Advances in Engineering Education

FALL 2007

A Hands-on, Interdisciplinary Laboratory Program and Educational Model to Strengthen a Radar Curriculum for Broad Distribution

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ABSTRACT

This paper describes the details of a National Science Foundation multi-year educational project at the University of Oklahoma (OU). The goal of this comprehensive active-learning and hands-on laboratory program is to develop an interdisciplinary program, in which engineering, geoscience, and meteorology students participate, which forms a community of university scholars. The program is intended to generate a unique, interdisciplinary research oriented learning environment that will train future engineers and meteorologists in the full set of competencies needed to take raw radar data to detect weather and aircraft. The program involves new coursework and is oriented around other successful programs to ensure wide distribution by many students and

scientists. Supported by the Division of Undergraduate Education at the NSF, the project began with a Phase I grant in the fall of 2004, which also recently received a Phase II grant to refine the project through 2010. In keeping with the global movement of electronic knowledge delivery via written, as well as visual media, several weblinks have been established for this paper.

Keywords: interdisciplinary, broad distribution, multi-function radar

INTRODUCTION

Severe and hazardous weather such as thunderstorms, downbursts, and tornadoes can take lives in a matter of minutes. In order to improve detection and forecast of such phenomena using radar, one of the key factors is fast scan capability. Conventional weather radars, such as the ubiquitous NEXRAD (Next Generation Radar developed in the 1980's), are severely limited by mechanical scanning. Approximately 175 of these radars are in a national network to provide the bulk of our weather information. Under the development for weather applications, the electronically steerable beams provided by the phased array radar at the National Weather Radar Testbed (NWRT) can overcome these limitations of the current NEXRAD radar. For this reason, phased array radar was listed by the National Research Council as one of the primary candidate technologies to supersede the NEXRAD [1]. By definition, a phased array radar is one that relies on a two-dimensional array of small antennas. Each antenna has the ability to change its phase characteristics, thus allowing the overall system to collectively locate specific interesting regions of weather. The NWRT is the nation's first facility dedicated to phased array radar meteorology, and it also has a multi-function capability to allow it to be used for detecting aircraft. In addition, the demand for students trained in this area will be high as new radar technologies replace the ones designed 20 years ago, and as weather radar usage extends into areas such as homeland security. From the Federal Aviation Administration's (FAA) perspective [2], "a multifunction radar can support weather, air traffic control, homeland defense and Department of Defense surveillance needs simultaneously. The multi-functionality is of interest to the FAA as a compliment to Automatic Dependant Surveillance—Broadcast (ADS- B) as well as a possible program cost reduction solution for its aging fleet of ground based radars." Moreover, it is consistent with one of the National Oceanic & Atmospheric Administration's (NOAA) Mission Goals for the 21st Century: to serve society's needs for weather information [3]. More details about the NWRT are available at NOAA's National Severe Storms Laboratory website. This lab is located in Norman, Oklahoma.

www.nssl.noaa.gov/research/radar/par.php

Long-term warnings have improved greatly over the last five years and are now being used for critical decision making [4]. Further improvements are being aimed at providing longer warning lead times before severe weather events, better quantification of forecast uncertainties in hurricanes and floods, and tools for integrating probabilistic forecasts with other data sets. Many other industries, groups, and individuals use weather information. For example, the construction industry uses weather information to schedule specific activities and to purchase materials. Across the nation, middle and high school teachers use weather data to develop math and engineering skills in their students, which is essential for the future [5, 6, 7]. Following the classic Boyer Report, it is very important that no gap exists between teaching and research [8]. In addition, faculty members who creatively combine teaching with research are essential to the improvement of undergraduate education [9, 10, 11, 12]. With this in mind, we now introduce the model that governs and sustains the teaching and research mission of our university laboratory, as depicted in Figure 1. The synergistic interaction between teaching and research, their drivers and end-results is also illustrated. These drivers can be classified into those of resource needs (e.g., qualified personnel) and technology related issues. Resource needs can be further classified into three types, as noted below.

- Design and application engineers
- Radar system integrators and managers
- Research scientists

These needs are met by BS, MS, and PhD graduates, respectively. Thus our undergraduate and graduate educational initiatives have been developed to provide an appropriate level of training at the BS, MS, and PhD levels in this lab. The foundational key of the entire endeavor is the undergraduate educational process—these students are the first ones to enter our cycle that stresses lifelong learning, creativity, global awareness, and interdisciplinary collaborations. Sharing exciting projects with students naturally occurs here, since the authors have collaborative research projects at the NWRT. The laboratory/teaching program provides abundant opportunities for individuals that may concurrently assume responsibilities as researchers, educators, and students. The NWRT facilitates joint efforts that infuse education with the excitement of discovery and enrich research through a diversity of learning perspectives.

The program leverages a very successful, comprehensive outreach program that exists at OU to enhance wide distribution. The principal investigators are partnering with the Oklahoma Climatological Survey (OCS) to adapt and implement project materials directly to middle/high school teachers via the OCS EarthStorm outreach program. Established in 1992, the EarthStorm project (NSF TPE-9155306, and currently funded by the State of Oklahoma) has provided over 250 Oklahoma schools with the materials and requisite education to apply real-time environmental data in support of math, science, and engineering curricula. For nearly a decade, the OCS has implemented weather curricula

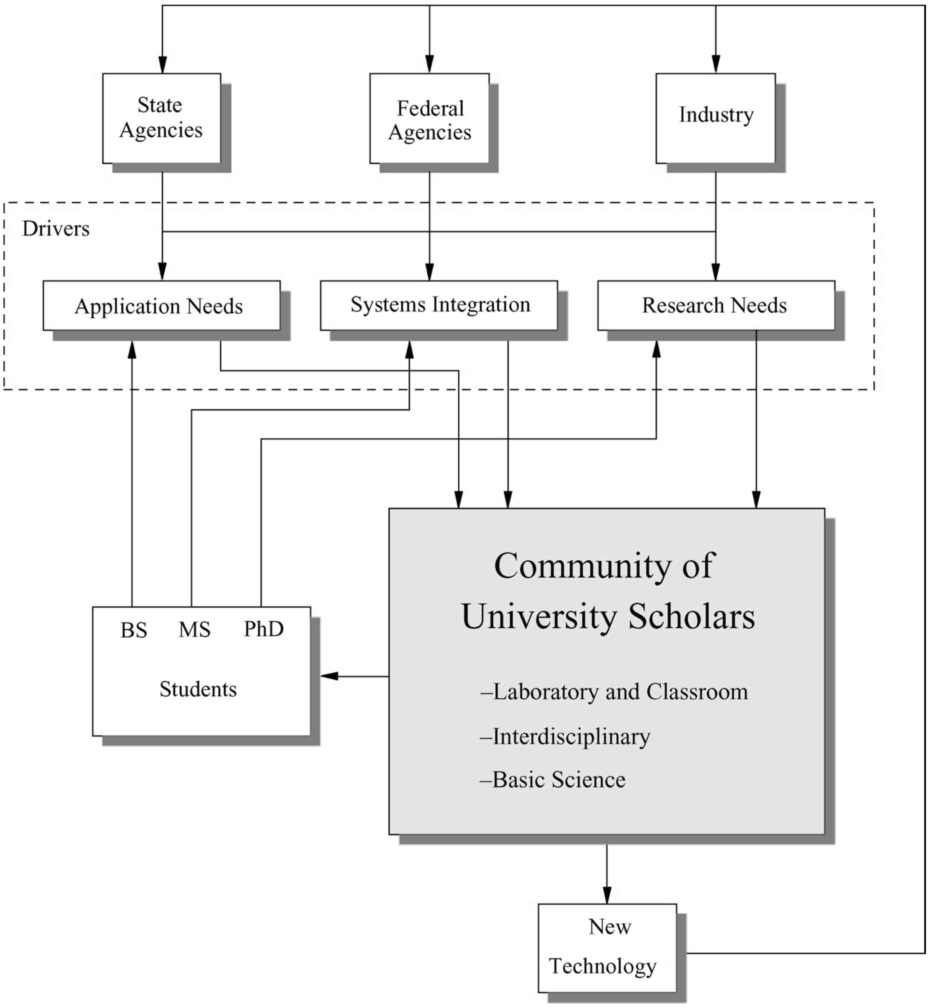

Figure 1. Students gain valuable hands-on knowledge from a rich diversity of projects. By employing a teamwork effort with their professors and project sponsors, a very satisfying community of scholars has been developed that provides innovative technical solutions and cross-training for professors and students alike.

as part of laboratory activities for undergraduate students (NSF DUE -9981098), conducted annual summer content institutes for K-12 teachers (State of Oklahoma funded), as well as hosted dozens of K-12 student science fairs (funded by US Department of Energy). Broadly, the authors are disseminating content-rich materials to the OCS for adaptation into the math and science curricula at the 250 middle/high schools (primarily middle schools) served by the OCS's outreach programs. These materials enhance teacher and student knowledge of fundamental atmospheric and engineering topics. Specifically, weather radar content has been integrated into the OCS summer content institutes for middle school teachers. Furthermore, teachers participating in the summer content institutes can be paired with our peer teachers in a mentorship arrangement to aid in the implementation of weather radar content into the middle school classrooms (peer teachers are discussed later). During the summer workshops, the middle school outreach have focused on basic radar fundamentals formulated around weather radar applications. For instance, in the summer of 2005, the OCS facilitated the weeklong EarthStorm Summer Institute in July. Approximately 48 teachers from 6th through 8th grade from around the state and surrounding states signed up to attend. During the preceding fall semester, our peer teachers took the courses offered by the team of professors. Then, during the spring semester, the peer teachers prepared laboratory exercises for the workshop during the summer. Finally, our assessment expert took survey data. Similarly, the team prepared materials for the EarthStorm workshop in 2006 and will do so again in 2007. Established in 1980, the OCS has a legislative mandate to acquire, process, and disseminate climate and weather data and information for use by the state's citizens. Hence, this significant organization in Norman operates a comprehensive website, and details about their outreach program are in the link below.

www.ocs.ou.edu

INTEGRATED INTERDISCIPLINARY CURRICULUM

The project is truly a cross-disciplinary effort between the School of Meteorology and the School of Electrical and Computer Engineering. This cross-fertilization between engineering and meteorology is also exemplified in efforts currently underway at our university to develop the cross-disciplinary Weather Radar and Instrumentation Curriculum. More details are available at the link below.

http://arrc.ou.edu

The classroom exposure to radar theory, with supportive real radar data projects, is greatly enhancing the educational experience of the students and will more thoroughly prepare them for active scientific careers. The team's efforts have culminated in the development of a revolutionary laboratory and coursework curriculum that coincides with the interdisciplinary development and integration of the School of Electrical and Computer Engineering and the School of Meteorology. A suite of courses has been developed, and where prudent, the courses were cross listed between the two departments. Cross listing has been shown to strengthen the bonds of these types of collaborative efforts, while welcoming, attracting, and retaining students [13, 14, 15]. These courses were supported by specific laboratory exercises.

- *Introduction to Meteorology* introduces students to important phenomena and physical processes that occur in the Earth's atmosphere. Through lectures and laboratory exercises, students will learn the basic radar concepts that are used to study atmospheric problems.
- *Electromagnetic Fields* is an existing course in which modifications are currently being explored and implemented which include plane wave propagation, polarization, reflection, and an introduction to radiation/antennas—all related to the study of the atmosphere.
- *Radar Engineering* introduces various radar system designs and their applications with an emphasis on weather radar. Radar system architecture and their functionalities and limitations of subsystems are discussed.
- *Radar Meteorology* is an established course (that has been updated with new laboratory experiments) that develops the quantitative relationships between a radar and its target—i.e., interpretation of the data.
- *Weather Radar Theory and Practice* is a new course (with supporting laboratory experiments) that concentrates on fundamental radar theory and the development of conventional signal processing algorithms.
- *Adaptive Digital Signal and Array Processing* is a new course devoted to the theory of adaptive algorithms for aircraft tracking and adaptive processing of radar signals to extract meaningful weather data.
- *Remote Sensing and Experimental Design* is a class which is devoted to the placement of various remote and in-situ sensors for significant studies in the field. The coursework was carefully tailored to fit within the current degree plans of both schools.

Prerequisites have been carefully observed to welcome and retain students. Special content for the new Introduction to Meteorology course was developed and served as a point of entry into the weather radar curriculum. Next, students may take Electromagnetic Fields. Subsequent to this, students can enroll in Radar Engineering and/or Radar Meteorology. These classes were taught and coordinated to ensure student success. Finally, students take the in-depth Adaptive Digital Signal/Array Processing or the Weather Radar Theory/Practice class—which culminates all previous learning, concentrates on deep projects, and serves as a spring board into the advanced graduate level programs in both schools. These were always offered in the fall, and will continue to be. Table 1 describes a layout of the courses, which have been evolving in the program since 2004. Two out-of-department assessment experts were responsible for carefully developing assessment instruments for each course. These specially designed, lengthy surveys were based on the learning objectives of the course syllabi. More details are available at the web portal below.

http://arrc.ou.edu/education

Course	Dept	Level	Semester	Status	Cross-list
Intro. To Meteorology	METR	Soph	Spring/fall	Refined	No
Electromagnetic Fields	ECE	Jr	Spring	Refined	No
Radar Engineering	ECE	Sr	Spring	New	Yes
Radar Meteorology	METR	Sr	Spring	Refined	Yes
Weather Radar Theory/	METR	Sr	Fall	New	Yes
Adaptive DSP and Array Processing	ECE	Sr	Fall	New	Soon
Remote Sensing/Experimental Design	METR	Sr	Fall	New	Soon

Table 1. Layout of The Interdisciplinary Classes

HANDS-ON LABORATORY EXERCISES:

Teaching modules have proven to be an effective means of introducing new material into an existing curriculum, without adding new courses [16, 17]. Moreover, the development of modules allows for the easy implementation at other institutions of learning [18]. There are many advantages to encapsulating a focused amount of material in a modular fashion, and modules were the educational cornerstone of DARPA's Rapid Prototyping of Application Specific Signal Processors program [19]. At the University of Oklahoma, the new modules, instruction, and assessment have been designed in accordance with the ABET Criteria 3 parts (a)-(k) [20]. They have also been carefully constructed to facilitate their adoption at other institutions. A few sample modules from selected courses are given below. Within the sequence of courses, the learning of scientific phenomena, such as interesting atmospheric events, is greatly enhanced when students are allowed to make measurements and construct mathematical models that govern their behavior [21]. Several teamwork-oriented laboratory modules have been integrated into each of the courses. These modules have been organized around four themes: 1.) data collection: developing different scanning patterns, 2.) data processing: computing and enhanced algorithms to extract weather information from the raw radar data, 3.) data display: placing the composite weather information on a user-friendly computer display, 4.) data interpretation: scientific understanding and discovery of the displayed data—this includes the locations and dynamics of storms, precipitation, tornados, downbursts, and the like. Each of the four items complement and build upon one another—thus solidifying the interaction between the courses. These hands-on laboratory modules are similar to the other university radar teaching methods [22, 23, 24]. The unifying themes that integrate the courses are as follows.

- Introduction and detailed study of the science of weather radar
- The engineering of data acquisition and analysis techniques
- The mathematics of weather radar processing
- The modern-day technology of displaying and interpreting weather phenomena on a conventional computer screen

Figure 2. Students working together.

Students have an unprecedented opportunity to take advantage of a unique federal, private, state and academic partnership that has been formed for the development of the phased array radar technology at the NWRT—thus helping to complete the cycle of innovation and collaboration that is depicted in Figure 1. Several participants contributed to the installation of the new radar, including: NOAA's National Severe Storms Laboratory and National Weather Service Radar Operations Center, Lockheed Martin, U.S. Navy, Federal Aviation Administration, and BCI, Inc. The project has very favorable institutional support, since: 1.) this effort is complementary to its research mission, 2.) it has the resolute potential to affect approximately 840 students across two departments, and 3.) it produces highly sought after students (by industry and graduate programs). Within the Engineering Center on campus that houses the School of Electrical and Computer Engineering, a special classroom has been dedicated for this teaching program; see Figure 2. This classroom known as the "Undergraduate Weather Radar Computing Laboratory" for use by all of the courses and community building activities. At the current time, contemporary infrastructure in the laboratory supports our mission: 12 new computers, a new server, and associated equipment to pipe the radar's data into this laboratory on the main campus—closely following other "client server models," where a server runs at the radar facility and the client program operates at remote locations. Looking forward, the flexibility of this laboratory setting will allow students at other universities to duplicate our course, since a future provision will allow data to be readily downloaded from the Internet. At the time of this writing, Java scripts are currently being prepared at the NWRT for this operation. Also helping to ensure that no gap exists between teaching and research, the weblink below has an online multimedia video for viewing the radar that serves as the point of data collection for our hands-on radar laboratory.

http://advances.asee.org/vol01/issue01/media/05-media01.cfm

At the current time, student activities are numerous. Computing algorithms are studied and implemented that convert radar data from the phased array radar into environmental measurements known as spectral moments—very similar to previous researchers associated with conventional rotating weather radars [25, 26, 27]. Spectral moments (*reflectivity, radial velocity, and spectrum width*) are the essential, required radar meteorological measurements that are used to make decisions about cloud locations, storms, rain fall, tornados, downbursts, hail and other important weather phenomena. Microbursts are strong downbursts of air from evolving rain-clouds which can develop in a matter of minutes and cause windshear, which are especially dangerous to aircraft [28, 29, 30]. These hazards are especially prevalent during landing, since the aircrafts operate at reduced speeds as they glide towards the runway. Through appropriate configuration of the phased array radar at the NWRT, it can be designed to provide this windshear information [28, 29, 30, 31, 32]. Although, detecting windshear is a classic problem for aircraft, many open problems exist. Up to this point, the team's work has mainly provided an image of the atmosphere surrounding the radar. In general, this will provide aircraft and other vehicles in the future an ability to make reasonable short term weather forecasts and decisions about improved situational awareness. In the dual-use mode, collecting weather information while tracking targets of homeland interest, the scan strategy of the radar will need to be devised to accommodate both targets—that is, an adaptive multiplexing operation that visits each target differently. With respect to weather, the radar does not have to radiate the entire volume every scan or sweep of the beams. Weather targets are much larger than aircraft and move at a slower rate. Understanding these concepts, and other radar related topics, is aided by hands-on teaching activities, which are discussed next.

In a recent paper by Shuman and his colleagues [33], the authors campaign for the philosophy that "One of the primary methods created to help integrate team learning into the engineering classroom is the development of formal curricular modules that could be used by various faculty planning to have students work on team projects." In fact, universities in remote locations, such as in Puerto Rico, have relied on teaching modules for especially difficult courses [34]. As such, compelling evidence exists that indicates that students do have a positive reaction to teaching modules [35]. In addition, such modules have also been a stimulus to increased retention for women in engineering [36]. By observing other successful pedagogical programs in the US, such as the Clark School of Engineering at the University of Maryland and their modular team training program that was funded by the National Science Foundation, we can assess their strengths, while avoiding known pitfalls—thus helping to complete the cycle of innovation. The goal of their "Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS)" pro ject was to provide a team based curriculum that can be easily adopted by engineering faculty from various schools and at different levels of the undergraduate curriculum [37]. A couple of our laboratory exercises are given below.

Statistical Properties of Weather Radar Data Module: This laboratory exercise is taught as a part of the Weather Radar Theory and Practice course. As eloquently articulated in the passages of the book *Engineer of 2020* [38], students will be expected to have a better understanding of the "natural world" and although natural disasters are beyond man's control, man's ability to predict them and adapt accordingly are essential to minimize impact. In fact, about one-third of the nation's $10 trillion economy is sensitive to climate variability and weather [39, 40, 41]. Predicting these natural disasters heavily depends, in part, on making decisions based on measured radar data. As such, experiential learning is a highly effective means to convey new concepts to students [42, 43, 44]; moreover, the voluminous amounts of data generated by a weather radar lends itself to this teaching strategy quite well. Expecting students to convert radar signals based on electromagnetic measurements into meaningful graphs and plots on a computer screen is something that is best learned by the students—by doing it themselves after the traditional classroom lecture and with small amounts of strategic guidance from the instructor. In this module, students investigated the NWRT data by calculating the three spectral moments for these data. Plotting the reflectivity and radial velocity gives a nearly instant snapshot of atmosphere, but more importantly, which they are combined with other variables, they can be used to initialize numerical weather prediction models. Moreover, a large number of studies by others have focused on the retrieval, often from single-Doppler radar measurements, such unobserved variables, in order to gain a full description of the state of the atmosphere, and to initialize numerical weather prediction models [45, 46, 47, 48, 49]. In addition, the students were required to study the statistical nature of these real data and compare to the theory presented in class. Based on [50], Figure 3 depicts one example of the collected and processed data from our hands-on experiments.

Multi-Function Module: On a national basis, airport capacity has increased by only 1 percent in the past 10 years, while air traffic increased 37 percent during that time, as reported by the American Society of Civil Engineers [51]. It is clear that America's infrastructure is aging. Providing discipline specific solutions will be extremely costly. However, by working together, a diverse group of scientists and engineers can develop the individual radars can be used in a multi-function capacity to provide both weather and target tracking data. This strategic alliance greatly reduces costs, while providing enormous benefits to the public. The left side of Figure 4 depicts aircraft detection measurements using the NWRT looking towards the Will Rogers International Airport in Oklahoma City, OK [2, 52]. Here, detections were made within a 90 degree sector. The set of concentric circles denote distances in units of kilometers away from the radar. The right side of Figure 4 depicts the team's aircraft detection measurements using the NWRT looking towards the Tinker Air Force Base, which is located east of downtown Oklahoma City. As depicted in the upper section of the graph at approximately 95 km, a single trajectory has been identified after processing with an adaptive algorithm has been applied. In order to collect the data, a series of STIM or "stimulus" packets were defined that contained the details of how, where and when the radar was to operate—more details about the STIM files for the NWRT are in [53]. The data was then packaged into blocks organized by STIM. The radar collected the data from a 45 degree sector of the atmosphere over a period of several minutes. Thus for this particular experiment, both the azimuth and elevation angles were scanned from 0 to 45 degrees. For

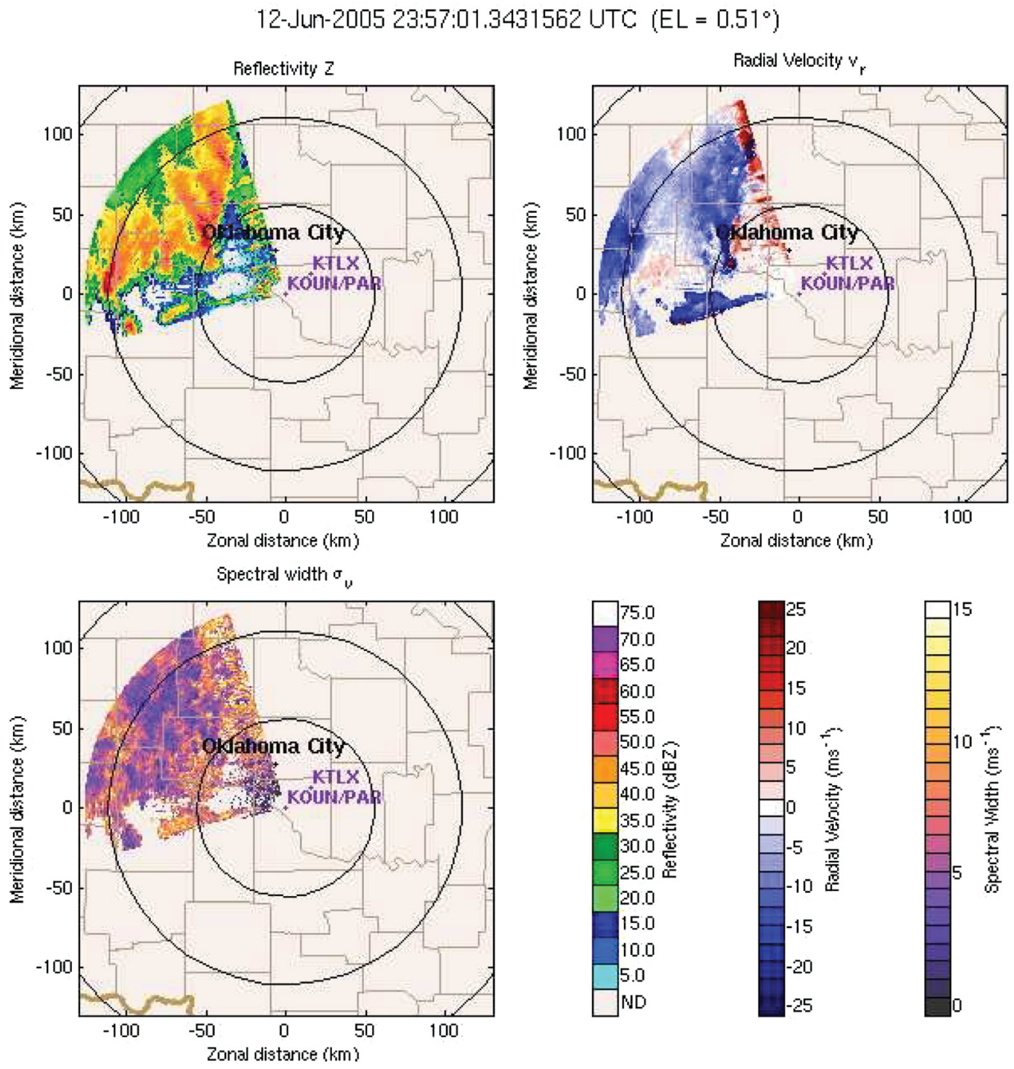

Figure 3. As the radar illuminates the atmosphere, raindrops will reflect energy back towards the radar. This reflectivity data can be used to determine the location of storms. By making additional calculations on the reflectivity data, students can make important estimates of rainfall rates. This is especially helpful for early-warning systems providing flash flood notifications.

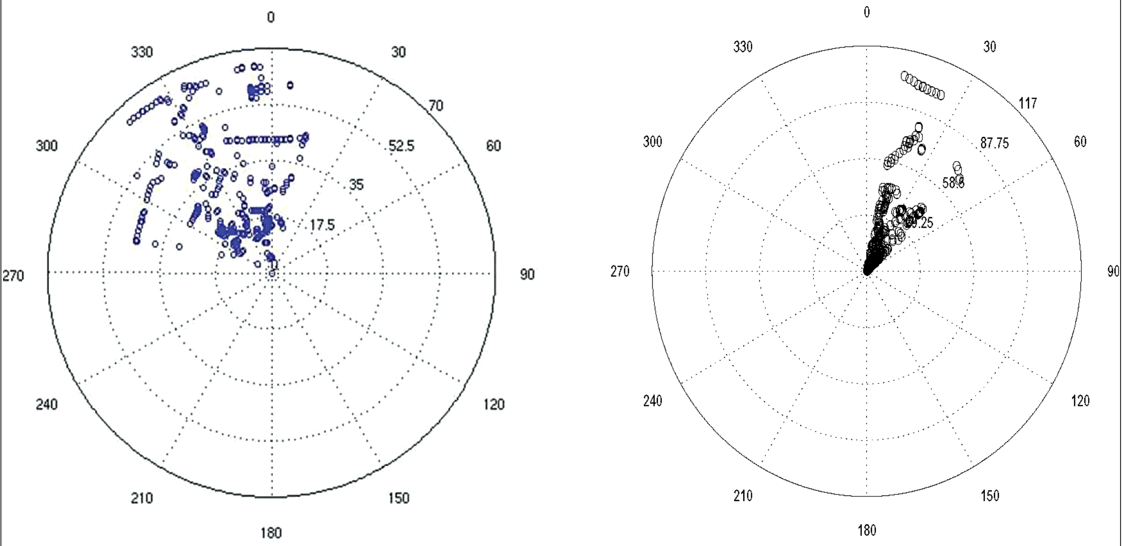

Figure 4. Left: For the first time, this figure depicts a airport traffic at a major international airport and vicinity, as measured by the NWRT. Right: This figure depicts the path of a specific plane north of the Tinker Air Force Base, located east of Oklahoma City. In addition to weather phenomenon, students are exposed to techniques for developing specific search volumes and detecting smaller targets of homeland interest, tracking these targets, and formulating hypothesis about the moving target's future trajectory.

each radial, the data was collected at a range between approximately 2.0 km and 117.0 km; 32 pulses were emitted and received along each radial. The received signal was sampled at 5 Mbps, leading to a range gate size of approximately 60 m for a total of 1856 valid range gates. The sector was swept using the tilt and scan strategy, thus rotating the radar's beams in azimuth from 0 to 45 degrees, increasing the beam's elevation angle by one increment, and revisiting the same azimuth locations.

UNDERGRADUATE PEER TEACHERS

Developing a community of scholars is important to sustaining an active program, and engaging a broad spectrum of students is an essential thread in the fabric of this goal. We define a peer teacher to be someone who is a very energetic and motivated student; is a member of our research program and radar curriculum; and is a diverse undergraduate student. A diverse student group has been enhanced with the assistance of the Diversity Coordinator within the Multicultural Engineering

Program (MEP) at our university. The judicious use of peer teachers has been shown to be a highly effective means to motivate and retain undergraduates in engineering [54, 55, 56]. The peer teachers have three primary duties: 1.) assist the instructor in the class/laboratory during periods of team-work activity, 2.) host tutoring sessions for fellow students outside of class/laboratory time, and 3.) assist with middle/high school outreach (described later). Since the peer teachers are close in age to the students and highly familiar with NWRT's research plan, they will be in a position to add significant value to the integrated program. During the first few semesters of our project, we have found that approximately 54% of the students who have served as a peer teacher also later joined our graduate program. Students have been organized into groups of teams and teamwork has been stressed [57]–[60]. The teammate selection will be carefully coordinated by the course instructor to ensure cross-disciplinary students. Teamwork has also been shown to increase retention [61, 62], and learning is enhanced when it resembles a team effort rather than a solo race [63]. Moreover, learning is achieved by individuals who are intrinsically tied to others as social beings, interacting as competitors or collaborators, constraining or supporting the learning process, and able to enhance learning through cooperation and sharing [64]. Various teachers have found that team-based learning can be especially helpful in classes with a high level of student diversity [65]. Team-based learning creates conditions in which people who are very different from one another learn that they need to work together. They find ways to make their differences an asset rather than a liability [65].

MERGING PEDAGOGICAL AND SCIENTIFIC LEARNING GOALS

The pedagogical goals and the curiosity driven scientific pursuits have been merged together with a taxonomy of significant learning—this strengthens the bonds of the community and helps to establish a logical framework that supports broad distribution. As originally defined by Bloom and his associates, a taxonomy is described as a "classification," so the well-known taxonomy of learning objectives is an attempt (within the behavioral paradigm) to classify forms and levels of learning [66]. Since the pioneering work of Bloom, other taxonomies have been developed. The most often cited ones include work by Anderson and Krathwohl [67]; Wiggins and McTighe [68]; and Fink [69]. Here, our pedagogical efforts follow the philosophies of Dr. L. Dee Fink, as his work provides a methodology that comes from an understanding that individuals and organizations involved in higher education are expressing a need for important kinds of learning that do not emerge easily from the Bloom taxonomy, for example: learning communication skills, character, tolerance, the ability to adapt to change, etc. As described in [69, 70], Fink's Taxonomy of Significant Learning is oriented around the idea that each kind of learning is interactive, as illustrated in Figure 5 [69]. (See http://www.ou.edu/pii/significant/siglearning.htm for more detail.) This means that each kind of learning can stimulate other kinds of

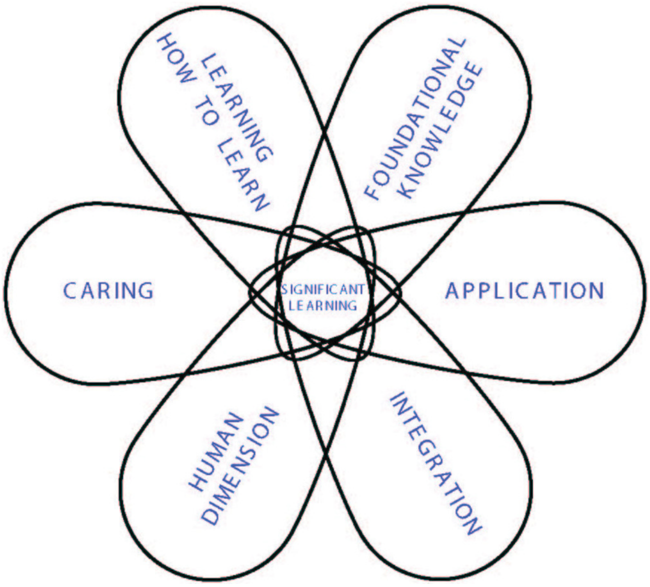

Figure 5. Interactive nature of significant learning [69].

learning. As each element of the model is included in the classroom, the more each element will support their counterparts, thus increasing the significance of the learning experience [69].

EVALUATION PLAN

The courses/laboratory modules supported by this project teach students the knowledge, skills and interest necessary to transform radar data into meaningful interpretations of weather, based on information displays generated by the students themselves. Activities are included that will 1.) increase the number of middle/high school students coming to college with an interest in weather radar and 2.) enable other universities to easily adopt similar programs. The evaluation plan is designed to assess how well the courses and other activities achieve their intended purposes [71, 72, 73]. This has involved the development of questionnaires, assessment instruments, and interview protocols for each project goal. During the first year of the project, questionnaires for the baseline data were developed. In addition, the project evaluator worked with the course teachers to (a) identify all major learning goals (e.g., knowledge, application) and then (b) develop assessment procedures for appraising each kind of learning. At the end of each course, two tasks were completed: student learning was assessed by the written methods and the professors were interviewed. The latter information was used to determine such things as how satisfied the teachers were with the level of student learning and whether the work load involved in teaching the course was within acceptable limits.

OUTREACH ASSESSMENT

Teachers participating in a recent EarthStorm workshop completed project evaluations describing what they learned from the project, the most and least helpful aspects, further information they would like to learn, concerns and suggestions, and appropriate changes. These evaluations were in the form of an extensive, written questionnaire. It is noted that the EarthStorm workshop had a duration of several days and that our materials were only a part of this comprehensive program. The assessment below summarizes the activities, while also shining light on our radar tutorials. *Information learned:* Respondents were overwhelmed by the wealth of knowledge they gained from EarthStorm 2005. Respondents indicated having a new understanding of the intricacies involved in weather; participants did not previously understand the number of variables affecting weather. In addition, participants valued the information presented concerning radar data analysis and interpretation. EarthStorm presented the past, present, and future of weather radar as well as potential applications of radar data. Respondents expressed appreciation for the thorough discussion of technical applications. *Helpful aspects:* EarthStorm participants found the thorough lesson plans and step-by-step instruction for classroom activities to be very useful. Several participants identified the comprehensive WeatherScope tutorial as the most useful aspect of EarthStorm. A majority of respondents identified detailed computer instruction as the most helpful feature. In order to improve EarthStorm content, survey respondents were asked to share the least helpful parts of EarthStorm. Several teachers believed that the portion of EarthStorm concerning inquiry teaching was unnecessary. *Further learning:* EarthStorm generated an interest in gaining additional knowledge about weather and weather radar. Several teachers expressed curiosity about the fundamental aspects of weather; teachers wanted to learn more about basic weather elements, climate, forecasting, severe weather, tornadoes, and hurricanes. While respondents appreciated technical aspects of EarthStorm, they wanted more material covering simplified meteorology. *Appreciation, concerns, suggestions:* Teachers expressed overwhelming appreciation of the friendly, knowledgeable, professional, and helpful staff. The variety of speakers provided a well-rounded week. Most respondents enjoyed the radar facility tour and weather balloon launch—similar to the events at the annual Weather Festival, which is held each fall semester. The EarthStorm participants were thankful for the impressive computer lab used throughout the pro ject; participants could work individually on computer-based labs. Teachers appreciated the staff and service at the hotel on campus. It was clear that participants were impressed with EarthStorm material, presentation, organization, and staff. Finally, EarthStorm is offered every year. For instance, Figure 6 depicts an activity during the summer of 2006. In addition to the OCS website mentioned previously, searching it points to a website with more detailed information.

http://earthstorm.ocs.ou.edu

Figure 6. Peer teachers work with middle and high school teachers during outreach activities. The fundamentals of radars are being taught in this exercise to determine the speed of a moving ball.

SUMMARY

This paper describes the curriculum details of a National Science Foundation (NSF) multi-year project at the University of Oklahoma. Supported by the Division of Undergraduate Education at the NSF, the project began with a Phase I *Course, Curriculum, and Laboratory Improvement* (CCLI) grant in the fall of 2004, which also recently received a Phase II CCLI grant to extend and refine the project through 2010. This comprehensive active-learning and hands-on laboratory program is an interdisciplinary program, in which engineering, geo-science, and meteorology students are encouraged to actively participate. The program is intended to generate a unique, interdisciplinary research-oriented learning environment that will train future engineers and meteorologists in the full set of competencies needed to take raw radar data and transform it into meaningful interpretations of weather phenomena. The heart of the program is the development of a set undergraduate courses, offered by the School of Meteorology and the School of Electrical & Computer Engineering, that provide hands-on laboratory experiences in the special knowledge and skills necessary for organizing real-time weather data and aircraft detections, improving and preparing that data for display, and interpreting its meteorological and scientific significance. In addition, programs are available for middle/high school students for the purpose of increasing their interest in science and engineering prior to entering college. Future works are many, including: efforts to interest other university departments in building similar or related curricula in their programs, the development of more teaching modules, putting the teaching modules on the web, and continuing to welcome students to participate in interdisciplinary projects—as discussed next.

The combination of high-performance computing and emerging radar systems provide a new window through which researchers can observe the natural world at a fidelity that could only be imagined a few years ago. As the future unfolds, the team will focus on these issues, as encouraged by the Boyer Report mentioned earlier. For instance, enhancements to storm tracking and short-time prediction will leverage the efficiency of real-time spectral moment calculations, in-depth raw data analysis, and innovative tracking techniques. It is anticipated that this trifecta can be gauged against contributions to these problems, which include [74, 75, 76], with an eye to the future of advanced nowcasting [77, 78, 79]. These activities will form the basis of MS/PhD projects and are excellent extensions of undergraduate programs. Before students can address these issues, new learning materials that can be quickly absorbed must be developed, whose development is guided by research on teaching. The educational taxonomy provides an excellent, balanced structure for this portfolio of diverse needs. The glue that holds this rich tapestry together is this taxonomy and our learning community. In a broader sense, the community involves university, federal, and industrial fellowship.

ACKNOWLEDGEMENT

Partial support for this work was provided by the National Science Foundation's Course, Curriculum, and Laboratory Improvement program under Phase I grant NSF-0410564 and Phase II grant NSF-0618727. Eight participants contributed to the installation of the new radar in Norman, OK. These are: NOAA's National Severe Storms Laboratory and National Weather Service Radar Operations Center, Lockheed Martin, U.S. Navy, University of Oklahoma's School of Meteorology and School of Electrical and Computer Engineering, Oklahoma State Regents for Higher Education, the Federal Aviation Administration, and Basic Commerce & Industries. Additional acknowledgement is also extended to the National Severe Storms Laboratory for making the video for this paper.

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