	5
Schools did not benefit enough from the data collection	3	1	1
Overall students were interested and keen to be involved in this project	4	5	5
Students seemed to measure and record the data accurately	2	4	5
Students were confused about how to measure and record data	4	1	1

were received. All teachers indicated that they would participate in a similar study again and, when asked what motivated them to get involved in this project, one teacher replied "I believe in the science and thought the students would appreciate collecting data that will be used rather than just for the educational experience," while another commented that the project was current and meaningful and helped students to "see a connection to their lives."

We also asked teachers to rank a series of statements on a scale of 1 (strongly disagree) to 5 (strongly agree). The statements and teacher scores associated with these are given in Table 4. The response of Teacher 1 to the survey indicated that they felt neutral about the project's organization and management, the clarity of the instructions and sampling protocol, and the benefits of the initial talk in November. Teachers 2 and 3 on the other hand responded very positively to these aspects of the project. All teachers felt strongly (scores of 4 or 5) that the data collection and analysis taught the students valuable skills and tied in well with the curriculum, that the time commitment for teachers was reasonable, and that students were interested and keen to be involved in the project. Teachers 2 and 3 strongly disagreed with the statement "schools did not benefit enough from the data collection," while Teacher 1 was indifferent to this statement. Finally, the last two statements were designed to gauge the teachers' feelings about data accuracy. Teachers 2 and 3 felt that students were clear on how to measure and record data accurately and carried this out successfully, while Teacher 1 felt that students were confused and did not seem to record and measure data accurately.

Finally, we asked i) whether there were any key problems with this type of collaboration; ii) whether there was anything that could have been improved to make this more interesting for students; iii) whether there is there anything that could have been improved to make this project easier to manage from a teaching perspective; and iv) for any additional comments. The comments made by teachers in this part of the survey are discussed below.

DISCUSSION

A number of issues arose during the course of this study that researchers and educators who are considering implementing a similar project in the future may wish to bear in mind. The key constraints and considerations that we encountered related to i) school engagement; ii) the geographic distribution of the participating schools; iii) the time frame of the project; iv) the time available to schools to work on the project; v) data quality issues; and vi) evaluation of the educational outcomes.

School Engagement

As outlined above, only 5 of the 41 schools initially contacted responded to our brochure and cover letter, and there were no responses from Vancouver schools. We are unsure as to the reason for the low level of interest in the project, but this could be due to the fact that we were trying to make contact over the summer months, or that we were not sufficiently clear in the brochure about the potential benefits of the project to students and teachers. It has also been suggested to us that one possible factor may be that Earth Science 11 is not a core science course and does not give students a pre-requisite for university-level science. For this reason, a project of this nature may be better-suited to Grade 12 physics or geography students who intend to pursue university-level science.

On reflection, we also feel that we should have spent more time following up on our letters via email or phone calls. We may have had greater success soliciting interest in the project through direct contact with science teachers rather than working through the principal's office. Also, because we don't reside in the target communities, we have no personal relationship or 'inside connection' with the schools that we approached, and this may have made this initial contact more problematic.

Geographic distribution of schools

Because schools were dispersed over such a large area, it was not feasible to regularly visit the classrooms. Ideally, it would be beneficial for students to have a researcher visit on a regular basis (e.g., weekly or monthly) over a set period of time to help teach an atmospheric science module. These contact hours would help maintain student interest in the project and the data collection process (Calhoun et al., 2003). It would also allow the researchers to develop a stronger two-way relationship with schools, increasing the levels of trust and commitment. The most productive interactions with students over the course of this study occurred when we were able to join Okanagan Mission Secondary on a winter field trip to a backcountry hut. Staying with students in a remote setting was the ideal opportunity to put the project in context for them and discuss the potential impacts of climate change in mountain environments. This also resulted in a strong student interest in the project both in terms of data collection and the broader implications of this research to climate change in southwestern Canada.

In the context of this project, it is difficult to conceive of how we could have avoided the broad geographical distribution of schools, as our research relied on obtaining precipitation samples across British Columbia. We do recommend, however, that researchers consider their geographical accessibility to teachers and students before undertaking a collaborative project.

Time frame of the project

We also encountered issues associated with the time frame of our project in relation to the school year. Initially it was difficult to set up this project over the summer break, as many teachers were away or out of contact with the school over this time. Consequently, until we knew how many schools were interested in participating, this made it difficult for us to plan and order equipment prior to fall. This would not be a problem with continued collaboration with these schools in future years, but we recommend that engagement with new schools be initiated in spring, when teachers are more accessible.

There was also a continuity issue associated with the change of classes between the fall and winter semesters. Because teachers did not have the same group of students through both semesters, they had to transfer the responsibility for this project over to a new class. The second group of students did not have any prior explanation of the project from the research team, and did not feel the same ownership and responsibility for the data collection process. This was solved at Okanagan Mission Secondary, Kelowna, by having the same group of students continue the project to completion for extra course credit. In future years we would plan a January visit to help bridge this transition, but we did not anticipate this issue in advance.

Another timing issue arose with the delivery of the assignment to teachers. Because we needed to visit all of the schools at the end of the study to download data, we could not compile the data and write the assignment until late spring 2007. This meant that the assignment was of little benefit to the students who had been involved in the data collection. Teachers commented in the survey that it would have been better to get the data sooner. On the other hand, the project did facilitate the transfer of information between schools, so that teachers gained a good dataset to use in future classes.

Some of these issues could be addressed through a revised project design. It may be possible, for example, for teachers and students to have immediate or online access to the weather data. With a greater budget, more advanced loggers and data control devices could be acquired to enable transmission of the weather data to a website where students and teachers could access the data without interfacing with the measurement devices. This would enable researchers to deliver assignments to students throughout the data collection process, and assignments could be designed to reflect key learning goals in the curriculum. From a learning perspective, we feel that this would also help students to stay engaged in the data collection process because they could more easily relate their own weather observations to what has been recorded by the instrumentation.

In addition, we probably did not transfer enough control over the data to the students, as we had concerns about data loss or faulty reprogramming of the data loggers. There are, however, ways to skirt these research risks. Duplicate instrumentation could be established, with one logger recording the research data and another providing information on demand to the students. As an alternative, relevant labs or modules could be provided to the schools in advance (e.g., in October), using synthetic data or data from a previous year of study. This would work well if we repeat the collaboration in future years.

Time available to schools

A reoccurring comment both in the survey and in discussion with teachers is that time is a key constraint in classroom situations. Science teachers generally have a 45-55 minute class session available and time spent supervising the equipment and data collection adds to an already stressful workload. Gaps in the data record were not generally due to lack of interest on the part of the teachers, but due to the fact that data collection often requires too much time and effort (Calhoun et al., 2003).

A solution to this might be better communication of the benefits and relevance of the program and some extra work on our part to integrate it into the curriculum material. With the intrinsic value of the research experience and its relevant themes, we believe that it should have been possible to embed the project in the regular curriculum, but this needs to be carefully discussed and planned with teachers and we appreciate that not all instructors will be amenable to modifying core curriculum material; it is extra work and the rewards need to be clear.

Data quality

By working with a number of different schools and having hundreds of students collect data, data quality issues inevitably emerge. Rain gauges are subject to numerous sources of error (WMO, 1983; Michelson, 2004), which are augmented by not having the same person consistently recording data on a daily basis. For this reason, we did not place a high reliance on the precipitation amounts that were recorded. Comparison with nearby Environment Canada data reinforces these concerns. Nevertheless, we feel that it was valuable for students to measure rain and snow amounts to gain practical experience with data collection. It also helped to have clear protocols in place that were consistent across all schools. We explained the sampling process to classes on our first site visits and taped waterproof instructions to the clipboards that students used for data recording.

Student adherence to these protocols was very much related to the level of teacher involvement in the project and the level of supervision. We found that the data quality was higher in schools where science teachers responded directly to our brochure, of their own volition. In two cases, the science teacher was directed by the school principal to contact us, and the level of commitment offered by both teachers and students at these schools was lower. Good results came from one school where the teacher incorporated this project into a Grade 12 core science class. According to this teacher, a high proportion of these students were intending to study university-level science and the level of enthusiasm and student involvement was noticeably higher than at other schools.

Overall, our research objectives were met and the temperature, humidity, and isotope data collected in this study are reliable and worthy of use in a formal scientific investigation. Data quality is therefore dependent on the specific demands and protocols required for a given task, as well as our success in communicating these. This is a critical issue that demands realistic, case-by-case assessment for a research project, as there is little point in such collaboration from the perspective of the researcher if it does not produce meaningful scientific results. There is no room for compromise on this for most scientific inquiries, and this has to be clear from the outset and embedded in the design of a successful collaboration.

Evaluation

Finally, we recommend that researchers build a strong evaluation component into their project design, so that the benefits to both teachers and students can be carefully assessed at the closure of the project. While the teacher survey described in the Results and Key Outcomes was useful in terms of evaluating teachers' opinions after the project, we advise researchers to undertake a more rigorous evaluation that also involves gauging student responses to the project. Unfortunately, once we began the evaluation process, students had moved on to other classes or left the school entirely. A better strategy would be to ask teachers to distribute surveys to participating students once near the beginning of the project and once closer to the end of the study. The initial survey could be geared to assess student learning goals and interests, and the final survey would ask students to reflect on what they had learned and what could have been done differently from their perspective. Involving students in project evaluation would also provide a beneficial learning experience that would reinforce the value of their participation in the study.

Our initial motivation and project design were oriented towards scientific research outcomes, with educational benefits seen as an important but ancillary objective. As a result, we did not give enough attention to evaluation of the educational experience. In retrospect, scientific and educational objectives are closely tied and cannot be separated; the more engaged and useful the experience is to the students and teachers, the higher the quality of the scientific data collected.

CONCLUSION

A key consideration for researchers undertaking projects in high school classrooms is to ensure that all involved benefit from the collaboration. It should not only be advantageous for the scientist, but students and teachers must see how their efforts contribute to the project (Barstow et al., 1996). If a true collaboration and two-way engagement can be obtained, a powerful environment for learning science can emerge (Morse and Sabelli, 1991), but this requires careful planning on the part of the researchers both in terms of the project design and implementation. In the absence of a genuine collaboration there can be a lack of student engagement and reduced benefits to all parties involved in the partnership. A project needs to be mutually beneficial to enable a sustainable, multi-year co-operation.

Some of the pitfalls of working with high schools can be avoided if scientists consult teachers early in the planning process so that the study can be designed around the school year. It is also important to ensure that the project fits within the curriculum, and researchers should consider tailoring the project to meet the needs of the teachers, even if this requires additional time or instrumentation. Finally, contact time with teachers and students is a crucial component of university-high school collaborations. Time spent in classrooms not only helps students understand why data quality is important, but enables researchers to put the project and the student efforts in a broader, 'real world' context.

The collaborative project that we undertook was a success for us, as researchers, and for those schools and students that engaged in it, and we would not hesitate to mount a similar effort in future years. That said, we were somewhat disappointed with the overall extent of interest and participation: 5 of 41 schools responded to our invitation and request to participate. Several factors may contribute to this, including i) an attempt to make contact in the summer months; ii) inadequate information or 'hooks' in the brochure that we produced in an attempt to explain the project and spark interest; iii) the fact that we targeted this project at Earth Science classes instead of a core science subject; and iv) the fact that we were an unknown group with no prior relationship or connection with the schools. This initial phase of establishing the collaborative partnership is critical and we feel that more effective networking and up-front effort in terms of follow up phone calls and discussion with teachers would have been time well-spent. However, this process would be considerably easier for researchers if more formal pathways were in place to facilitate this type of interaction and remove some of the structural obstacles that currently prevent researchers and educators from implementing collaborative projects.

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