The Satellites, Weather and Climate (SWAC) Teacher Professional Development Program: Making the Case for Climate and Geospatial Literacy

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ABSTRACT

In July 2008, a new professional development program called Satellites, Weather and Climate (SWAC) began at the University of Vermont. Its goal was to enhance the competency of in-service K–12 science and mathematics Vermont teachers in the atmospheric, climate, and geospatial sciences. The pilot program ran until 2010, during which time 14 teachers representing three cohorts were exposed to the eight training modules developed specifically for the program. The SWAC program is social constructivist in nature and implemented in such a way that participating teachers built upon prior SWAC content knowledge with each passing year in the program. SWAC modules were based on inquiry, problem, and project-based techniques and were presented in lectures, outdoor observation, and remote sensing laboratory settings. Participating teachers typically began the program during a weeklong, intensive summer program that covered the core SWAC concepts and skills. This was followed by two 1-h workshops every month during the academic year in which participants focused on a specific content module, geospatial skill, or technique. These content and skill workshops alternated with lesson planning sessions to allow teachers to develop lessons, units, or projects with SWAC materials. Program effectiveness was quantified by pre- and posttest evaluations of the modules, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis in January 2010, and a comprehensive survey of participants' pedagogical changes, as well as the skills and attitudinal changes of the 927 students they taught during the pilot phase. Teachers reported that participation in SWAC transformed their pedagogical approaches and in-class effectiveness while dramatically improving their students' observational abilities, critical thinking skills, and understanding of geospatial technology. An additional outcome of the SWAC program was the Teacher Learning Community that developed, in which participants were able to share activities and challenges across grade levels, school systems, and institutional barriers in a setting not found anywhere else in their professional development environments. © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/11-238.1]

Key words: climate literacy, teacher professional development

INTRODUCTION

> In order to stimulate [a child] to accuracy, he is encouraged to measure and record carefully. The weather lends itself to this method of training quite as easily as any other subject.… A wide-awake teacher with a maximum and minimum thermometer and a rain gage [sic] can soon develop such an interest in a practical way that the lessons in physical geography, instead of being dull, will become intensely interesting and the scholars will have demonstrated to them in practice what the geographies teach theoretically.

This quote from the 1899 *Monthly Weather Review* editorial by H. E. Wilkinson, the Local Forecast Official and Director at Vicksburg, Mississippi, suggests that using the atmospheric sciences and geography as learning/teaching tools is not a new endeavor. Today, over a century later, numerous, well-established educational programs bring weather and climate knowledge and techniques to K–12 audiences. Some of these programs fall under teacher professional development, while others are designed to enhance the knowledge and skills of K–12 students. Programs include EarthStorm, COMET, The GLOBE Program, CERES S'COOL, CIMSS, and measuring barometric pressure (Snow et al., 1992). The EarthStorm Project uses real-time data from the Oklahoma Mesonet for K–12 teacher enhancement (McPherson and Crawford, 1996). The Oklahoma Climatological Survey also hosts one-day climate training workshops on core weather and climate concepts targeted at decision-makers and planners across the state (Shafer et al., 2009). COMET (Cooperative Program for Operational Meteorology, Education, and Training) (Jackson and Carr, 1995) reaches a broad base of university students, faculty, and operational meteorologists. The American Meteorological Society (AMS) offers a suite of programs including Project ATMOSPHERE, DataStreme Atmosphere, DataStreme Ocean, and DataStreme Earth's Climate System (http://www.ametsoc.org/amsedu/). Project ATMOSPHERE began in 1990 as a professional development program to bridge the gap between the American Meteorological Society and K–12 educators (Ginger et al., 1996). The GLOBE Program uses "hands-on, inquiry-based" techniques to train teachers "to teach students how to take measurements of environmental parameters at quality levels

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acceptable for scientific research" (Butler and MacGregor, 2003, p. 9). Similarly, the S'COOL (Students' Cloud Observations On-Line) is a global project in support of NASA's research on the Earth's radiation budget, in which K–12 students provide ground truth measurements to validate the CERES satellite instrument. Finally, the Cooperative Institute for Meterological Satellite Studies (CIMSS) represents a cooperative agreement among the University of Wisconsin–Madison, NOAA, and NASA to foster collaborative research among these three entities and to "stimulate the training of scientists and engineers in the disciplines involved in atmospheric and Earth sciences" (http://cimss.ssec.wisc.edu/mission_statement.html). All of these program offer online educational resources for the K–16 environment.

Many of these programs have been in existence since at least the mid-1990s and as such, a number of common themes have emerged. These include the need to tailor programming to the curricular constraints within which teachers function, the applicability of weather and climate concepts and techniques across multiple disciplines, and the role of inquiry-based approaches in enhancing student skills and learning. Yet, despite the documented articulation of these best practices, gaps still exist in geoscience students' understanding of elements of scientific inquiry (e.g., Orion and Kali, 2005) and teacher preparation in this area (Geoscience Education Working Group II, 2005).

THE NEED FOR A NEW PARADIGM

Over the last decade, as concerns about geoscience literacy have come to the fore, a number of literacy frameworks have collectively emerged around Ocean Literacy (2005), Earth Science Literacy Principles (2009), Atmospheric Science Literacy (2008), and Climate Literacy (2009). Many of these literacy frameworks are specifically linked to the grade-appropriate benchmarks and principles of the formal K–12 education structure. In reviewing the implementation of these frameworks across the U.S., Hoffman and Barstow (2007) found that significant improvements in Earth System science education were needed. Their study also revealed the mediocre incorporation of the atmosphere, weather, and climate into state standards, with 30, 12, and 8 states directly or indirectly addressing these concepts, respectively, or failing to address them altogether.

Some of the challenges to achieving geoscience and climate literacy are curricular in nature while others are related to institutional constraints and individual learning. For example, Kastens et al. (2009) report that some students may be spatially challenged, which influences their ability to conceptualize many geoscience and climate science phenomena that are two-dimensional and three-dimensional in nature. Other institutional barriers include the unevenness with which climate science, physical geography, or Earth science are delivered. Dupigny-Giroux (2010) reports that in some Vermont school districts, neither geography nor Earth science is taught at the K–12 levels, and a curricular disconnect exists between the weather observations mandated by the state's K–4 state standards, the hydrologic cycle in Grades 5–8, and weather map interpretation in Grades 9–12. Earth science continues to be perceived as a remedial course and not "real science" suitable for college-bound students. Many students are introduced to climate science basics for the first time in an undergraduate geography or meteorology class.

Perhaps the greatest challenge to geoscience literacy in general, and climate literacy in particular, is teacher preparation. Many K–8 school teachers are not content area specialists, particularly in the Earth and physical sciences, not having had science content courses that could serve as appropriate professional development for their teaching practice. Content knowledge deficiency leads to poor self-confidence in teaching science content effectively, which may manifest itself in science anxiety and a decline in overall science achievement on the part of students (Czerniak and Chiarelott, 1991). "Nonexistent or poor early science instruction can affect students' attitudes toward science and their future willingness to take elective courses in science" (Malcom, 2006, p. 46). Student achievement, interest and motivation hinge "on improving the teaching expertise of the individual teachers who work with the children" (Saphier, 2005). Dupigny-Giroux (2010) noted that not only can educators stimulate students' interest and begin their process of lifelong learning, but in many cases, act as their first point of contact with weather and climate information. More importantly, however, teacher preparation has important implications for workforce issues as outlined by the Geoscience Education Working Group II: "The need for sufficient numbers of highly qualified Earth Science teachers in the K–12 workforce is a problem that has contributed to a lack of awareness of, and interest in, the geosciences among students" (2005, p. 9).

It is not sufficient, however, to overcome the science achievement dilemma by reducing anxiety and increasing teacher content knowledge. Teachers need to develop a level of enthusiasm and flexibility in order to create innovative and investigative experiences for their students. They must also adopt innovative and effective teaching strategies in order to increase student achievement in science. The Satellites, Weather and Climate (SWAC) program was designed to address the continuous professional development needs of K–12 teachers enabling all students to receive the level of teacher expertise and education to make them scientifically literate and competitive in the 21st century job market or in advanced science study.

In preparing to solicit National Science Foundation funding for the SWAC pilot program, a climate education and literacy needs assessment (Table I) was administered to the 22 K–12 educators who participated in the 2007 Vermont Geographic Alliance's Summer Institute, held at the University of Vermont. Their responses shaped the formulation of the original grant proposal and the survey instrument has been administered to all participating SWAC teachers, in the pilot phase and beyond. Survey questions probed teachers about the skills and concepts needed to better teach about weather and climate, specific curriculum assistance, activities most appropriate to their students' grade level, current resources, incentives for participating in federally-funded research, and accreditation requirements. Both the original pre–SWAC respondents and participating SWAC teachers have been quite vocal in their specific needs for professional development targeted at the atmospheric, climate, and geospatial sciences. Responses indicated that:

- Students at all levels had limited knowledge of atmospheric principles and/or some knowledge of a

TABLE I: Survey instrument used to assess the climate education and literacy needs of Vermont educators. The survey was first administered in 2007 to 22 K–12 participants of the Vermont Geographic Alliance's Summer Institute held at the University of Vermont. It has since been administered to each new cohort of participating SWAC teachers.

1.	What grade levels do you teach?
2.	Do you think that your students understand how the atmosphere works?
3.	Where do you think most of their information about the atmosphere, weather, climate, etc. originates?
4.	Is there a gender difference between how well the boys and girls in your class(es) understand scientific concepts? Weather and climate concepts?
5.	If there is a difference, do have any thoughts on what might be the cause? What might you do to rectify this gap?
6.	What skills/concepts would you like to acquire to better assist you in teaching about weather and climate?
7.	With what elements of the curriculum would you like assistance?
8.	What time frame would be best for you to learn about new pedagogy, skills, and techniques to enhance your curriculum?
	– week during the summer
	– after-school meetings during the school year
	– other suggestions?
9.	What types of activities would be most appropriate for your grade level(s)?
10.	What resources are currently available for activities?
11.	What incentives would be appealing to you should you participate in a grant-funded opportunity (monetary or otherwise)?
12.	Do you have specific licensure or accreditation needs?

specific aspect only, such as the hydrologic cycle or climate change.

- Most of the current students' knowledge was gleaned from television (e.g., forecasts), school, or from farming and hunting activities at home.
- Most of the teachers did not perceive any gender differences in terms of scientific or climate concepts. One teacher raised interesting issues about boys thriving at mechanical and engineering topics while girls performed better on assessments requiring "parroting answers." Regardless of their response to this question, all of the teachers agreed that they needed to incorporate as much science into their teaching as possible.
- The teachers were most interested in gaining digital image interpretation skills, understanding weather forecasting, connecting classroom activities with actual data collection and manipulation (a Vermont State Standard), gaining a better understanding of Earth System science; connecting with real scientists; and getting technical and technological assistance because "techie things" advance so quickly.

Such feedback from educators echoes the call made by the Geoscience Education Working Group II that "[g]eoscience teachers need opportunities to gain content-area knowledge so that they have the confidence to make changes in their lessons, going beyond the facts given in textbooks" (2005, p. 21). The successful implementation of climate and other knowledge is often constrained, however, by the lack of cohesion in the curricula or fragmented resources faced by European teachers (Uherek and Schüepbach, 2008), a feeling of personal isolation and lack of preparation to impart climate science (Johnson et al., 2008), and the need to "teach to the test."

The primary objective of this paper is to present the conceptual and logistical framework of the SWAC program and its resulting outcomes as a template for addressing teacher professional development needs and constraints in one realm of the geosciences.

THE SWAC PEDAGOGICAL AND SCIENCE FRAMEWORK

SWAC began in July 2008 at the University of Vermont (UVM), as a 2-y pilot project funded by the National Science Foundation's Geoscience Education program (GEO-0807787) to create a professional development project for enhancing the competency of in-service Vermont science and mathematics teachers at K–12 levels in the climate and geospatial sciences. It closely followed two important outcomes of the CERES S'COOL project: the importance of starting a pilot project with a small, local audience and growing via teacher feedback, and the need to keep learning modules simple and flexible to maximize teacher enhancement (Chambers et al., 2003). SWAC's overarching curricular framework is based on the backward design approach to student learning and curriculum development (Wiggins and McTighe, 2005). The major objectives of the 2-year pilot program were to develop reflective teacher practitioners who have a deeper understanding of geoscience principles and science pedagogy. The end goal of SWAC is to engage students in inquiry-based and project-based learning that connects to SWAC related questions and issues in their own lives.

Between 2008 and 2010, SWAC trained three cohorts of middle and high school teachers. These 14 educators engaged with 927 Grade 8–10 students in subjects such as Earth science, history, chemistry, physics, biology and environmental science. Self-selection into the SWAC pilot program did not include any elementary teachers. Six teachers (one middle school and five high school) formed the first SWAC cohort in September 2008. Additional

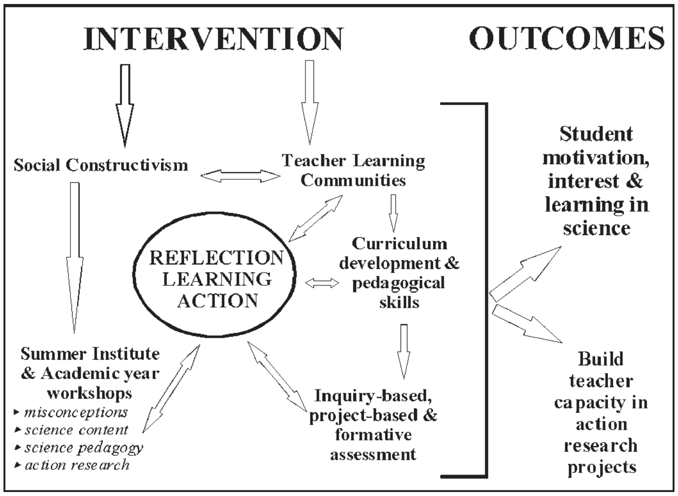

FIGURE 1: Conceptual framework of the Satellites, Weather and Climate (SWAC) model of professional development (designed by K. Colley).

funding from the Vermont Department of Education's Math and Science Partnership allowed another five high school teachers to become the second cohort in July 2009, with three more middle and high school teachers joining in July 2010.

Conceptually, SWAC is a multiphased teacher professional development program grounded in social constructivist theories of teaching and learning (Solomon, 1987; O'Loughlin, 1992). SWAC's methods and practices are rooted in the principle that knowledge is socially constructed from prior knowledge and experiences and that students and teachers learn best when learning experiences are contextualized, reflective, collaborative, inquiry-based, and relevant to everyday experiences (McMahon, 1997). The program follows a model of inquiry- and project-based instruction and formative assessment within a continuous cycle of reflection, learning and action (Shulman, 1998; Moon, 1999), whereby participating teachers work in Teacher Learning Communities (TLCs) to plan and integrate these strategies into their curriculum and teaching on a daily basis (Fig. 1).

In addition to being social constructivist in nature, the SWAC program is based on the fundamental premise that all students who are consistently engaged in relevant, engaging, content-rich inquiry, and data driven research projects in school and during informal science experiences will demonstrate increased achievement, interest, and enthusiasm for the geosciences, environmental issues, and careers. In order to motivate and engage students in challenging, content-rich investigative geoscience experiences, teachers themselves must be consistently engaged in professional development that models inquiry, problem, and project-based approaches involving advanced technologies in the geoscience classroom today. In SWAC, these professional development experiences consistently focus on the fundamental "big ideas" and essential processes that are inherent to the geosciences (e.g., "The Sun is the primary source of energy for Earth's climate system" [USGCRP, 2009]).

Pedagogically, teachers engage in reflection and self-examination through preassessments, surveys, and focus group discussions around their own prior knowledge, beliefs, and practices about science, teaching, and assessment, and the extent to which these beliefs and knowledge influence what and how they teach and assess science. From a content perspective, teachers learn through authentic SWAC investigations using the most current research, technology, and instruments upon which scientists rely. They also engage in relevant readings, discussions, presentations, and curriculum planning that are focused on the methods of inquiry, project-based learning, and formative assessment for engaging, motivating, and connecting their curricula to students' life experiences. Academic year lesson planning allows teachers to take action on and integrate the science knowledge and pedagogical strategies they have learned. During the school year, teachers also enter another phase of reflection, learning, and action as they continue to work in their school-based TLCs and implement curriculum that focuses on promoting inquiry-based, project-based, and formative assessment strategies in their own science classrooms. Finally, monthly workshops during the academic year are designed to elicit and address many of the misconceptions that teachers hold about the geosciences and science teaching, while presenting science content, principles, and applications that are based on best practices of science teaching and the most current standards of research.

SWAC's core concepts are directly aligned with those of the Climate literacy framework (USGCRP, 2009) and concept mapping of AAAS' Project 2061 (AAAS, 2007). All SWAC modules integrate the AAAS Benchmarks about Scientific Inquiry that begin with raising questions about the world in Grades K–2, progress through keeping observations in a notebook in Grades 3–4, and culminate with scientific data collection and interpretation in Grades 6–12. The dual understanding of electromagnetic radiation as both an energy transfer process and its role in remote sensing is critical. Other core understandings include weather versus climate, atmospheric forces, climate controls, hydrologic cycle, anthropogenic influences on the atmosphere-land-ocean system, photointerpretation of the atmosphere versus the land or ocean, combining field observations with atmospheric and land surface imagery, and deductive inferences about landscape health and functioning as a function of weather and climate inputs.

From an atmospheric and geoscience perspective, SWAC is also aligned with the constructs examined by Kastens et al. (2009) who analyzed the approaches and perspectives that set geoscientists apart in their study of the Earth as a system. They suggest the use of imagery to help students think about time, the notion that "feedback loops function as a threshold concept," learning in the field leads to "professional vision," spatial thinking and the notion that some students are spatially challenged, and geoscientists' experiences, approaches, and values lead them to problem-solve in a connected, interdisciplinary way.

The SWAC program models the use of remotely sensed imagery and geospatial technologies to frame and solve problems associated with the environment, weather, and climate in Vermont and beyond. As an inquiry-based program, SWAC is aligned with the needs assessment of Sturtevant and Marshall (2009) who highlight the following: (1) successful inquiry-based teacher professional development programs should be connected to state grade expectations, benchmarks, and national science standards;

(2) data should be connected to concepts and experiments to local experiences; and (3) a forum for teacher discussion should be engaged. Three levels of education standards are met by the SWAC program. The first are the Vermont State Learning Standards (6.7 Geographical knowledge [part of History and Social Standards, or HSS] and Science, Mathematics, and Technology [SMT]). The second are the National Geography Standards (The world in spatial terms 1,3; Physical processes 7,8; Environment and society 14–16; The uses of geography 17–18). The final tier are the National Science Education Standards for content (A.1.2–3; A.4.21–23; A.5.29–30; B.3.22–25; B.4.32–34; C.4a.1,5–7; C.4b.19; C.4c), science as inquiry, general skills teaching, assessment, and professional development. Tables IIa and IIb summarize the alignment of SWAC modules with the Vermont State Learning Standards.

Finally, SWAC is aligned with a number of national and federal education plans. The NOAA Education Strategic Plan supports environmental literacy and has a goal of preparing "teachers to learn about and explore NOAA science" (2009, p. 33). The plan supports "experiential activities [for] students [and] educators" while promoting strategies that "support and implement professional development to strengthen scientific knowledge and build inquiry and decision-making skills." NOAA is interested in the connection between the environment and society, realizing that the place-based science "makes these lessons more powerful and longer-lasting." NASA's Earth Observatory has long been a leader in creating atmospheric and Earth science content and modules for K–16 audiences, the media, and the public. By focusing on increased content knowledge of the atmospheric, climate, and geospatial sciences, SWAC contributes to the development of a climate- and geospatial-literate citizenry. Multilevel, dispersed programs are needed to address the needs of both teachers and students. SWAC's thematic framework is in keeping with the AAAS (1989) *Science for All Americans* and the AAAS Project 2061's (AAAS, 2007) mission to help all Americans become literate in science, mathematics, and technology.

IMPLEMENTING THE SWAC FRAMEWORK

The SWAC program is delivered in two phases. Every year, a new cohort of SWAC teachers is recruited. Each new cohort attends a weeklong Summer Institute designed to introduce new teachers to core SWAC concepts and skills. The second phase of SWAC includes the 2-h, monthly workshops during the academic year that are devoted to a specific content module, geospatial skill, or technique. Content and skill workshops alternate with lesson planning sessions during which participating teachers focus on developing individual lessons, units, or an entire project using SWAC materials. Ongoing teacher support is an essential element of SWAC and scheduled lesson planning sessions facilitate the development of Teacher Learning Communities (TLCs), in which teachers can share experiences, activities, and challenges across grade levels, school systems, and institutional barriers. Lesson planning sessions also allow for more individualized interaction with SWAC team members than is possible in a larger group setting. Between workshops, team members also support the teachers by contributing timely resources, such as satellite images of recent events, atmospheric profiles, forecasting tips, and severe weather summaries to the SWAC Wiki that was created by a participating teacher. The Wiki has also provided a forum for teachers to post questions and receive feedback about planned curricular strategies.

During the pilot program, eight SWAC modules were developed (Table IIa). They were offered sequentially to build progressively upon each other around the themes of the atmosphere, land processes, and the use of technology. Like many of its predecessors, the introductory SWAC modules (1–3) focus on fundamental concepts, such as understanding the electromagnetic spectrum, cloud observation, and satellite interpretation, and incorporate the use of pre-existing online resources. The remaining five modules were designed entirely by SWAC team members. SWAC's uniqueness lies in its conceptual framework, as well as in the integration of meteorology, climatology, engineering, and geospatial technologies, to address both atmospheric and land processes in a problem- and project-based environment that is accessible to students at all levels from K–12.

Each module has three primary elements, regardless of whether it was offered as part of the Summer Institute or a 2-h workshop during the academic year. Element 1 is the actual content or geospatial skill. Element 2 is an activity or field exercise created by the SWAC team to allow teachers to gain familiarity with the contextual topics or satellite interpretation methods. Finally, each module is assessed by a pre- and posttest (Element 3) on the day of the workshop. Table IIa summarizes the science content and elements used in each module. It also highlights the alignment between each module, the Vermont State Learning Standards and the Climate Literacy Principles (USGCRP, 2009). Lecture presentations, activities, and readings are all archived online at http://www.uvm.edu/~swac/?Page=modules.html.

Using Module 7, the Geoviewers module, to highlight the sequencing through a typical SWAC module, teachers were first introduced to the NASA's GEOMAP online data viewer, a geospatial platform that facilitates hypothesis creation and testing based on landscape and atmospheric observations. This preformatted system was followed by the use of the Google Earth tool, through which teachers learned how to customize Google Earth data to specific locations (e.g., their school surroundings). They also learned how to georectify old maps or images as well as how to create geocaching activities around a local school. Participating teachers then worked on individualized lesson or lab plans for incorporating these technologies into their classes. Examples created by teachers included an activity about water pollution in Lake Champlain and redesigning an entire course to incorporate Google Earth in teaching Earth Science.

Module 4, the CricketSWAC balloon launches (Fig. 2a–f), are one of the most interactive components of the SWAC program, appealing to all grade levels (including kindergarten [Fig. 2c]) and teachers alike. Four successful CricketSWAC balloon launches were made on 18 October 2008, 31 July 2009, 7 May 2010, and 30 July 2010, using the sensors refined over the course of the pilot project by SWAC team engineer Fortney. The CricketSWAC Junior sensor is an outgrowth of the sensors that he originally designed as part of the NASA CricketSAT program. CricketSWAC Junior functions as an environmental sensor that is sensitive to light, motion, gas composition in the air (Fig. 2a), and the standard meteorological variables of temperature, pressure,

TABLE IIa: Description of the eight SWAC content modules developed by the SWAC team during the pilot phase of the project and the alignment of these modules to the (a) Vermont State Science (VSS) and Mathematics Standards, and (b) Climate Literacy Principles (CLP).

SWAC Module	Description		Standard	
	Content	Elements	VSS	CLP
1. Introduction to electromagnetic spectrum, atmospheric physics, and satellites	Introduction to the basics of the electromagnetic spectrum within the context of both remote sensing and atmospheric dynamics. Orbital characteristics of geostationary platforms and polar-orbiting satellites are introduced. Participants learn the basics of visible and infrared image interpretation from geostationary satellites.	PowerPoint lecture, hands-on kinesthetic and online activities to demonstrate wave properties and satellites	SMT 7.4, 7.12	1a
2. Cloud identification and monitoring	Mechanisms for cloud development and the identification of the 10 basic cloud genera are discussed. This is followed by outdoor observations of the clouds present during the module. The module wraps up with the interpretation real-time GOES visible and infrared imagery of the same clouds for use in identifying weather patterns.	PowerPoint lecture, 30-min outdoor observations, interpretation of online NOAA GOES imagery	SMT 7.4, 7.15	2a, 5b
3. Satellite weather interpretation and forecasting	This module builds upon the first two by combining visible and infrared cloud interpretation from the NOAA GOES satellite with the fundamentals of weather forecasting.	PowerPoint lecture, 30-min activity, take-home activity	SMT 7.12, 7.15	4b, 5b
4. CricketSWAC sensor building and balloon launch	SWAC engineer Fortney leads participants through an outdoor balloon launch where the payload includes CricketSWAC sensors he has designed to measure temperature, barometric pressure, and humidity. The data are relayed in analog format to the ground receiving device and used to plot the vertical profile of the atmosphere. These graphs are then compared with National Weather Service radiosonde data from Albany, New York (the closest such location) to explain inversions, storm dynamics, wind flow, and calculating true altitude	30-min introduction using PowerPoint and actual instruments, 1–2 h outdoor launch and data collection, 30-min graphing and data interpretation	HSS 6.7; SMT 7.1, 7.2, 7.15, 7.19	5b
5. Land surface interpretation	Introduction basics of photointerpretation of land imagery acquired from polar-orbiting satellites. Greyscale and color composites of regional and local sites are used to examine landscape characteristics including moisture stress in plants, delta formations, and water pollution.	PowerPoint lecture, 45-min hands-on interpretation activity, online resources	SMT 7.4, 7.11, 7.12, 7.16	
6. Satellite interpretation of permafrost	An applied module that uses the land surface interpretation of the previous module to perform change detection of continuous and discontinuous permafrost around the world as a manifestation of global environmental change.	PowerPoint lecture, 30-min hands-on interpretation activity, online resources	SMT 7.11. 7.12, 7.16	4d, 5b, 7e
7. Geoviewers	Use of online geospatial resources (Google Earth and NASA's geoviewers) to introduce spatial analysis of landscape and hydroclimatic patterns at varying temporal and spatial scales. This lab-based module allows teachers to become conversant with tools (such as georectifying historical documents for use with current data, urban heat island effect, and influence of continentality) that can be used in the classroom to view, edit, and create geographic products for students.	Combination of PowerPoint lecture and online demonstration; 30-minute hands-on interpretation activity, 1-h Google Earth activity	SMT 7.19	
8. Air quality tracking via satellites	The first SWAC "just-in-time" module designed to allow participants to acquire the science and satellite-based resources to bring current events into the classroom as they occur. This module focused on the Québec forest fires of 31 May 2010 that raised air quality and health issues for New England and New York. Geostationary and polar-orbiter imagery were used to explore air quality issues related to forest fires, ozone concentrations, and volcanic eruptions.	PowerPoint lecture, interpretation of land and atmospheric imagery of smoke plumes, online resources	SMT 7.19	2e, 3e

TABLE IIb: Explanation of the Vermont State Standards for History and Social Science (HSS) and Science, Math, and Technology (SMT) used in Table IIa (available at http://education.vermont.gov/new/html/pubs/framework.html)

Vermont Standard	Description
History and Social Science, HSS 6.7	Students use geographical knowledge and images of various places to understand the present, communicate historical interpretations, develop solutions for problems, and plan for the future.
Science, Math, and Technology, SMT 7.1	Students use scientific methods to describe, investigate, and explain phenomena and raise questions in order to:
	Generate alternative explanations—hypotheses—based on observations and prior knowledge;
	Design inquiry that allows these explanations to be tested;
	Deduce the expected results;
	Gather and analyze data to compare the actual results to the expected outcomes; and
	Make and communicate conclusions, generating new questions raised by observations and readings.
SMT 7.2	Students design and conduct a variety of their own investigations and projects. These should include:
	Questions that can be studied using the resources available;
	Procedures that are safe, humane, and ethical;
	Data that are collected and recorded in ways that others can verify;
	Data and results that are represented in ways that address the question at hand;
	Recommendations, decisions, and conclusions that are based on evidence, and that acknowledge references and contributions of others;
	Results that are communicated appropriately to audiences; and
	Reflections and defense of conclusions and recommendations from other sources, and peer review.
SMT 7.4	Students understand the history of science, mathematics, and technology.
SMT 7.11	Students analyze and understand living and nonliving systems (e.g., biological, chemical, electrical, mechanical, optical) as collections of interrelated parts and interconnected systems.
SMT 7.12	Students understand forces and motion, the properties and composition of matter, and energy sources and transformations.
SMT 7.15	Students demonstrate understanding of the Earth and its environment, the solar system, and the universe in terms of the systems that characterize them, the forces that affect and shape them over time, and the theories that currently explain their evolution.
SMT 7.16	Students demonstrate an understanding of natural resources and agricultural systems and why and how they are managed.
SMT 7.19	Students use technological/engineering processes to design solutions to problems.

and humidity. During the launch, the data were transmitted back to the ground via a Yagi antenna (Fig. 2d). They were plotted in Excel (Fig. 2f) to create vertical tropospheric profiles that were then compared with the National Weather Service soundings from Albany, New York, which are the closest readings for Vermont. Figure 2f clearly indicates the presence of inversion (temperature increase with height) and isothermal (constant temperature with height) layers in 2008, as well as the dry slots (regions of low atmospheric humidity) in the atmosphere at higher altitudes.

PILOT PROGRAM OUTCOMES

The results of the SWAC pilot program can be evaluated in terms of teacher pedagogy, student learning, and at a programmatic level. The three cohorts of teachers have spent 1–3 y using backward design (Wiggins and McTighe, 2005) and project-based learning (Krajcik et al., 2002; Colley, 2008; Toolin and Watson, 2010b) to create inquiry-based, SWAC-themed learning experiences for students in their chemistry, physics, Earth science, history, global studies, biology, and astronomy classes. Their SWAC immersion has allowed them to effect curricular change in varied ways that are appropriate to their specific curricular challenges.

Figure 3 summarizes the pretest and posttest results from five teachers across the pilot period, assessing their knowledge about two selected modules—cloud processes (Module 2) and land surface interpretation methods (Module 5). Data from these five teachers represent a cross-section of participants with the most consistent attendance across the three cohorts. Data from the other modules were contaminated by nonresponse rates and/or absenteeism and are not presented here. A number of nonparametric tests including the Friedman rank test and its associated *P*-value were computed, but not reported here because they were affected by the small sample size of teachers surveyed, as well as the high non-response rate, which is shown as missing bars on Figure 3. The mean scores, as reported by teacher, highlight their varying disciplinary backgrounds and content preparation. The cloud assessment tested items such as the four mechanisms for cloud development, the connection between convective clouds and fronts, the meaning of comma clouds on visible satellite imagery, and the difference between the two rain

TABLE IIc: Explanation of the Climate Literacy Principles (CLP) used in Table IIa (available at http://www.climatescience.gov/Library/Literacy/).

Climate Literacy Principle	Description
1	The Sun is the primary source of energy for the Earth's climate system.
a.	Sunlight reaching the Earth can heat the land, ocean, and atmosphere. Some of that sunlight is reflected back to space by the surface, clouds, or ice. Much of the sunlight that reaches Earth is absorbed and warms the planet.
2	Climate is regulated by complex interactions among components of the Earth system.
a.	Earth's climate is influenced by interactions involving the Sun, ocean, atmosphere, clouds, ice, land, and life. Climate varies by region as a result of local differences in these interactions.
e.	Airborne particulates, called "aerosols," have a complex effect on Earth's energy balance: they can cause both cooling (by reflecting incoming sunlight back out to space) and warming (by absorbing and releasing heat energy in the atmosphere). Small solid and liquid particles can be lofted into the atmosphere through a variety of natural and man-made processes, including volcanic eruptions, sea spray, forest fires, and emissions generated through human activities.
3	Life on Earth depends on, is shaped by, and affects climate.
e.	Life—including microbes, plants, animals, and humans—is a major driver of the global carbon cycle and can influence global climate by modifying the chemical makeup of the atmosphere. The geologic record shows that life has significantly altered the atmosphere during Earth's history.
4	Climate varies over space and time through both natural and man-made processes.
b.	Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals.
d.	Scientific observations indicate that global climate has changed in the past, is changing now, and will change in the future. The magnitude and direction of this change is not the same at all locations on Earth.
5	Our understanding of the climate system is improved through observations, theoretical studies, and modeling.
b.	Environmental observations are the foundation for understanding the climate system. From the bottom of the ocean to the surface of the Sun, instruments on weather stations, buoys, satellites, and other platforms collect climate data. To learn about past climates, scientists use natural records, such as tree rings, ice cores, and sedimentary layers. Historical observations, such as native knowledge and personal journals, also document past climate change.
7	Climate change will have consequences for the Earth system and human lives.
e.	Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change. Animals, plants, bacteria, and viruses will migrate to new areas with favorable climate conditions. Infectious diseases and certain species will be able to invade areas that they did not previously inhabit.

clouds (cumulonimbus and nimbostratus). The land surface interpretation questions focused on the use of tone (amount of radiation reflected or emitted by a surface), why leaves appear green at the visible wavelengths while water bodies appear dark, and other deductive tools (e.g., the shape, size, and location of objects on the landscape) routinely used in remote sensing. Of the two modules reported, larger gains were observed in cloud content knowledge. In contrast, the smaller gains (if any) noted in the land surface interpretation module may reflect the fact that human beings are remote sensors, making many of the basic skills used in remote sensing seem more intuitive.

Teachers reported using SWAC materials in a variety of classroom and outdoor settings. These included beginning class with a "weather minute" start-up activity or mystery photo of that day or previous day's systems, using SWAC information and resources to support "student's flippant comments related to science," and modifying their curriculum to include semester-long units devoted to a problem-based activity or project. Project-based group work encouraged students to become independent learners as they developed their problem posing and solving skills. Other teachers reported that the more content they acquired, the more enthusiastic they became in class and the better able they were to simplify material for their students. Sample projects by SWAC teachers included:

- An inquiry-based ozone project in which students posed research questions that led them to the enduring understanding that "ozone can be beneficial as well as detrimental to life on Earth, depending on its location and concentration." This project could be broadened for use in biology and chemistry classes by incorporating the sources of ozone (e.g., forest fires, welding) and the ways in which plants like milkweed are affected.
- Prior to Tropical Storm Irene in August 2011, the Flood of 1927 was the flood of record across much of Vermont. In designing a project around the latter natural disaster, one teacher exposed her history students to the complexity of the human–environment interaction where an appreciation of weather and climate processes gave new insights into the historical analysis of this event. A similar approach was taken by the same teacher using the D-Day

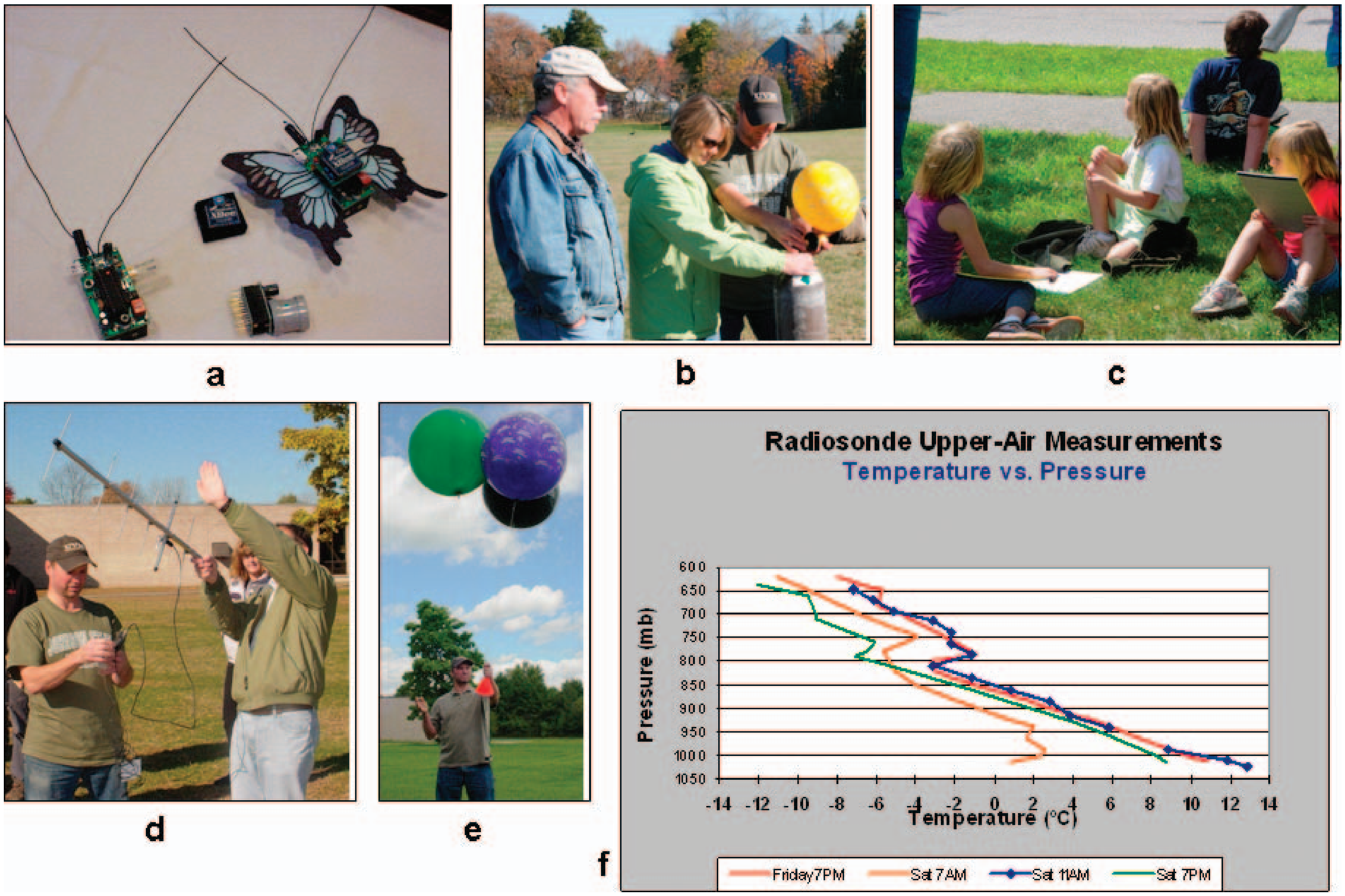

FIGURE 2: CricketSWAC Junior with gas sensor unit designed by M. D. Fortney (a); SWAC teachers M. Powers and N. Kenyon assisting M. D. Fortney with balloon inflation in October 2008 (b); Milton, Vermont summer camp prekindergarten students recording temperature observations in July 2010 (c); data collection by M. D. Fortney and S. Hogan using a Yagi antenna and speaker in October 2008 (d); M. D. Fortney preparing for balloon launch in July 2010 (e); Balloon launch data comparison from 18 October 2008—CricketSWAC temperature profile (blue) at 1100 EDT vs. radiosonde data from Albany, New York (1900 EDT 18 October, 0700 EDT 19 October, 1900 EDT 19 October) (f).

invasion as a theme to allow students to explore the pivotal role that weather prediction played in that event.

- One middle school teacher's students summarized their semester long daily observations in a number of creative ways, including creating a cloud book for younger students, forecasts for the rest of the school, and weather and topographic maps.
- High school students used field notebooks and electronic weather station data at their school to observe and analyze daily weather trends, with a focus on specific events and why they change over time. In keeping with Wilkinson (1899), these students were able to compare the daily weather observations at their school with those recorded by the National Weather Service and identify changes in air pressure with altitude, a concept that is often difficult for elementary and middle school aged children to grasp.
- Finally, one teacher reported using SWAC "to design curriculum that is problem-based and framed around essential questions and understandings," a design that "has added relevance, clarity, and organization to

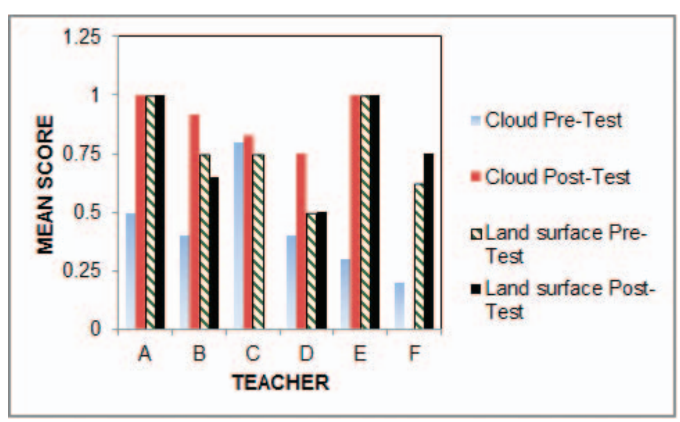

FIGURE 3: Mean pretest and posttest scores for the Cloud and Land surface interpretation modules, reported for five selected teachers.

TABLE III: June 2011 summary survey of 12 teachers to quantify SWAC's impact on their pedagogy and their students' learning during the 2010–2011 academic year.

	Mean
A. How has participating in SWAC influenced your approach to teaching?	
I use more Internet-based resources now than before SWAC	1.33
I use more project-based approaches than before SWAC	1.22
I use restructured parts of my curriculum	1.20
I use more outdoor activities now than before SWAC	1.00
I use more inquiry-based approaches than before SWAC	1.00
I am more collaborative with other teachers in my school	0.78
I have restructured my entire curriculum	0.50
B. How have the following SWAC frameworks changed or assisted you as an educator?	
The varying disciplinary expertise of the team members	1.44
Content knowledge	1.44
The opportunity to interact and share with other teachers	1.33
Geospatial skills	1.33
The opportunity to present my SWAC modules and projects	1.22
The ability to expand and think across disciplines in my teaching	1.22
My effectiveness as a teacher	1.22
C. SWAC content and activities have helped your students to improve the following skills	
Observational skills	1.86
Critical thinking skills	1.57
Collaboration in small groups	1.50
Interpretation skills	1.43
Mapping skills	1.33
Research skills	1.29
Technology	1.17
D. Your students' knowledge has increased in the following fields	
The atmosphere in general	1.67
Cloud identification	1.60
Weather forecasting	1.50
Use of Google Earth and other geoviewers	1.43
Health of the environment around them (vegetation, streams)	1.33
Ability to think in three dimensions (e.g., tropospheric profile)	1.17
Applications of the electromagnetic spectrum	1.00
Remote sensing in general	1.00
E. Have you observed improvement in your students' attitudes towards science in general and climate science in particular over this academic year?	
Better understanding of the world around them	1.43
Interest in atmospheric and climate science	1.29
Interest in science	1.25
Improved interest in conducting research projects	0.71
Expressed interest in a science career	0.57
Improved motivation about school overall	0.50
Expressed interest in an atmospheric/climate science career	1.33
Expressed or renewed interest in applying to college or university	0.20
Expressed interest in a technology-related career	0.17
Expressed interest in an engineering career	0.17

TABLE III: continued.

	Mean
F. What were your challenges in the implementation of SWAC content in your curricula?	
Not teaching physical science this year	2.00
Need more practice in applying the content	1.00
Lack of funding to purchase resources	0.86
Monthly workshops have been too short	0.71
Lack of access to computers or other technology	0.71
Too much material has been presented	0.50
I forget some of the material	0.50
Inadequate support from the SWAC team	0.33
Too much time between monthly workshops	0.25
Lack of institutional support	0.00

my weather unit." In response to this shift "[s]tudents have appreciated this and have invested more time and energy into their learning."

In June 2011, 12 SWAC teachers were surveyed about the degree of influence (none, some, strong) that participation in the program had had on their pedagogy and students' learning experiences over the 2010–2011 academic year (Table III). Pedagogically, teachers reported the largest impact on their increased use of Internet-based resources, project-based approaches and restructuring parts of their curriculum (Table III.A). In terms of the SWAC programmatic framework (Table III.B), teachers reported strong influences in every aspect especially the interdisciplinarity of the team, content knowledge, the Teacher Learning Community, and geospatial skills.

Student exposure to SWAC content occurred during class time, individual and group projects, lab sessions, outdoor activities, and other homework activities. Teachers' survey responses (Table III.C–E) indicated marked improvement in student skills (Table III.C), especially their observational skills, critical thinking, and ability to work in small groups, in keeping with other programs such as GLOBE and S'COOL (Chambers et al. 2003; Butler and MacGregor, 2003). Increases in student content knowledge (Table III.D) were greatest for atmospheric concepts, cloud identification, weather forecasting, and the use of Geoviewers. Conversely, the least gains in student knowledge (as reported by the teachers) were observed about remote sensing in general and the applications of the electromagnetic spectrum. Finally, the teachers reported that SWAC's influence on students' attitudes (Table III.E) was greatest in understanding the world around them, an increased interest in science generally, and atmospheric and climate science in particular. SWAC did not have any appreciable influence on students' interest in pursuing science or engineering careers or applying to postsecondary education. This lack of student interest in Stem, Technology, Engineering and Mathematics (STEM) careers and tertiary education may be due to the fact that most of the participating teachers taught Grade 8–10 students during the pilot project.

Teacher-reported student comments about SWAC content, techniques or pedagogy echo their teachers' perception and include:

- That science is their favorite subject. "I would rather be in science than . . ."
- "I liked going outside and taking our own data like real scientists."
- "When we did the weather books it really helped me to understand the symbols and the clouds. It helped by doing it every day to get practice. I can now use those terms and skills to understand the weather on the weather channel."
- "I liked checking the rain gauge and seeing how much snow converted to water when melted."

Programmatically, when asked to compare the SWAC pilot program design with other professional development programs in which they have participated, teachers stressed that it "promotes teacher understanding and development of lessons and units that will engage students in problem-based learning and connects to real-life situations"; "makes me a more informed teacher, which makes it easier to teach the subject matter—easier to simplify concepts if my understanding is deeper"; "[h]elps one integrate weather and climate into a variety of science classes as well as other disciplines"; is "a stimulating learning environment for me [that] has made my teaching more enjoyable"; allows greater access to experts; is "[l]ong term, not just a week or a semester." As Table III.F highlights, meeting every month during the academic year and alternating lesson-planning workshops with content workshops, which both contribute to the successful implementation of SWAC content.

One of the most enduring outcomes of the SWAC program is the Teacher Learning Community. Modeled after the SWAC team's own interdisciplinary expertise (climatology, meteorology, engineering, technology, and education), teachers share their pedagogical successes and failures, experiments, and project ideas all in a safe, supportive environment that is often lacking in their home institutions. Out of these sharings have emerged cross-disciplinary teaching practices between SWAC teachers and their non-SWAC counterparts at their home institutions (e.g., physical science and biology) around common climate projects involving the role of climate in influencing plant and animal life. Other SWAC teachers have used their weather and satellite knowledge to contribute to curricular change at the whole-school level in an effort to use climatology and

TABLE IV: SWOT analysis completed by nine SWAC teachers and one SWAC team member in January 2010.

Strengths	Weaknesses
– "Real time correlation of theory with practical application" – "Sharing ideas with other teachers" – "Having access to experts in the field" – "Subject matter can be used in many areas of study," "Relevant" – "Multidisciplinary expertise" – "Significant resources" – "High level of technical knowledge" – "Authentic curriculum" – "Multiyear grant opportunity sustains the work" – "VGA partnership provides cross discipline exposure and opportunities" – "The ideas we all bring will reach a much broader student base than if we were working independently" – "Respectful and engaging climate for teachers"	– "Small scale" – "We are limited in the number of teachers we are currently reaching" – "Time constraints (two hours flies by)" – "Too much information can be hard to process in one sitting" – "Could benefit from more help incorporating information into actual lesson plans/units" – "Need more opportunity to practice what we learn with more feedback" – "Lack of media coverage" – "$$ is always an issue, marketing to the public costs money. Public support and involvement funds should be included."
Opportunities	**Threats**
– "Correlate weather/climate with impacts on people" – "Collaborate with State and Federal agencies/groups" – "Participate in job fairs emphasizing atmospheric sciences (research vs. operational work)" – "The world wide interest in global warming is something we could capitalize on" – "Our work to coordinate the standards with the lessons would help to propel SWAC forward" – "Make use of the push to incorporate project based learning and 21st century skills" – "Use the upper-level teachers to help the elementary teachers" – "Use various means to spread word about SWAC. Teachers are always looking for ways to bring the info into their classrooms – especially if the lesson plan is already written." – "Capitalize on authentic experiences for students outside the classroom" – "More media coverage, educational opportunities for the community" – "Outreach to nonparticipating schools" – "SWAC newsletter"	– "Lack of interest or understanding of atmospheric/climatic scientific concepts and how these sciences impact people" – "Limited options for teachers" – "Common assessment coupled with some teachers' unwillingness to compromise" – "Lack of funding" – "Curriculum changes or change in teaching assignments of core SWAC members" – "Lack of recruitment" – "The only risk to SWAC is obscurity. Keeping it visible and interesting for the public in general as well as other educators will keep it going."

ecology to create meaningful, outdoor, place-based, and project-based learning experiences for their high school students.

MOVING SWAC FORWARD

The SWAC pilot program was a small-scale exploration of the use of core atmospheric and earth science concepts as the basis for enhancing educators' competencies in these and related disciplines. Initial funding was requested for eight teachers per year. Recruitment strategies including leveraging existing long-term relationships between Vermont School Districts and the University of Vermont's College of Education and Social Services, targeting school principals, word of mouth, and the use of balloon launches as a marketing tool. In January 2010, the growth potential of the program was evaluated via a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis (Table IV). Results indicate that while the program provided authentic curriculum in a respectful atmosphere, there was still room for expansion in terms of recruitment, higher profile publicity, and widespread understanding of the need for climate literacy. These suggestions were incorporated in the post-pilot phase and included partnering with Science Museums for recruitment and dissemination of the program.

There are a number of ongoing curricular challenges to the full incorporation of SWAC across the curriculum. As a consequence of the de-emphasis of Earth science in many high school science curricula in Vermont, many teachers were faced with the challenge of trying to fit Earth science concepts into physics, chemistry, and biology classes. Other teachers were challenged to integrate physics and chemistry into Earth science as one SWAC teacher attempted to do through the aforementioned ozone project that she implemented with her students in November 2008. To address this challenge, the SWAC team created an online document that explicitly linked SWAC core concepts to Vermont Learning Standards and sample classroom activities using satellites, weather or climate tools (http://www.uvm.edu/~swac/docs/CoreConceptsPacket.pdf).

The SWAC program recognizes the more fundamental challenges that regularly confront secondary teachers with respect to students meeting basic literacy and numeracy standards at the high school level. SWAC teachers have reported that some of their ninth grade students read at a fifth grade level, while others never acquired processing and problem-solving skills in the K–8 levels. In addition, teachers have reported that there is a significant challenge in some school districts where 25%–33% of the students are non-native English speakers, further compounding the aforementioned literacy concern, as well as the science and technological concepts that are superimposed upon this uneven student landscape. In response to these basic literacy needs, SWAC team and module delivery model principles and practices of differentiated instruction to address the range of literacy needs for the diversity of students in the science classroom, while differentiating instruction in order to meet the needs of various cohorts of teachers who began the SWAC program at different times.

Conducting long-term, standards-based projects that are interesting and relevant is essential to science teaching and learning today (Krajcik et al., 2002). The projects that SWAC teachers design are a means of engaging students in true geoscientific inquiry. By posing and answering questions that are relevant to their own lives and communities, students ultimately produce tangible products that can have meaning far beyond the walls of the science classroom (Colley, 2008). In the project-based classroom, the teacher becomes a manager or coach who learns alongside students and directs them toward worthy and credible resources. Often, the most successful projects involve a community expert (such as a local meteorologist or engineer) who is as invested as students are in the project. When new project topics emerge, students should be encouraged to find the appropriate sources on the internet or in the local community. With guidance, students learn to critically evaluate sources of information (Toolin and Watson, 2010a,b).

Dissemination of the SWAC program results included the content knowledge, lessons learned, teacher action research, and recruitment. Participating teachers receive a SWAC Module notebook—a hard copy and electronic compilation of the presentations, background materials, sample exercises, and lesson plans of the eight modules. The SWAC website (http://www.uvm.edu/∼swac) archives instructional videos of step-by-step implementation guidelines for the geospatial modules (e.g., using Google Earth to perform Earth science, biology, or geography labs), as well as the narrated versions of the atmospheric and land surface modules. SWAC brochures described the program and its benefits and were used as a recruitment tool for new teachers.

One of the expectations of the SWAC program is that participating teachers plan and implement an action research project assessing the impact of SWAC activities on their teaching ability and/or their delivery of science instruction and/or their students' science achievement or interest. Participating teachers have presented the results of their project-based pedagogy at two SWAC Fairs held locally in Burlington, Vermont in 2010; at an Action Research Conference at the University of Vermont, also in 2010; as well as at the National Science Teachers Association (NSTA) meetings in Philadelphia (2010) and San Francisco (2011). Summaries of project-based lesson plans and activities have also been disseminated to other teachers at these venues as well as on the SWAC website. At the same time, SWAC team members have presented the research findings of the program at scholarly conferences such as the American Meteorological Society Annual Meeting, the American Geophysical Union Fall Meeting, a GLOBE workshop at the World Meteorological Organization, and the Association for Science Teacher Education Annual Conferences.

SUMMARY

The SWAC pilot trained a total of 14 middle and high school teachers from 2008–2010. SWAC core concepts were found to be transparent across various science classes, which together with the very make-up of the three teacher cohorts, helped moved the pedagogy towards interdisciplinarity. Participating teachers gained confidence, not only in the subject matter and geospatial skills, but also in terms of curricular enhancements, with one teacher suggesting to the school administration a "new" way "to teach science." Teachers have become more reflective in their own teaching, partly from the experience of being SWAC "students" themselves and experimenting with new teaching and learning methods. Most of all, teachers now gravitate towards creating strong, place-based learning experiences for their students that are deeply rooted in real-world data and meaningful in their outcomes.

One of the unique contributions of SWAC is the use of geospatial technologies to address both atmospheric and land processes in a problem and project-based environment that is accessible to students at all levels from K–12. In so doing, SWAC brings to the K–12 curriculum what Dutton (1992) observed about post-secondary education in the 1990s, that atmospheric and Earth science students needed to focus on the innovative use of technology as remote sensing and computer-enhanced visualization became more commonplace. It is interesting to note that such dynamic visualization of real-world examples was critical in producing the greatest benefit among learning disabled and disruptive students during the EarthStorm project (McPherson and Crawford, 1996).

By incorporating SWAC content and geospatial skills into a variety of student learning experiences, participating teachers were able to report that the program's largest impact was on their students' observational and critical thinking skills, knowledge about the atmosphere and its components, and interest in the atmospheric and climate sciences. Pedagogically, teachers also reported an increased use of Internet resources, project-based approaches, and curricular restructuring. At the end of the pilot phase, the SWAC Team received a Phase II NSF Geoscience Education Award (GEO-1034945) to expand the pilot results for an additional 4 y. The new program will feature greater depth and breadth of the core knowledge and skills, as well as reach off-site teachers via distance learning technologies.

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