USING THE AMAZING ATMOSPHERE TO FOSTER STUDENT LEARNING AND INTEREST IN METEOROLOGY

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After touring NOAA and Air Force Weather Agency facilities, students pore over numerical weather prediction output, surface observations, and satellite and radar imagery and then head to the field to view severe convective storms.

In meteorology education, undergraduate enrollments have been increasing substantially since the middle 1990s, a trend that has continued into the late 2000s to reach levels unprecedented in at least the last 40 years (Knox 2008). That growth has materialized at the United States Naval Academy (USNA) Oceanography Department too, as we have seen our number of Bachelor of Science degrees essentially doubling during the 2000s, from the low 40s to over 80 granted per year (our B.S. degree includes meteorology and oceanography coursework at roughly equal levels). Part of the challenge with increased interest, and subsequent increased undergraduate enrollments, is to develop curricular programs that both engage students and further their knowledge of the atmosphere. To that end, the Oceanography Department designed and implemented a new field activity in May 2010, the Severe Weather In-Field Training (SWIFT).

The educational goals of SWIFT were to 1) deepen student understanding of the complex atmospheric processes that result in severe weather; 2) equip students to comfortably use, in real time, the variety of observational and numerical modeling data available; 3) offer students repeated opportunities to apply course content—such as atmospheric dynamics, synoptic meteorology, and thermodynamics—to real-world situations; and 4) move students from role of passive learner to that of active participant in scientific inquiry (e.g., Thielman et al. 2011). As active learners, SWIFT had the potential to increase student interest in scientific research at the undergraduate level (Gonzalez-Espada and LaDue 2006). The professional development goals of SWIFT were to 1) introduce students to a variety of Department of Defense and civilian careers in meteorology and 2) increase their interest in pursuing a science-related career upon graduation. The primary activities of

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SWIFT were 1) National Oceanic and Atmospheric Administration (NOAA) SKYWARN spotter training, 2) daily student-led weather discussions, 3) visits to operational weather centers including the Air Force Weather Agency and the Storm Prediction Center, 4) visits to major NOAA research facilities, 5) discussions with academic staff about graduate school and research opportunities, and 6) observations of various modes of severe convective storms and their products, including tornadoes, large hail, and strong winds, on the Great Plains. SWIFT took place in both 2010 and 2011, and this article focuses on events and learning outcomes from both years.

The USNA mission to develop its students academically is only part of a broader goal to graduate leaders dedicated to naval service with potential to assume the "highest responsibilities of command, citizenship and government" (USNA 2010). Like college students in other institutions across the country, USNA midshipmen take a rigorous academic course load during the traditional fall and spring semesters. However, they also spend their summers participating in required training activities designed to prepare them for a demanding career as a Naval or Marine Corps officer. SWIFT was designed to satisfy this institutional mission and give future officers a deeper, richer understanding of weather through an exciting field experience. The remainder of this article contains a justification for SWIFT from the peer-reviewed science and educational literature, a brief description of the logistics and implementation of SWIFT, and a summary of student learning outcomes.

EDUCATIONAL JUSTIFICATION. To maintain student interest in science and help them retain information they learn in the classroom, it is important to engage students in critical-thinking activities, particularly early in their major curriculum (e.g., Lathrop and Ebbett 2006). This reinforcement is especially beneficial given that large-lecture introductory meteorology courses typically incorporate teaching methods only "adequate for content learning" (for example, lecturing) that do not accomplish the goal of "application learning" (Kahl 2008). The primary components of SWIFT engaged students actively in key stages of the scientific method including developing hypotheses, taking and analyzing observations, and forming conclusions based on their hypotheses and observations. Specific emphasis was placed on repeated interrogation of real-time observational data to help students better understand the physical processes in the atmosphere (Etherton et al. 2011).

Recent studies have shown that undergraduate students understand scientific principles through field experiences (e.g., Knapp et al. 2006; Lathrop and Ebbett 2006; Aitchison and Ali 2007; Elkins and Elkins 2007). Recognizing their value, many university meteorology degree programs have incorporated formal field courses into their undergraduate-level curricula. For over a decade, The City College of New York offered an instrumentation course where students traveled to Storm Peak Laboratory in the Colorado Rocky Mountains to collect cloud droplets (Hindman 1993; Borys and Wetzel 1997; Hallar et al. 2010). In 1999, the University of Arizona developed an undergraduate course that allowed enrolled students to take vehicle-mounted measurements to actively investigate the heat island effect in Tucson, Arizona (Comrie 2000). The field campaign Rain in Cumulus over the Ocean (RICO) took special efforts to involve undergraduate students in the project (Rauber et al. 2007). Faculty at Texas Tech University developed a field program to connect measurements and laboratory analysis (Schroeder and Weiss 2008), and the meteorology department at Pennsylvania State University implemented a field course in Doppler radar analysis (Richardson et al. 2008). Western Kentucky University (WKU) implemented a field-based course as a "capstone" option for their meteorology majors in 2010 (WKU 2010), and The College at Brockport, the California University of Pennsylvania, and the College of DuPage offer similar storm chasing courses. Finally, the University of North Carolina at Asheville offered a joint storm chasing-career development class in 2008 and 2009 (Godfrey et al. 2011). These and other similar courses and projects with an emphasis on active learning (see Table 1) have engaged undergraduate meteorology students in the learning process through hands-on measurements, analyses, field experiences, and writing exercises.

The curriculum structure of SWIFT emphasized critical thinking by requiring students to frequently analyze, interpret, and then make decisions based on charts of numerical weather prediction (NWP) model output and surface, satellite, and radar observations. For example, throughout each day, students had to note changes in surface wind direction and speed, surface moisture content, cloud cover, and sea level pressure and analyze the positions of pressure centers and any associated dry line, cold front, warm front, or outflow boundaries, all with the goal of correctly identifying the location and timing of severe convective storms. Students then had to discuss with each other and synthesize these observations and create

Table 1. Selected meteorology courses and activities with emphasis on active learning.

Program/Location	Experience and activities	Author(s)
Storm Peak Laboratory	Hands-on cloud physics experiments	Hindman (1993); Borys and Wetzel (1997); Hallar et al. (2010)
Heat island effect	Vehicle-mounted instrument study of urban heat island in Tuscon, AZ	Comrie (2000)
Rain in Cumulus over the Ocean (RICO)	Measure and model microphysics of tropical cumulus clouds	Rauber et al. (2007)
Measurement and Analysis Laboratory	Measure properties of the dry line and environment of severe convective storms	Schroeder and Weiss (2008)
The Pennsylvania Area Mobile Radar Experiment (PAMREX)	Integrating classroom learning and research in a mobile Doppler radar field experience	Richardson et al. (2008)
Field-based capstone course	Meteorology major capstone storm-chasing class	WKU (2010)
Undergraduate field course	Career enhancement and storm chasing	Godfrey et al. (2011)

(in the morning) or critically analyze (during the day) their logistics plan for that day's activities. If they concluded that new observational data or model output indicated a different geographic region or time of convective initiation, they had to decide whether to accept that new information and amend the logistics plan. At each point in this process, students discussed their thinking with the faculty and received feedback on their decisions. Once severe convective storms formed, students had to analyze radar data and decide the best positions to view a selected convective storm. Throughout SWIFT, faculty communicated high expectations: a correct forecast and safe, optimal routing. This hands-on and student-led component of the course reinforced core content from several Oceanography Department courses: Introduction to Meteorology, Atmospheric Thermodynamics, Synoptic Meteorology, and Atmospheric and Oceanic Processes. It also emphasized higher-order thinking skills and training of students to use these skills effectively to benefit their careers (Seguin and Smith 2010). Finally, SWIFT satisfied all seven good practice principles of undergraduate education: frequent student–instructor interaction, student cooperation, active learning, prompt feedback, task emphasis, clear communication of high expectations, and respect for diversity in learning styles (Chickering and Gamson 1987).

LOGISTICS AND IMPLEMENTATION. The Oceanography Department solicited SWIFT participants by email and an information session early in the spring semester, and in 2010 (2011) 20 (30) sophomore- and junior-level students applied. Application was open to all USNA students. Students were selected based on their essay responses to the following questions: 1) Why do you want to participate in SWIFT? 2) What will you contribute to SWIFT by participating? 3) What do you expect to learn? 4) How will your participation in SWIFT benefit you in your future career? These four questions were designed with two goals in mind: to help the faculty leaders gauge student interest and to set a tone that SWIFT would be a learning activity.

To maximize the effectiveness of students' time in the field, in the weeks leading up to departure, SWIFT participants met frequently for training. This training consisted of weather discussions, overviews of trip logistics, and a discussion of three scientific papers relevant to dynamics and forecasting of severe convection (Doswell and Burgess 1993; Doswell 2001; Rasmussen 2003). Two weeks before departure, a representative from the local National Weather Service forecast office in Sterling, Virginia, came to USNA and presented the Basic I spotter training class, which drew over 70 people from both USNA and the greater Annapolis community.

On a typical day with severe storms, students and faculty members would spend between 8 and 12 hours on the road, divided between driving to the target area, waiting at the target area for convective storm initiation, and traveling alongside an existing convective storm. Therefore, to increase interaction between students and faculty, and to ensure that all students were able to participate in any impromptu conversations, participation was limited to the capacity of one 15-passenger van (10 students and 2 faculty members). A group any larger than this would need

Table 2. List of duties for weather and logistics teams.

Team	Duties
Weather team	Lead daily a.m. weather discussion and provide updates throughout day
	Complete forecaster worksheet (see Table 2)
	Maintain situational awareness with weather data: surface, satellite, radar
	Stay abreast of NWS and SPC weather products (watches, warnings)
	Report observed severe weather promptly to authorities
	Take measurements at stops with Kestrel 3500 and compare to nearby surface observations
Logistics team	Coordinate navigation with weather team
	Clean and gas up vehicle
	Make lodging reservations and plan food stops
	Record the day's activities electronically (photos, videos) and charge equipment at night
	Send pictures and updates via social media
	Summarize each day's activities in a blog entry posted online

additional vehicles, leading to a more fragmented learning environment whereby student learning would differ between vehicles. Furthermore, because the trip cost around $1,000 per student (partially supported by generous support from the USNA Science, Technology, Engineering, and Mathematics STEM office), increasing the number of participants would further increase costs.

To ensure that students were indeed engaged in active learning, they were split into two teams of five, each led by a senior student and supervised by one of the principal investiagtors (PIs): a weather team and a logistics team. Teams rotated duties daily (so the weather team members on day 1 became the logistics team for day 2, etc.), and while group leadership stayed constant, the team "point person," who sat in the front of the van and was responsible for making decisions for the team, rotated among each of the group members. Each team was assigned specific tasks for the day (see Table 2). The weather team led the morning weather discussion (Fig. 1) and, on days with expected severe storms, selected a target area, monitored weather data throughout the day to refine the target area, and positioned SWIFT in a region favorable for observing severe storms. The weather team was guided by a forecasting worksheet (Table 3), which they completed daily. The logistics team handled the van servicing (gas and cleaning) and made arrangements for food and lodging en route, coordinating regularly with the weather team to determine optimal routing and likely locations. The logistics team was also responsible for sending pictures and status updates in real time to over 200 SWIFT followers on our social media accounts, as well as submitting storm reports via the Spotter Network and phoning the local National Weather Service (NWS) forecast office. The weather team was equipped with laptop computers with GRLevel3 radar software and mobile internet access via a broadband USB modem, along with three hand-held Kestrel 3500 instruments that they used to measure surface temperature and dewpoint temperature conditions during stops (Fig. 2) and compare with nearby Automated Surface Observing System (ASOS) observations. The logistics team had access to DeLorme road atlases as well as dedicated laptops of their own. Students rotated their positions within the van daily depending on their team duty. Feedback from participants in 2010 indicated that student participation in either the weather or logistics team was more difficult from the back row of the van. Therefore in 2011, students were split into three teams that rotated among weather, logistics, and "down." This third team sat in the back of the van and assisted in social media updates (during the day) and prepared for the following day's weather discussion (during the night).

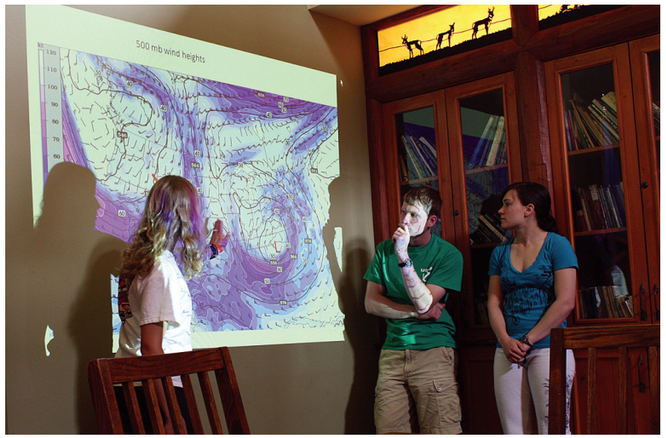

Fig. 1. Weather team leading the morning briefing in Lone Wolf, Oklahoma, at 10:00 a.m. CDT 16 May 2011.

Table 3. Sample from 18 May 2010 severe weather worksheet: a quick guide to forecasting severe weather. Parameter thresholds are taken from Rasmussen (2003).

Time: 0000 UTC	Date: 18 May 2010	Lead forecaster:	
Other forecasters:			
Upper-level features	**Forecaster comments**		
500-mb trough/jet	Trough axis near NV/NM/CO; 35-kt jet		
700 mb-low/jet	Low located over NV, shortwave ridge over eastern OK		
850-mb jet	Low-level jet ~10 kt		
850-mb moisture axis	Humidity along NM/TX border		
Surface features	**Forecaster comments**		
Trough/low pressure	Trough axis over NV/AZ/NM/S TX		
Surface winds	NNE west of NM/TX border		
Moisture axis	North to south on TX/NM border		
Dryline	Diffuse dryline over eastern NM		
Warm front	Over moist axis above TX/OK		
Cold front	N/A		
Outflow boundaries	Eastern terrain of NM		
Severe parameters and indices [thresholds from Rasmussen (2003) in parentheses]	**Current magnitude** (if applicable)	**Forecast magnitude** (if applicable)	**Forecaster comments**
CAPE axis (> 2,100 J kg^{-1})	N/A	3,000 J kg^{-1}	Northwest TX
0–6-km vertical shear (>40 kts)	> 60 kt	60 kt	N/A
0–3-km helicity (>180 m^2 s^{-2})	> 40 m^2 s^{-2}	> 100 m^2 s^{-2}	N/A
0–1-km helicity (>120 m^2 s^{-2})	>10 m^2 s^{-2}	> 50 m^2 s^{-2}	N/A
Today's forecast	**Forecaster comments**		
Time of convective initiation	Approx. 1600 LT in northeast NM and northwest TX		
GO/STANDBY/NO-GO	GO		
Target area	Dalhart, TX		
Secondary target area (if applicable)	Clayton, NM		
Expected storm mode	Large hail, supercells, tornadoes		
Departure time	0800 local		

In addition to forecasting and observing severe convective storms, SWIFT also included professional development activities. In 2010, students visited Offutt Air Force Base in Omaha, Nebraska, to speak with both civilian and duty officers tasked with preparing and improving forecasts for Air Force operations. In 2011, students visited the Air Force's Operational Weather Squadron based at Fort Campbell, Kentucky. SWIFT students also visited the National Weather Service forecast office in Norman,

Fig. 2. Taking surface temperature and dewpoint temperature observations near Goodland, Kansas, on 23 May 2010 with a Kestrel 3500 ten minutes before tornado touchdown.

Oklahoma, and observed the preparation and launch of a 0000 UTC OUN radiosonde. Students were also briefed on meteorological research during tours of the NOAA National Severe Storms Laboratory, the NOAA Radar Operations Laboratory, the NOAA Phased-Array Radar, and field visits with scientists participating in the Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2; Fig. 3). Finally, in 2011, SWIFT students learned about one of the unfortunate consequences of severe convective storms: damage and destruction as a result of the EF-5 tornado in Joplin, Missouri (NWS 2011). After coordinating with the Joplin Fire Department and receiving a formal invitation, the students spent the last day of SWIFT involved in search and rescue efforts. While an unexpected part of SWIFT, that activity significantly impacted their learning experience by solidifying the important societal benefits understanding and accurately forecasting severe convective storms.

In response to student feedback, future SWIFT iterations might consider reducing the number of students to nine (to give extra space in the cramped van), as well as including more diverse and hands-on professional development visits. Additionally, a visit to a storm-affected community such as Joplin, Missouri, to assist with rebuilding can also be included. Otherwise, student feedback (total of 20 responses) was overwhelmingly positive and suggested that the logistics of the trip were well organized.

ASSESSMENT OUTCOMES.

To evaluate student learning, SWIFT used one indirect and four direct assessment activities: 1) a pre- and post-SWIFT interest questionnaire from each student; 2) a pre- and post-SWIFT content quiz, also from each student; 3) a daily forecast worksheet and briefing from that day's weather team leader; 4) a daily journal from each student; and 5) a post-SWIFT essay from each student. The questionnaire measured student awareness of careers in meteorology and the atmospheric sciences and measured their interest in science research in a meteorology-related Navy career (see Table 4). In both 2010 and 2011, student predeparture responses indicated an already high level of interest in the Navy Meteorology and Oceanography (METOC) officer community, atmospheric science research, and operational meteorology. Not surprisingly, then, the post-SWIFT responses in these three areas were essentially unchanged. The most interesting movement was student interest in research in Science, Technology, Engineering, and Mathematics (STEM), with mean pre-departure interest (out of 10, with 10 being high interest) of 6.6 and 6.8 in 2010 and 2011, respectively, climbing to mean of 7.9 and 7.5 after SWIFT,

Fig. 3. Briefing near Leedey, Oklahoma, 19 May 2010 on the science objectives of the VORTEX2 field project with Dr. Daniel Dawson, National Severe Storms Laboratory mobile mesonet operator.

Table 4. Student interest inventory. Both before and after participating in SWIFT, students were asked: "On a scale of 1–10, with 1 being low and 10 being high, how would you rate your interest in [a given subject]?" While the final interest item, research in STEM, increased after SWIFT, none of the results was statistically significant at the 95% confidence level using a Student's *t* test.

	(rated 1–10, with 10 highest)			
Interest in:	**2010**		**2011**	
	Before	After	Before	After
Navy Meteorology and Oceanography (METOC) officer community	8.4	8.4	7.4	7.3
Research in atmospheric science	8.7	8.6	7.6	8.1
Operational meteorology	8.0	8.6	7.9	7.9
Research in science, technology, engineering, and mathematics (STEM)	6.6	7.9	6.8	7.5

indicating that participation in SWIFT resulted in increased interest in STEM research. These increases were not statistically significant at the 95% confidence level using the Student's *t* test. Given that the measure of interest is quite subjective, the results suggest either that other measures or further sampling are needed to assess the level of interest and its change.

The first six questions of the second direct assessment activity (Table 5) were designed by the faculty to test knowledge of basic concepts in atmospheric science that students would likely use during SWIFT. These questions reside at the lower-order thinking skills of Bloom's taxonomy: "Knowledge and understanding" (Anderson and Krathwohl 2001). Question 7 (Table 5) was designed to test middle-order thinking skills: "Apply and analyze." Overall student performance on the quiz improved significantly after SWIFT: the mean predeparture scores were 54.4% and 63.9% in 2010 and 2011, respectively, while the post-SWIFT means were 90.4% and 90.6%. Student performance on the "apply and analyze" question showed similar improvement, with student scores moving up from an average of 61.4% in 2010 and 63.9% in 2011 to an average of 90% in 2010 and 86% in 2011 after SWIFT. Student improvement on this assessment from before to after the course—particularly the improvement on question 7—suggests that students increased their understanding of complex atmospheric processes leading to severe weather. All of these results were statistically significant at the 95% confidence level using the Student's *t* test, with the exception of the score on question 1 in 2011, which was significant at the 90% level.

The third direct assessment tool, the daily forecast worksheet and briefing (Table 3), was motivated by a desire for students to have a guide to assist them in the challenging requirement to organize and then present a convective forecast for their assigned day. The faculty participants provided students with an example

Table 5. Content and context quiz questions. Students were asked: "Please answer each of the following questions to the best of your ability. If you honestly do not know, please say so." Students answered the same questions before and after SWIFT and graded on accuracy out of 100%. Numbers in bold represent statistically significant differences at the 95% confidence level using a Student's t test.

Content questions	2010 *n* = 10		2011 *n* = 10	
	Before	After	Before	After
1. Define the term "upper-level trough"	**56.7**	**93.3**	67.6	86.7
2. What is a low-level jet?	**36.7**	**90.0**	**56.7**	**90.0**
3. What is a supercell?	**46.7**	**90.0**	**63.3**	**86.7**
4. What are the atmospheric ingredients necessary for supercell formation?	**70.0**	**96.7**	**60.0**	**86.7**
5. What is a tornado?	**70.0**	**100.0**	**73.3**	**96.7**
6. What are the atmospheric ingredients necessary for tornado formation?	**63.3**	**96.7**	**63.3**	**90.0**
7. Imagine a scenario where you are a forecaster responsible for predicting a severe weather threat. What information about the atmosphere do you want to know? What information would you communicate to the users of your forecast?	**61.4**	**90.0**	**68.6**	**85.7**

worksheet and brief during predeparture training and also for the departure day. The most experienced students (those who had taken the most courses) were selected to lead the early daily briefings and fill out the worksheet. As SWIFT proceeded, subsequent students used those examples to prepare their own worksheets and briefs. Worksheets from the end of SWIFT, when compared with worksheets from the start, were different primarily in their clearer focus on synoptic and mesoscale features in the target area. For example, in early worksheets, students highlighted midlevel shortwave troughs far from the target area (in one case, in eastern Canada), while by the end of SWIFT, students were much more focused on the mesoscale features that they considered pertinent to severe convective storm potential in their area of interest.

The indirect assessment activity, the daily journal, was motivated by the thought that for an activity as intense as SWIFT (with up to 18-h days consecutively), students would not remember details unless they wrote them down daily. Faculty regularly asked students about their journals and encouraged them to write daily, although there was no formal discussion of journal entries. Students used their journal entries to help in writing their post-SWIFT essay. Future iterations of SWIFT, or faculty implementing similar courses, may consider formally grading both the daily journal and the daily forecast worksheet.

Responses on this final assessment tool, the essay, indicated that students were exposed to variety of career options, increased their interest in science careers, deepened their understanding of complex atmospheric processes, were equipped to comfortably use real-time meteorological data, and applied course content to real-time situations. One student responded, "Participating in this training has been extremely rewarding and educational. [The tours] showed how the military [forecasters] play such a key role in predicting weather for military operations." Several students also commented on forecasting tools, with one saying "I became much more comfortable using [numerical] weather [prediction] models during this trip." Another student commented on the connection between science and operations: "We learned that major strategic operations . . . are greatly influenced by weather and in turn, accurate forecasts are needed." A fourth student highlighted the high expectations that the faculty had of the students: "I did not expect SWIFT to emphasize so heavily . . . my professionalism and organizational skills. A great deal of responsibility was placed on each of us throughout the trip." Finally, many students from 2011 commented about the impact of the rescue efforts in Joplin, with one student saying "getting to volunteer at the Joplin site was an opportunity that I will carry with me the rest of my life . . . (it) enhanced my training experience and gave me a whole new understanding of meteorological applications." Student essay content and synthesis suggested that they learned not only the science behind severe convective storms but also the tools and techniques involved in making successful forecasts.

CONCLUSIONS. Science and education literature are clear that students learn most during active learning and when they are engaged in the scientific process (e.g., Etherton et al. 2011). SWIFT was created as a unique learning activity that engaged students and furthered their knowledge of the atmosphere. Assessment outcomes indicated 1) that student interest in a pursuing a science career increased (although not statistically significant) as a result of participating in SWIFT and 2) that students' low- and middle-order thinking skills, particularly their ability to analyze data and make hypotheses, increased during SWIFT. Qualitative assessments outcomes also indicated student academic growth as a result of their participation in SWIFT: students clearly noted the most important atmospheric parameters for severe weather, and students synthesized these parameters and discussed the weather they observed as a result.

Although not a for-credit course but rather a training activity for the USNA Oceanography Department, we believe the educational justification, assessment outcomes, and logistical implementation details presented herein provide ample description for other interested universities and faculty members to implement a similar activity as a for-credit course. With available technology, very willing science organization hosts, and unprecedented interest in our field of meteorology, such courses can be excellent vehicles to further science education and develop the next generation of American scientists.

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ABSTRACT

To engage students in active learning, the Oceanography Department at the United States Naval Academy developed a new, not-for-course-credit training activity for its students, the Severe Weather In-Field Training (SWIFT). In SWIFT, 10 students and 2 faculty members traveled to the Great Plains and met with operational and research meteorologists, led daily weather discussions, made daily convective forecasts, and verified their convective forecasts by observing severe storms. Participation was solicited from sophomore- and junior-level students. SWIFT built on similar activities developed by other universities with its particular emphasis on assessing student learning and broadening awareness of both Department of Defense and civilian career opportunities in meteorology. Assessment outcomes from SWIFT indicate that students deepened their understanding of severe weather processes, were equipped to use observational and modeling data in real time, applied course content to real-world situations, became active participants in science inquiry, were introduced to a variety of meteorology career options, and increased their interest in pursuing a science-related career.