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Working Together for Better Student Learning: A Multi-University, Multi-Federal Partner Program for Asynchronous Learning Module Development for Radar-Based Remote Sensing Systems

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***Abstract*—Students are not exposed to enough real-life data. This paper describes how a community of scholars seeks to remedy this deficiency and gives the pedagogical details of an ongoing project that commenced in the Fall 2004 semester. Fostering deep learning, this multiyear project offers a new active-learning, hands-on interdisciplinary laboratory program in which engineering, geoscience, and meteorology students are encouraged to participate actively. Storms, tornadoes, and hazardous weather cause damage and loss that could be minimized through enhanced radar technologies and longer warning lead times. To study these topics, the program has generated 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 them into meaningful interpretations of weather phenomena.**

***Index Terms*—Active learning, educational modules, Internet, radar systems, remote sensing, weather environment.**

I. INTRODUCTION

THROUGHOUT many universities and institutions of higher learning, teaching modules have proven to be an effective means of introducing new material into an existing curriculum without adding new courses [1], [2]. Moreover, the development of modules allows for easy implementation at other institutions of learning [3]. As noted by [4], modularity allows a program to be easily transportable in full or in parts, thus allowing faculty to customize based on class structure, project design, and course material. The new modules, instruction, and assessment have been designed in accordance with the ABET Criteria 3 parts (a)–(k) [5]. They have also been carefully constructed to facilitate their adoption at other institutions. 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 [6]. The teamwork-oriented modules are organized around five 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, tornadoes, downbursts, and the like;
5) *Radar system design:* to enhance the previous themes, hardware understanding is taught.

Each of the five items complement and build upon one another—thus solidifying the interaction between courses and students.

Students are not exposed to enough authentic data drawn from real life. This endeavor leverages a variety of weather radar systems in Norman, OK, to develop interdisciplinary, hands-on laboratory exercises to satisfy this need—particularly in the area of severe weather detection. For instance, the new National Weather Radar Testbed (NWRT) is an example of such a radar system, as are other weather radars as discussed in Section II-A. The NWRT is a resource that combines the talents of engineers and meteorologists for the study of weather. It is the world's first facility dedicated to phased array radar meteorology. Severe and hazardous weather such as thunderstorms, downbursts, and tornadoes can lead to a loss of life in a matter of minutes. The importance of this activity offers a compelling area of study to engage students' interest. Data from NWRT and other radars will be studied to prepare students for the

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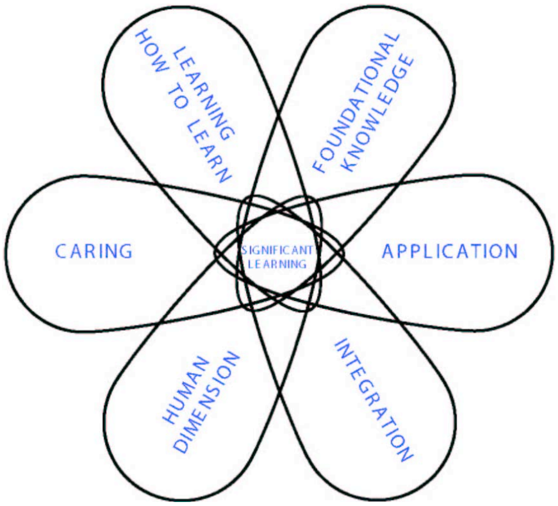

Fig. 1. A taxonomy of significant learning, which is employed for sustained module impact.

next generation of technology. As eloquently articulated in the passages of the book titled *Engineer of the 2020* [7], students will be expected to have a better understanding of the "natural world," and although natural disasters are beyond humanity's control, man's ability to predict them and adapt accordingly are essential to minimize their impact, especially through observations systems such as radar. For example, in the United States, about one-third of the nation's $10 trillion economy is sensitive to climate variability and weather [8]–[10].

The pedagogical goals and the scientific goals have been merged together with a taxonomy of significant learning so that the modules can have sustained impact. 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 [11]. As well as providing a basic sequential model for dealing with topics in a curriculum, it also suggests a way of categorizing levels of learning in terms of the expected ceiling for a given program [11]. Since the pioneering work of Bloom, other taxonomies have been developed. Those most often cited include work by Anderson and Krathwohl [12], Wiggins and McTighe [13], and Fink [14]. Here, the team's effort follows the philosophies of Fink. As described in [14] and cited in other works, including [15]–[17], Fink's *Taxonomy of Significant Learning* is oriented around the idea that each kind of learning is interactive, as illustrated in Fig. 1 [14]. This means that each kind of learning can stimulate other kinds of 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. For example, the *human dimension* is a type of learning that allows students to discover personal and social implications for what they are studying, which is important for reinforcing radar concepts and the study of severe weather. As another example, *learning how to learn* helps a student to be more inquisitive and self directed, which is important for the teaching modules. Finally, the *integration* concept is important for the large team of partners, as students gain exposure to new strategies to connect learned material with other ideas, people, or realms of life.

II. Module Implementation and Discussion

As described previously, a taxonomy to guide the content of the modules was developed. This led to a set of modules. These modules are designed to complement classes related to weather, radar systems, and the atmospheric studies. On the other hand, the modules also have sufficient introductory materials so that they may be employed independently and adopted easily by others. Students and learners may use the modules in sequence or selected as needed. The modules are available through the National Science Digital Library (NSDL), which is on the Internet. The team's modules will quickly appear by an efficient keyword search that may include *radar*, *weather*, and *module*.

As a shift toward learner-centered education [18] continues to occur, the Internet offers a medium that supports the manifesto of anytime, anywhere learning that is oriented around a student's educational pursuits at his or her pace, with or without teammates. Known as asynchronous learning, this type of learning differs from learning in the traditional classroom by offering self-contained laboratory modules. Each of the team's modules has six common elements, these are: 1) Title; 2) Learning Objectives; 3) Introduction; 4) Hands-On Activities; 5) Conclusions; and 6) Assessment. The *Hands-On Activities* is one of the most important segments of the module. The activities are oriented around: a) where to find the data on the team's Web site; b) sample software snippets provided; c) theory versus observational analysis; and d) teamwork or individual exercises. Providing the decentralized data for the students allows for the data from the equipment in Norman, OK, to be used by students at distant locations. Fig. 2 depicts the layout of the modules.

The modules are intended to be taught within the 11 classes offered at the University of Oklahoma (OU), Norman, which focus on atmospheric measurements and weather radar systems (see [19] and [21] for more details). The modules have been carefully designed to be *standalone* in nature so that others may use them. This is done by offering them on one central Web site, providing a detailed introduction to each module, providing example results that guide the students, and making the data for each of the modules easily accessible. As an example of one utilization, students commonly select modules for independent studies. The module titles are:

1) Phased Array Antenna;
2) The Doppler Spectrum—Radial Velocity Distributions;
3) Phased Array Radar: Time Series and Power;
4) Visualization and Processing of Weather Radar Data;
5) Intermodulation Product Computing Techniques for Broadband Active Transmit Systems;
6) Reflectivity Factor and Statistical Properties of Weather Radar Data;
7) Adaptive Pattern Recognition for Tornado Detection;
8) Rayleigh and Mie Scattering Cross Section Calculations for Weather Radar Observations;
9) Z-R Relationships;
10) Supercell Radar Signatures;
11) Spatial Response of Practical Patch Antenna Systems;

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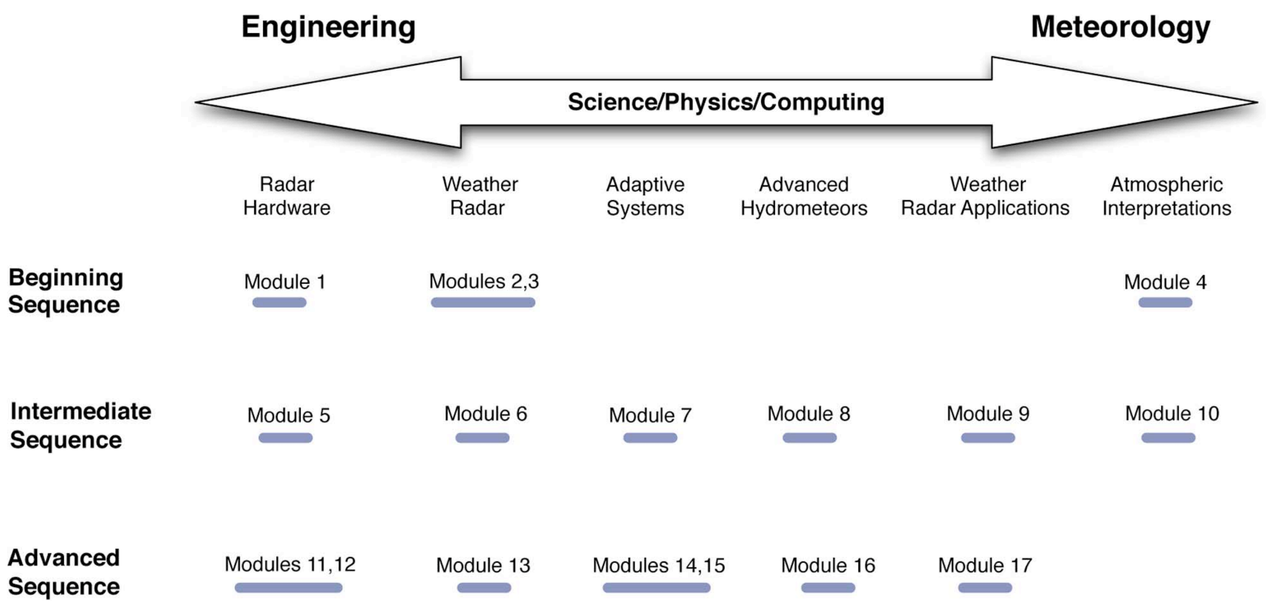

Fig. 2. Layout of the modules. A strong emphasis on fundamental science, physics, and computational computing bridges the gap between engineering and meteorology to create a united foundation that serves as the bedrock for the modules.

12) Real-Time Adaptive Weather Radar Data Compression;
13) Digital Beamforming and Imaging Radar;
14) Level 1 Signal Modeling and Adaptive Spectral Analysis;
15) Temporal Clutter Filtering via Adaptive Techniques;
16) Calculation of Polarimetric Radar Variables;
17) Wind Shear Hazard Index.

A. Data for the Modules

Six weather radars are discussed here, as pictured in Fig. 3. In order for students and researchers to study the various radar characteristics, resources are available on campus for experiments. Students, therefore, 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, as depicted by panel 1 in Fig. 3. Eight participants contributed to the installation of the new radar, including: the National Severe Storms Laboratory (NSSL) and National Weather Service Radar Operations Center, Lockheed Martin, the U.S. Navy, the Federal Aviation Administration, and BCI, Inc.

Panel 2 in Fig. 3 depicts a mobile radar known as the *Shared Mobile Atmospheric Research and Teaching Radar*, or SMART-R [22]. This research and educational portable enterprise is a coalition of scientists from OU, NSSL, Texas A&M University (TAMU), and Texas Tech University (TTU) who embarked on a project to build and deploy two mobile C-band Doppler weather radars for storm-scale research and to enhance graduate and undergraduate education in radar meteorology. This project culminated in the successful development and deployment of the first mobile C-band Doppler weather radars.

Panel 3 in Fig. 3 depicts a snapshot of a radar that is on OU's north campus, which is operated by the NSSL. It is a dual-polarized radar, which implies that it can distinctly measure reflectivities in both the vertical and horizontal polarizations. This radar is known as KOUN, and it has the unique capability of collecting massive volumes of time series data over many hours. This radar is nearly identical to a Weather Surveillance Radar, model 1988 or WSR-88D, with the main difference being that the latter has a single polarization. In general, weather surveillance radars, particularly the WSR-88D, have proven to be an important tool to observe severe and hazardous weather remotely and to provide operational forecasters prompt information of rapidly evolving phenomena. As an example, students routinely share in the excitement of testing new tornado detection algorithms and testing new storm cell identification techniques. Panel 4 illustrates a picture of a new radar that was recently built on campus, known as the "OU Polarimetric Radar for Innovations in Meteorology and Engineering" or OU-PRIME. It is very similar to the radar pictured in panel 3, except its beamwidth is smaller (i.e., 0.5°) and its operational frequency is higher (i.e., C band).

Panel 5 depicts one node of a networked radar system. With the advances in networking technology, a new paradigm of networked radars is on the verge of becoming a reality. These networks of radars have brought innovative improvements to the science of radar meteorology. The NSF-sponsored Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) is a prime example of emerging distributed collaborative and adaptive systems [23], [24]. OU is a partner of the CASA initiative, along with three other universities. The vision of the CASA is to expand a scientist's ability to observe the lower troposphere through distributed collaborative adaptive sensing (DCAS), improving the ability to detect, understand, and predict severe storms, floods, and other atmospheric and airborne hazards.

Finally, as depicted in panel 6 of Fig. 3, vertically pointing radars provide height profiles of fundamental quantities such as wind vectors, precipitation microphysics, and the intensity of clear-air turbulence and are powerful observational and research tools within the meteorological community. These instruments are capable of routinely providing estimates of the

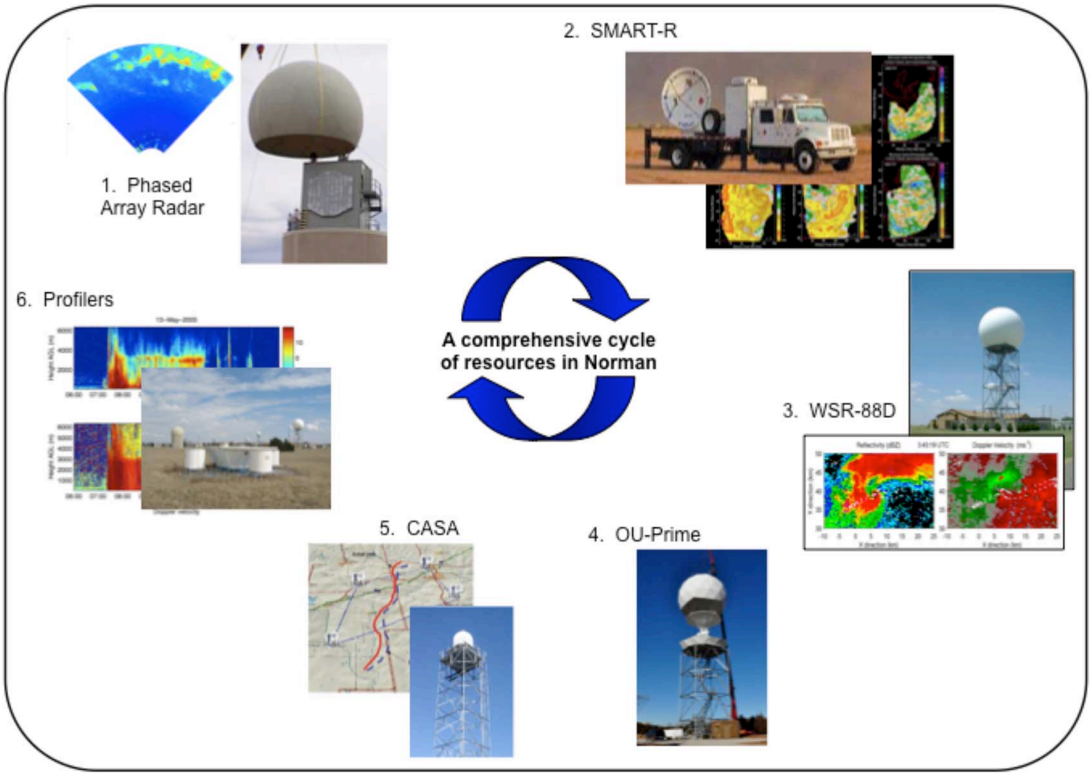

Fig. 3. To address the general problem that "students are not exposed to enough hands-on data," the faculty team has a rich variety of atmospheric data sources on its north and south research campuses, in close collaboration with their federal and corporate research partners. These data sets are essential elements of the modules.

wind field aloft while also facilitating studies of turbulence, atmospheric stability, and precipitation. The complementary use of profiling radars together with NWRT and KOUN offer exciting and unique research opportunities. Sections II-B and C describe how data from the instruments in Fig. 3 may be used in two sample modules.

B. Sample Module 1: Weather Radar Polarimetry

This laboratory exercise is taught as part of the course Weather Radar Polarimetry, also known as METR 5673 or ECE 6613. As studied in the course, the National Weather Service's network of WSR-88Ds will be upgraded to have polarimetry capabilities [25], [26]. Here, polarimetry implies an ability to transmit and receive vertically and horizontally polarized waveforms, which allows for a greater sophistication of atmospheric measurements and understanding. Over the next few years, the impact of polarimetry will rival that of the Doppler capability added in the 1980s. In addition to reflectivity, the polarimetric KOUN radar, depicted in panel 3 of Fig. 3, measures differential reflectivity (ZDR), differential phase (ϕ_{DP}), and copolar cross-correlation coefficient (ρ_{hv}). Polarization radar measurements contain rich information about precipitation microphysics and have been successfully used to classify hydrometeor types [27], [28], to improve quantitative precipitation estimation, and to retrieve raindrop size distribution (DSD) [29]. On the other hand, microphysical properties such as particle type, density, shape, orientation, and size distributions are measured at the ground level by video disdrometers. Through the calculation of polarimetric radar variables from disdrometer data provided in the module, students gain better understanding of the radar measurements and their potential use in quantitative precipitation estimation and forecasts [30]. Fig. 4 depicts a plot of four polarimetric radar variables that were derived from measured radar data that students create in this module. These variables may be used later to calculate estimates of rainfall rates. In summary, this module provides several key elements of significant learning, as depicted in Fig. 1. For instance, students are required to integrate knowledge from mathematics, science, and engineering.

C. Sample Module 2: Statistical Properties of Weather Radar Data

This laboratory exercise is taught as part of the course Weather Radar Theory and Practice, also known as METR 5673 or ECE 4973/5283. In general, radar data may be processed to reveal a variety of information. In particular, the radar's in-phase (I) and quadrature (Q) signals can be processed to produce environmental measurements known as "moments," which are the first three statistical moments of the data. The moments are efficiently calculated using lags of the signal's autocorrelation or in the spectral domain. Detecting various weather scenarios 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 [31]–[33]; moreover, the voluminous amount 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

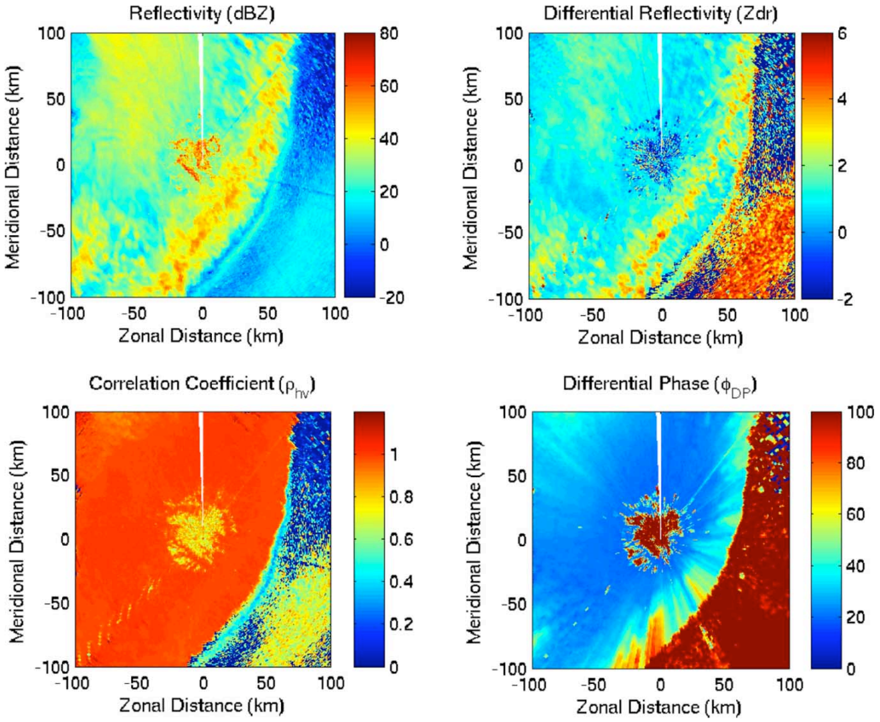

Fig. 4. Polarimetric radar measurements of a rain event that occurred on May 13, 2005, in central Oklahoma, as measured by the radar in Fig. 10.

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 from June 2005. In particular, students prepared power estimates, and these reflectivity factor values were used to estimate rainfall rate associated with severe weather. 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 [34], Fig. 5 depicts one example of the collected and processed data from hands-on experiments in June 2005. The reflectivity, radial velocity, and spectral width imagery are shown, which represent the first three moments of the measured data. In summary, this module provides students an opportunity to integrate new and previous knowledge for a significant learning experience, which strengthens the taxonomy as illustrated by Fig. 1.

D. Societal Awareness, Modules, and the Team's Taxonomy

Understanding how radar systems work is important for understanding severe weather and its societal impacts, which is crucial for the human dimension that enhances significant learning, as in Fig. 1. Flooding is one example that results from severe weather, and it will be discussed next as it relates to radar imagery. Great strides have been made in building observational networks, understanding fundamental physical processes, and developing numerical weather prediction models, as pointed out by [35]. These accomplishments have reaped immeasurable rewards by contributing to improved monitoring, understanding, and modeling of the atmosphere [35]. Consequently, these scientific and engineering gains have led to better long-term forecasts and short-term forecasts of imminently hazardous conditions, based on the data generated by remote sensing systems. For example, these hazards include severe storms, flash floods, hurricanes, tornadoes, rain-induced mud slides, damaging hail, and icing conditions. Of these hazardous conditions, flash floods continue to claim many lives.

Fig. 5 provides insight into the conditions that foster flash flooding. The upper-right image depicts intense rainfall within a small region. The upper-left image depicts the "radial velocity," or how quickly the storm is moving relative to the radar. The lower-left image depicts the amount of turbulence. From the data, flash floods are characterized by their suddenness, fast and violent movement, rarity, small scale but high level of damage. They are particularly difficult to forecast accurately and leave very little lead-time for warnings. Flash floods can surprise people who are in the midst of their daily activities, with particularly serious impacts when people travel across roads vulnerable to flooding [36], [37]. In fact, *most of the people killed by flash floods in the US and France are in cars*. Experts call for a comprehensive integration of social and natural sciences and engineering to better understand public responses; these include [38] and [39]. Recently, research has been conducted to address people's travel patterns during flash floods, and it uses a spatio-temporal analysis to better understand the link between human behaviors and sudden change of the environment [36], [37]. Helping to link public safety and scientific understanding of radar measurements requires strong collaborations with social scientists to build common research questions addressing public response to warnings. As an example of the linkage between rainfall estimates and rapid consequential flooding impacting a populated area, Fig. 6 depicts the cycle of a heavy rainfall and the resulting flood surge for a particular region of study [36]. Here, the discharge

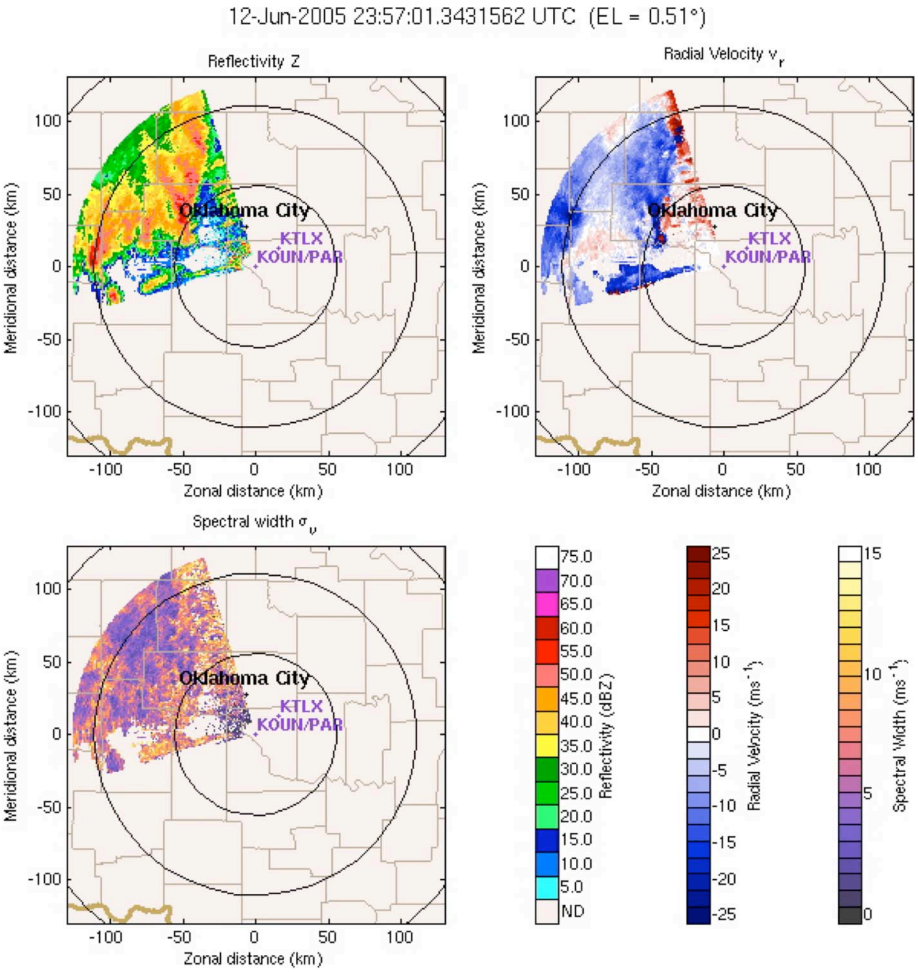

Fig. 5. As the radar illuminates the atmosphere, raindrops will reflect energy back toward the radar. This reflectivity data can be used to determine the location of storms. By making additional calculations on the reflectivity data, students can make important estimates of rainfall rates. This is especially helpful for early-warning systems providing flash flood notifications.

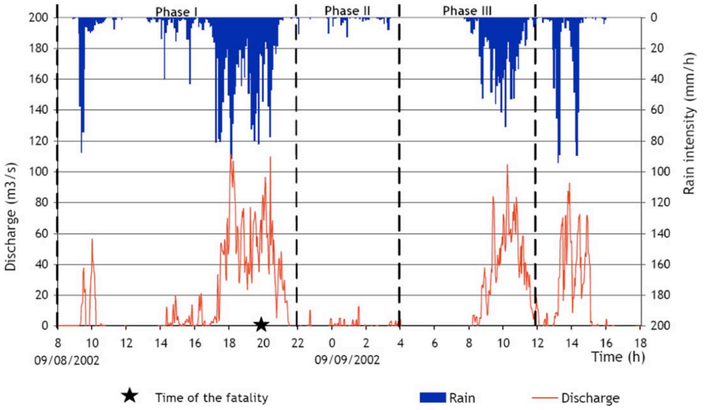

Fig. 6. The upper portion depicts the rainfall intensity that may be measured by a radar-based remote sensing system or other sensor system. The lower graph depicts the hydrological response. Here, the discharge of the flooding is strongly correlated to the dynamics of the rain in the region of study or catchment area.

of the flooding is strongly correlated to the dynamics of the rain in the region of study or catchment area. After the strong flooding in Phase I of the storm, a death was reported. Radar systems can be used to estimate rainfall rates for a given region, and flood warnings may be issued more accurately than before. The team's teaching modules, which are described later in this paper, explain how students can transform radar data into calculated rainfall estimates.

E. Discussion of Modules

As pointed out by Bourne, Harris, and Mayadas in [40], "providing self-paced modules to students allows additional time for

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participants in instructor-led courses to engage in interactive exercises." In short, instructional modules have been helpful for lifelong learning, project management, teaming, and time management [41]. Moreover, in a recent paper, Shuman and his colleagues [4] 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 [42] in the past and are eager for more. In addition, such modules have also been a stimulus to increased retention for women in engineering at this [43]. Similarly, content delivery via case studies has been an effective method to teach students about various weather phenomena [44]. As such, compelling evidence exists that indicates that students do have a positive reaction to teaching modules. As noted in [45], survey data indicates a positive student reaction to this type instructional material.

The interdisciplinary team also has a partner in the College of Journalism at OU to assist with broad, high-quality dissemination via the Internet. A well-prepared dissemination plan is an underlying factor that supports the elements of the six-starred model of significant learning in Fig. 1. A review of the current literature indicates that the Internet is a dynamic medium unlike any before and that traditional mass communication models may not have an appropriate fit [46]–[48]. For instance, Chaffee and Metzger have suggested that future researchers should "not simply apply old models of mass communication to the new media because of fundamental differences between the old and new technologies," but instead create new communication models, which take into account an active audience who select content for themselves [49]. Thus, the team's approach was to merge the ideas from gratifications theory with media system dependency theory to understand how dependent relationships are formed on the Internet through a person's media usage. This revealed that user-selectable modules and their social implications are highly conducive to the adoption of the learning concepts within them. In particular, from classroom discussions and surveys, the program's students have fostered a reliance on the team's hands-on Internet-based learning modules to aid their comprehension.

F. Assessment

At this point, the team is in Phase II of the project, and qualitative assessment has occurred at OU and the University of Puerto Rico at Mayaguez (UPRM). At this juncture, the assessment is *formative*, as refinements to the program are occurring, and a formal summative assessment will occur after the project. In particular, the modules have been assessed as part of their respective classes at OU. At UPRM, the modules were assessed for ABET (a)–(k) criteria, as part of its department's planning process. Specific details are below. At OU, it should be mentioned that these learning modules are currently being offered through 11 relatively new courses, which comprise approximately 300 credit hours per year [20]. As such, the students have gained many intangible benefits. For instance, students have deepened their understanding of waveform design, data collection, weather product calculations, and the preparation of meaningful weather radar imagery.

For all of the modules, a standard one-page assessment tool has been prepared, with three principles: a) to have compliance and annual oversight by OU's Institutional Review Board (IRB); b) to be relatively simple so that a standard instrument could be implemented for all of the modules; and c) to have the guidance of the team's external assessment specialist. The following questions were focused on assessing the usefulness of each module for determining areas of weakness/strength and possibilities of improvement of the overall learning experience. Moreover, these six have been approved by OU's IRB Office. The assessment instrument was based on six questions:

- Q1. On the whole, the learning objectives were met (circle 1,2,3,4,5).
- Q2. I would recommend this lab to another student (circle 1,2,3,4,5).
- Q3. The data were easy to access, load, and use (circle 1,2,3,4,5).
- Q4. Relative to other labs I have had at OU, the amount of effort was reasonable for what I have learned (circle 1,2,3,4,5).
- Q5. How many total hours did you spend completing this assignment?
- Q6. Please provide any suggestions for improving the learning experience provided by this signal processing assignment.

Fig. 7 provides a graph of results for the modules that were completed during the Fall 2008 and Spring 2009 semesters. The graph is an average for questions 1–4 above. On the average, the students spent 8.27 h to complete each module. As such, each module is a comprehensive learning experience that is beneficial to student learning. For instance, this is supported by the fact that the average for Q1 was 4.5659.

In Fall 2008, the 17 modules were evaluated by UPRM on the basis of six relevant metrics within the ABET (a)–(k) criteria. This study was completed as part of their preparation for a visit from ABET. The criteria were: (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; (e) an ability to identify, formulate, and solve engineering problems; (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. Normalized to a scale of 0 to 1, Fig. 8 depicts a distribution of the individual ABET criteria and their respective rankings for the complete set of modules. For instance, the students found criteria (a) and (k) to be the most compelling aspects of the modules, while criteria (h) was the least compelling. The 0-to-1 normalized graph was prepared from rubric data, with 1 being the highest and 0 being the lowest.

Fig. 9 depicts the course evaluations that have benefitted from the inclusion of modules. This data summarizes the results of

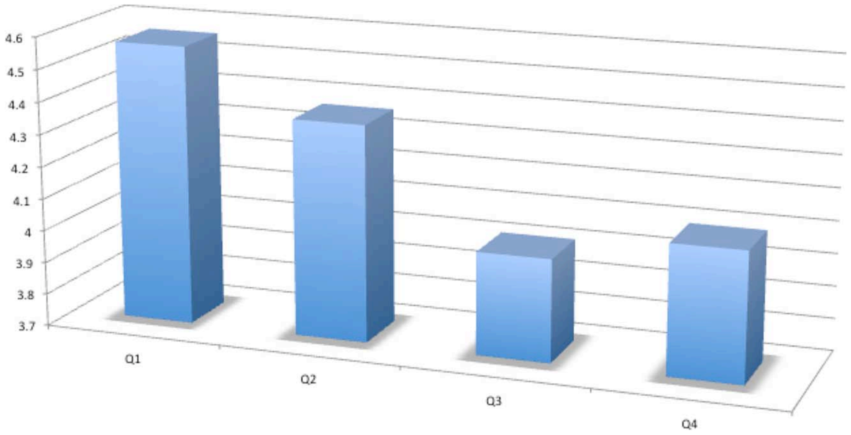

Fig. 7. Plot of the average of the assessment questions Q1–Q4, on a scale of 1 to 5.

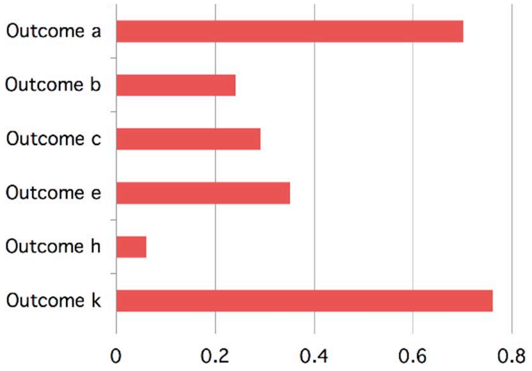

Fig. 8. Module assessment via relevant ABET evaluation criteria for the seventeen modules, on a normalized scale of 0 to 1.

the team's Phase I grant NSF-0410564, and the team's Phase II grant is still in progress. Here, the basis of this analysis is the average of the Student Faculty Evaluation (SFE) scores that are used at OU as a single score to rate the effectiveness of a professor's class (with 5 being the highest and 1 being the lowest). From the graph, it is seen that the average scores of the classes with the modules are typically above the average scores in the college. As one example of how the modules help the classes, the Weather Radar Theory and Practice class may be analyzed. Beginning with its inception in Fall 2005, its class SFE scores have consistently increased.

G. *Activities That Support the Modules*

Several student activities have reinforced the impacts of the modules. For instance, the upper portion of Fig. 10 is a photograph of a class visit to OU's north campus to see a polarimetric radar. These trips have helped the students to understand how the data is collected for the modules. In general, computing algorithms are studied and implemented that convert radar data from the radars into environmental measurements known as spectral moments—very similar to previous measurements associated with conventional rotating weather radars [50]–[52]. Spectral moments (*reflectivity, radial velocity, and spectrum width*) are the essential, required radar meteorological measurements that are used to make decisions about storms, rainfall, tornadoes, downbursts, hail, and other interesting weather phenomena. Microbursts are strong downbursts of air from evolving rain clouds that can develop in a matter of minutes and cause windshear. These present hazards for aircraft, especially when taking off or landing. These windshears or strong downbursts are especially dangerous to aircraft [53]–[55], and hands-on activities are available via one of the team's learning modules [56]. Finally, understanding how radar data may be processed to allow the comprehension of severe weather has reinforced the tenants of the team's taxonomy of significant learning.

In addition, a module has been developed for a summertime outreach program. As part of the team's long-term vision, programs for middle school teachers have been generated for the purpose of increasing their students' interest in science and engineering prior to entering college. The principal investigators partnered with a major statewide climatology center [the Oklahoma Climatological Survey (OCS)] during the summers of 2005–2008 to adapt project materials to, and directly implement them with, middle school teachers via its Earthstorm outreach program. Earthstorm is a weeklong workshop that is hosted by the OCS in Norman, OK, in collaboration with its partners. During the workshops, a weather radar module was presented during an afternoon session, and in addition a tour of the mobile radar was given (see panel 2 in Fig. 3). Student peer teachers provided the module and tour.

III. CONCLUSION

This paper describes a set of online learning modules that provide self-directed instructional materials and access to data sets. The modules are available on the Internet through the NSDL via a keyword search of: weather, radar, and module. These modules can be of use to instructors of courses in remote sensing applications, wave propagation, atmospheric science, and engineering. Other broad applications could include statistical analysis, signal processing, and applied mathematics. A well-known taxonomy has been employed so that the modules will provide a significant learning experience for students in diverse settings. Differing from other educational taxonomies, it is not hierarchical, but rather relational and interactive. In summary, the main contribution of this paper is a set of unique and hands-on learning modules that employ data collected from a large set of

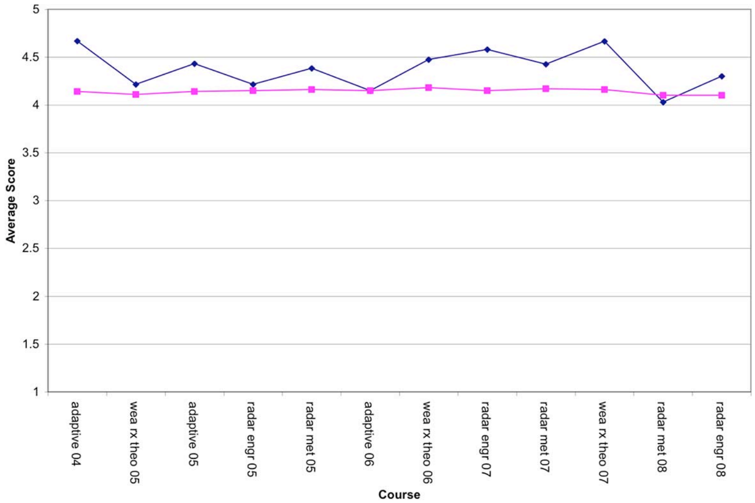

Fig. 9. The blue line with the diamond symbols represents the average Student Faculty Evaluation (SFE) scores that are used to rate the effectiveness of a professor's class at OU. The cyan line with the square symbols represents the average SFE scores from the college. In the rubric, 5 is the highest and 1 is the lowest.

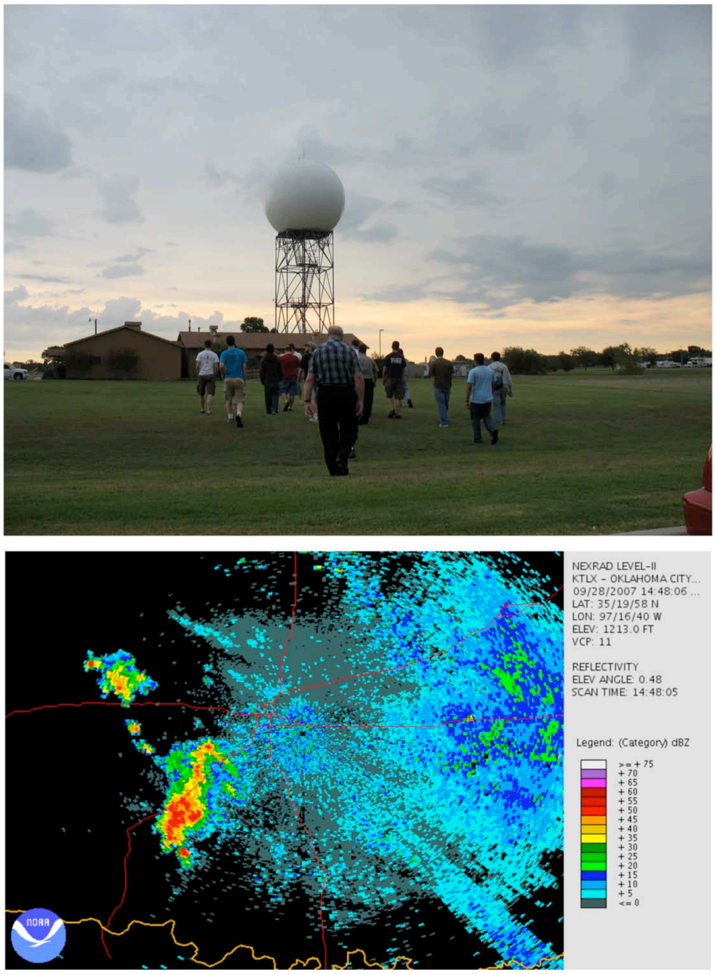

Fig. 10. Above: Students tour the radar facilities on OU's north campus, which are operated by the NSSL under NOAA. The name of this radar is KOUN, and the students enjoyed climbing the stairs to the top of it. Below: Radar imagery depicting a plot of weather radar intensities, as collected from the KTLX weather radar, which is located about 20 miles north of KOUN. This data was recorded at 9:48 a.m., the same time that the picture was taken. The KTLX data was downloaded from the National Climatic Data Center (NCDC) Web site. By approximately 11:00 a.m., the storm had slightly drifted northeast, and the first band of the storm produced a light stratiform rain on the students.

radars, thus bridging the gap between theory taught in the classroom and processing real weather data in order to gain a better understanding of radar data processing, statistics, and societal implications.

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