Weather Radar Education at the University of Oklahoma

An Integrated Interdisciplinary Approach

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The future of radar meteorology is critically dependent upon the education and training of students in both the technical and scientific aspects of this subdiscipline of meteorology. Not only should meteorology students be knowledgeable in the use of radar for studies of the atmosphere, but they should also be comfortable with topics which may have previously been considered in the realm of engineering. Furthermore, engineering students who choose to work in this exciting field should have enough background in the atmospheric sciences to effectively communicate with the radar system users. Only through such an interdisciplinary approach can true leaps forward in both technology and science be achieved.

Weather radar first came to Norman and the University of Oklahoma (OU) in 1962 when the National Severe Storms Project—which eventually evolved into the National Severe Storms Laboratory (NSSL)—installed the WSR-57 radar, marking the beginning of its Weather Radar Laboratory. Around the same time, in 1960, OU started its new meteorology group, which grew into the School of Meteorology (SoM). The synergy between NSSL and OU helped both programs flourish, and this collaborative nature still exists today and now includes several other departments. Founded in these early efforts, much has changed, but weather radar has always played an important role in the direction of OU and NSSL.

Over the past several years, OU has pursued a new paradigm of interdisciplinary education that focuses on atmospheric studies. To support this, the university has invested heavily in the development of a strategic initiative in radar meteorology. Ten new faculty members, with interests in weather radar, have joined the SoM and the Schools of Electrical and Computer Engineering (ECE), Computer Science (CS), and Civil Engineering and Environmental Science (CEES). Several members of this interdisciplinary team of meteorologists and engineers have coalesced to establish the Atmospheric Radar Research Center (ARRC; http://arrc.ou.edu). One of the fundamental goals and unique aspects of the ARRC is to provide OU students with a comprehensive, challenging education in the area of radar meteorology, emphasizing both the engineering and meteorological aspects of the field.

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GENERAL EDUCATIONAL GOALS. To guide the development of OU's educational radar program, the following three overarching goals were created:

- Provide a comprehensive interdisciplinary education in weather radar at both the undergraduate and graduate levels.

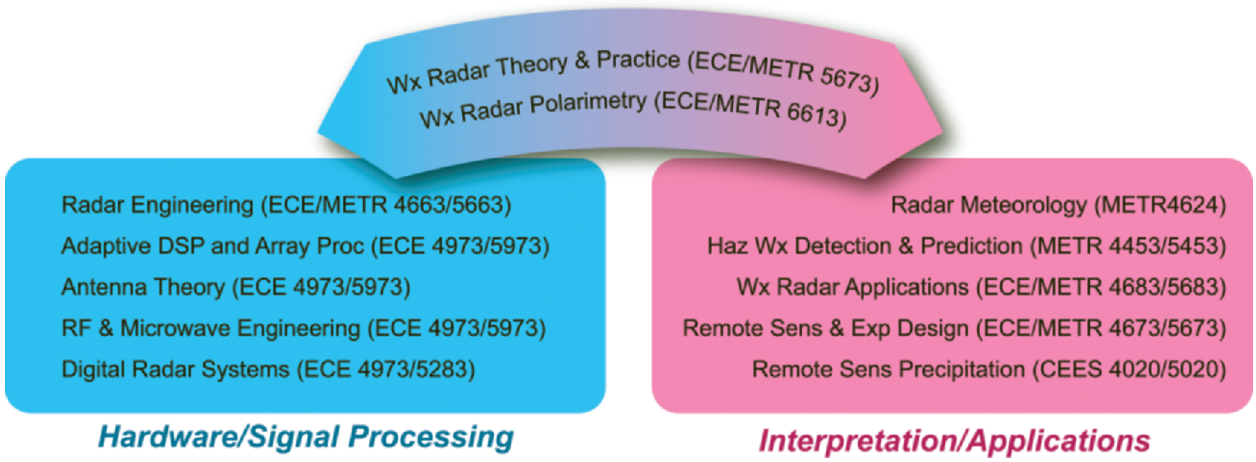

Fig. 1. List of courses at the University of Oklahoma, which make up the interdisciplinary weather radar program. By providing background materials in a just-in-time format, emphasis has been placed on making it possible for engineering and meteorology students to succeed in all courses.

- Provide extensive hands-on experience.
- Combine the talents of faculty members from different departments across campus with those of local scientists and engineers.

To implement a curriculum to realize the goals, the classic Bloom's Taxonomy of Learning was employed. Well known in the educational community, this model is based on six successive levels or categories of learning—knowledge, comprehension, application, analysis, synthesis, and evaluation—that ascend in difficulty from factual knowledge to evaluation. This model serves as the glue that strengthens the bonds of our interdisciplinary goals and the team's curiosity-driven class projects. More importantly, it helps to establish a logical framework for the entire program.

Given the importance of weather radar for many observational studies of atmospheric phenomena, it is essential to include a significant hands-on component for the students. The radar program at OU was designed in an attempt to provide a theoretical framework with which to understand weather radar theory while also providing access to local weather radar systems and their data. Largely through OU's close collaboration with the NOAA's NSSL and the NWS's Radar Operations Center (ROC), numerous opportunities exist for hands-on training with both research-quality and operational weather radars. As a specific example, students in Weather Radar Theory and Practice (discussed in the next section) are provided the opportunity to study the application of phased array technology to weather observations. In a planned and logical sequence, the presentation of phased array theory in class is followed by a tour of NSSL's Phased Array Radar (PAR). A hands-on laboratory using actual PAR data to illustrate the advantages and limitations of such radars immediately follows these more traditional activities. In order to emphasize the interdisciplinary nature of the field, students work in teams (engineering and meteorology) to complete the laboratory assignments.

One of the major benefits of developing a curriculum based on weather radar at OU is the collocation of the university with several NOAA and NWS entities, which is facilitated by the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS). Due to an inherent interest of the scientists and engineers, both the development and implementation of OU's radar program has included colleagues from the NSSL and the ROC. By combining these worlds, OU students are afforded a unique perspective on the field of weather radar. It should be emphasized that our NOAA colleagues do not simply come into the classroom for "guest lectures," but provide an integral component of the classes, often providing 2- to 3-week segments on their areas of expertise, which are also enhanced with on-site tours. Leveraging nonacademic expertise has proven important for OU students' appreciation of the subject matter and should be implemented, if possible, in other programs.

OVERVIEW OF EDUCATIONAL PROGRAM IN RADAR.

With the overarching goals discussed in the previous section guiding the process, several university-wide educational retreats were held in 2004 to help design a curriculum that would best prepare our students for careers in radar meteorology/engineering and instill the importance of lifelong learning and curiosity. Emphasis was placed on providing background material where needed to encourage interdisciplinary participation. For example, the study of propagation of electromagnetic waves through the atmosphere requires some basic knowledge of atmospheric layers, stability, and thermodynamics. To encourage interaction between the disciplines, these topics are provided to the engineering students using meteorology students as peer teachers. Furthermore, the depth and coverage of material was chosen for each course to allow time for a meaningful hands-on experience. For example, courses that focus on signal processing would include exposure to algorithm development and actual implementation based on a user-friendly computing environment (e.g., Matlab). In a hardware design course, time would be set aside for the actual fabrication of microwave circuits designed as part of class projects.

A summary of the courses that evolved from this development process is provided in Fig. 1. The left panel shows more traditional engineering courses, in which topics are covered such as radar system design, signal/array processing, antenna design, and microwave circuit design. It is interesting to note that even with their engineering flavor, many meteorology students have successfully taken these courses, due in large part to the background material provided and the encouragement of the faculty to work within an interdisciplinary environment. The right panel encompasses the courses that cover applications of weather radar and more scientific uses. Bridging the gap between the "engineering" and the "scientific" courses are two offerings: Weather Radar Theory and Practice, and Weather Radar Polarimetry. With some exceptions, the courses are cross-listed between meteorology and electrical and computer engineering, thus allowing engineering and meteorology students the possibility to satisfy traditional program requirements. In addition, most courses can be taken at the undergraduate or graduate level. As a particular example of OU's commitment to interdisciplinary education, one of these courses (Hazardous Weather Detection and Prediction) was developed as an educational component of the National Science Foundation Engineering Research Center Collaborative Adaptive Sensing of the Atmosphere (CASA). This course has been and is currently taught by a meteorology professor, but is only open to nonmeteorology majors.

Since the initial development of the curriculum in 2004, planning meetings are conducted every semester to discuss possible changes/enhancements. As the program further develops and the research field evolves, it is anticipated that new courses may be added and others removed or modified. Such changes are necessary, encouraged, and specifically designed into the ARRC's administration of the curriculum. In addition to Fig. 1, detailed course descriptions are available on the ARRC Web site at http://arrc.ou.edu/education.

HANDS-ON RADAR LABORATORY FACILITIES—CURRENT AND PLANNED.

With an educational taxonomy, and given the major goal of providing students a hands-on experience, modern and well-maintained laboratories and radars are available to support the classes in Fig. 1. As part of OU's strategic radar initiative, the ARRC has developed two new laboratories dedicated to student training and the study of the atmosphere using electromagnetic waves. The Radar Innovations Lab (RIL) is focused on the design, fabrication, and testing of unique, research-quality Doppler radars and supports capabilities up to frequencies of 50 GHz. The Electromagnetics and Microphysics Lab (EMPL) is being developed for precision measurements of the interaction of electromagnetic waves with hydrometeors, and is centered on an anechoic chamber testbed. Future plans for the EMPL include an environmentally controlled facility and equipment for the study of hydrometeor interactions (collision, coalescence, breakup, etc.), which will be important for several courses, including Weather Radar Polarimetry and Weather Radar Applications, for instance. Recent photographs from the RIL and EMPL are provided in Fig. 2. It is interesting to note that although the laboratories were initially developed for student-led research purposes, the first project in the RIL was an undergraduate capstone project in the ECE department, where the students built and fielded a boundary layer profiling radar clutter-cancellation receiver. Other classes, such as Radar Engineering and Digital Radar Systems, are able to help students learn by introducing new concepts via design strategies taken from numerous other projects that are underway, as discussed next.

In addition to indoor laboratory facilities, the educational activities at OU are supported by access

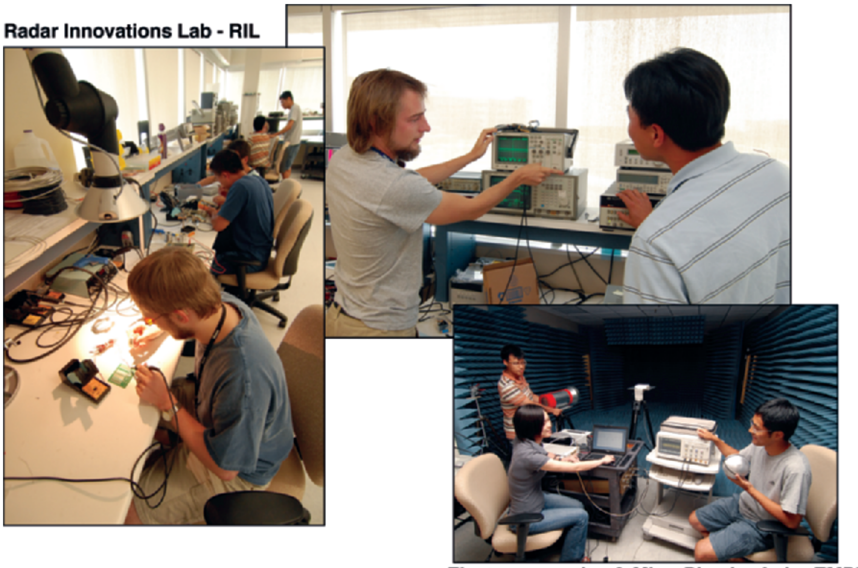

Fig. 2. As one illustration of hands-on activities, this figure depicts the microwave laboratory facilities in the One Partner's Place building just east of the National Weather Center. The Radar Innovations Lab (RIL) is used for fabrication and testing of microwave circuits with capabilities up to 50 GHz. The Electromagnetics and MicroPhysics Lab (EMPL) is currently under development, but has already yielded interesting results for in-situ measurements of hydrometeor scatters. For example, students enrolled in Microwave Engineering and Weather Radar Polarimetry have strengthened their understanding of theoretical concepts in these labs.

to a host of local weather radar systems (see Fig. 3). The Phased Array Radar (PAR), which is the centerpiece of the National Weather Radar Testbed (NWRT) in Norman, is the first phased array radar used for observations of severe weather. The PAR is an S-band Doppler weather radar developed by a government/university/industry consortium led by NSSL. Largely supported by NSF's Division of Undergraduate Education, OU has worked closely with NSSL to integrate the PAR into its educational program, and has developed a suite of laboratory modules (http://arrc.ou.edu/education). NSSL also operates the first prototype polarimetric WSR-88D radar (KOUN), which is used in the classroom as well as in several joint projects between OU and NSSL. With the nascent upgrade of all WSR-88D radars to dual-polarization over the next few years, access to KOUN is invaluable for OU students. For instance, students in Weather Radar Polarimetry learn approaches for more accurate hydrometeor classification and actually implement these algorithms as a class project. With the major goal of education at its core, the SMART Radar (Shared Mobile Atmospheric Research and Teaching Radar) program affords students the experience of field observations with mobile radars, which is an important component of the Radar Meteorology course. One of these C-band radars will soon be upgraded to dual-polarization emphasizing the importance of such measurements for studies of severe weather, quantitative precipitation estimation (QPE), etc. NSSL and OU have also partnered to develop a mobile X-band dual-polarimetric radar known as NO-XP that will be used in classroom teaching and educational outreach activities. The combination of mobile systems at different frequencies provides students the ability to examine non-Rayleigh scattering effects and to combine multiwavelength observations to gain further insight into cloud and precipitation processes.

For new educational paradigms, additional radar facilities have either recently become available or are being currently developed. OU-PRIME (Polarimetric Radar for Innovations in Meteorology and Engineering), for example, became operational in early 2009 and is shown on the right side of Fig. 3 during the final phase of construction. This C-band, polarimetric radar has the highest angular resolution (one-half-degree beamwidth) of any research radar of its kind in the world. The new facility is operated by the ARRC and will play a major role in the educational experience of our students. By leveraging the curriculum, a student-led mobile imaging radar is being developed by a student team, which embraces all six elements of the pedagogical taxonomy. Based on array processing methods, this radar will allow students to study advanced beamforming methods in practice. Finally, work that the ARRC conducted with the ROC has allowed students to gain experience with the nation's operational weather radar network. Although the goal of these development projects is to enhance the opera-

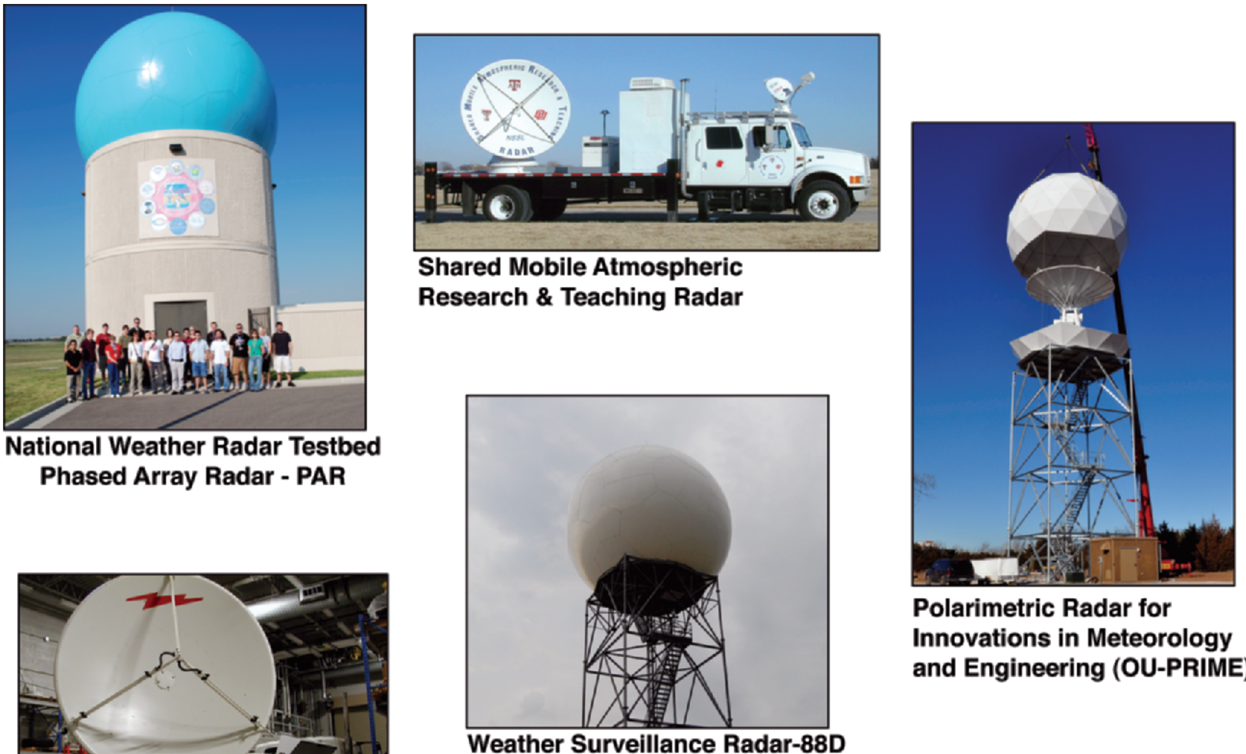

Fig. 3. Radar facilities currently available to OU's curriculum through close collaboration with partners at the National Severe Storms Laboratory and the Radar Operations Center. In addition, OU-PRIME has recently been commissioned and will play a major role in the education of our students.

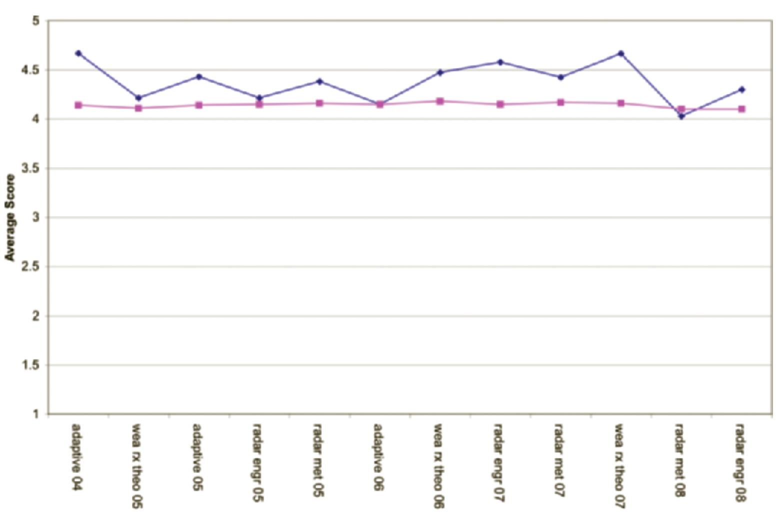

Fig. 4. The blue line with the diamond symbols represents the average Student Faculty Evaluation (SFE) scores that are used to rate the effectiveness of a professor's class at OU. The cyan line with the square symbols represents the average SFE scores from the college. In the rubric, 5 is the highest and 1 is the lowest.

tions of the WSR-88D radars, unique datasets are available on ARRC's servers for student use.

LESSONS LEARNED, FUTURE PLANS, AND CONCLUSIONS.

Since 2004, OU's weather radar curriculum has continued to evolve and currently offers 11 courses for a total of approximately 300 credit hours per year. In any interdisciplinary endeavor, it is important to engrain in the participants the importance of each discipline and the fact the entire field cannot move forward without a variety of talents. In a classroom setting, this is manifested by things as simple as how students choose team members for group projects. Almost without exception, OU's radar classes have as an integral component a group project, in which an interdisciplinary team is strongly encouraged. For example, during the Fall 2008 semester, students in Weather Radar Theory and Practice formed groups for the final project, with topics including tornado detection (signal processing and storm dynamics), attenuation correction (electromagnetic wave propagation and precipitation physics), and radar hydrology (QPE and hydrological modeling), among others. Without consistently reinforcing the importance of all fields involved in radar meteorology, such interaction would not be possible.

Figure 4 depicts the course evaluations that have benefited from the inclusion of hands-on radar modules. These data summarize the results of our Phase I grant NSF-0410564, and our Phase II grant, which 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 is 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 the fall of 2005, its class SFE scores have consistently increased. Through student interviews and more casual conversations, students consistently stress the importance of hands-on activities in the often-challenging area of radar meteorology.

Currently, the SoM has an undergraduate minor for engineering students. Similarly, a minor in electrical engineering is under study. On the graduate front, a new interdisciplinary master of science program in weather radar has been designed and is being vetted with the appropriate academic units.

As part of OU's radar education, internships with both the private sector and governmental entities are being pursued. For example, an internship program has recently been initiated with a large radar firm, which usually focuses on federal procurements related to the defense industry. Recently, two OU graduate students (one meteorology and one electrical engineering) participated in long-term internships at this firm's research facility.

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