Integrating Research and Education through Measurement and Analysis

BY JOHN L. SCHROEDER AND CHRISTOPHER C. WEISS

The training of future scientists to efficiently develop and use instrumentation demands classroom access to platforms and supporting infrastructure. Unfortunately, funding-strapped universities have recently been reducing investment in classroom instrumentation. Conversely, observational facilities at Texas Tech University (TTU) have expanded over the last decade. Integrating the growing observational capabilities into a classroom setting was a logical extension to the ongoing research efforts. This idea served as the impetus for the development of a new laboratory and set of graduate courses.

FIG. 1. Photograph of the classroom in the measurement and analysis laboratory at Texas Tech University.

LABORATORY DEVELOPMENT. To help foster an innovative environment, a new laboratory was developed in 2002 using approximately $175,000 in total financial support from the National Science Foundation (NSF) and TTU, as well as equipment donations from private corporations. The laboratory includes a classroom (Fig. 1) and an associated workroom. The classroom maintains six individual system suites; each suite includes a dual-boot PC equipped with a variety of software capabilities, and various instrumentation and data acquisition (DAQ) resources. An adjacent workroom provides an open area for construction of new instrument platforms as well as testing and maintenance of existing systems. The room includes stand-alone and PC-based test equipment, including oscilloscopes, wave-form generators, digital multimeters, power supplies, and a spectrum analyzer. A variety of hand and power tools, soldering and desoldering stations, and electronics supplies are also available.

The laboratory is located at the Wind Science and Engineering (WISE) research facility, part of the Reese Technology Center, about 10 miles west of campus. A wealth of existing field facilities are located nearby and are available for use in the classroom. These facilities include several mobile hurricane towers, five instrumented mobile mesonet racks, the WISE 200-m meteorological tower, 24 StickNet platforms (quickly deployable 2.5-m-tall meteorological stations), as well as all of the assets of the West Texas Mesonet. Additional instruments, some already under development, are expected to become available as the research infrastructure continues to grow. The location of the laboratory encourages interaction between the students and the technical staff of the WISE Research Center and West Texas Mesonet, and also allows staff to make use of the same laboratory equipment. An upgrade to the laboratory is planned for early 2008 using NSF funding; future upgrades to the laboratory will depend on the availability of internal and external funding.

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COURSE DEVELOPMENT, OBJECTIVES, AND EXAMPLES. The laboratory classroom provides an optimal setting for student development, and three courses in atmospheric science (ATMO) have been developed utilizing the laboratory's capabilities. Other courses also make use of the laboratory, including a graduate course in engineering measurements.

The first graduate course (initiated in 2003 and taught every two years), Meteorological Data Acquisition and Instrumentation Systems (ATMO 5351), is focused on understanding, designing, and building measurement systems. Students gain an understanding of the entire instrumentation system, not just the sensor, allowing them to quickly design and develop observation systems made from off-the-shelf components, explore more complex instrument designs, and understand system limitations and response. To accomplish this goal, the first half of the course is dedicated to DAQ issues (e.g., software development, hardware limitations and performance, signal conditioning), while the second half is focused on sensor-related issues (e.g., static and dynamic performance characteristics, sources of error, limitations).

The course reinforces theories and concepts with hands-on experiments and projects. For example, student teams connect sensors into PC-based DAQ hardware, develop appropriate National Instruments' Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software to acquire, display and store relevant meteorological observations (recognizing appropriate offsets and scaling factors), and verify system precision relative to expectations. Later in the semester, students connect sensors into provided Campbell Scientific dataloggers and develop appropriate acquisition software for the datalogger. The dataloggers are then interfaced with a PC using RS-232 serial communications, and timing issues (datalogger-controlled sampling rates relative to communications rates) are explored.

The second course (initiated in 2002 and taught every two years), Meteorological Research Methods (ATMO 5352), is largely focused on analysis and interpretation of collected datasets. Students gain an increased awareness of the research process and background on commonly used analysis techniques, allowing them to effectively analyze and interpret exceedingly large and diverse datasets. To accomplish these goals, the course is broken into two main segments. The first segment provides discussion of the research cycle (proposal writing, research process, and dissemination of results). The second, more significant, segment focuses on specific analysis techniques (e.g., descriptive statistics, visualization, correlation, time-series analysis, filtering, wavelets, etc.).

Students learn theories and concepts in lecture, which are reinforced using in-class examples. For example, students develop Mathworks' MATLAB code to provide basic quality control (e.g., step test, range test, etc.) for raw West Texas Mesonet data early in the semester. Temperature data collected from a single mesonet station, and the inherent diurnal temperature cycle, are then used to introduce Fourier analysis. The instructor then generates a predefined sinusoidal signal using an available signal generator. The students acquire the known signal using the available DAQ hardware and a specified sampling rate, and provide visualization of the signal in the time and frequency domains. The instructor then slowly increases the signal frequency until the energy peak in the frequency domain of the sampled signal starts to wrap back toward lower frequencies, providing a simple, but powerful, in-class example of the Nyquist frequency.

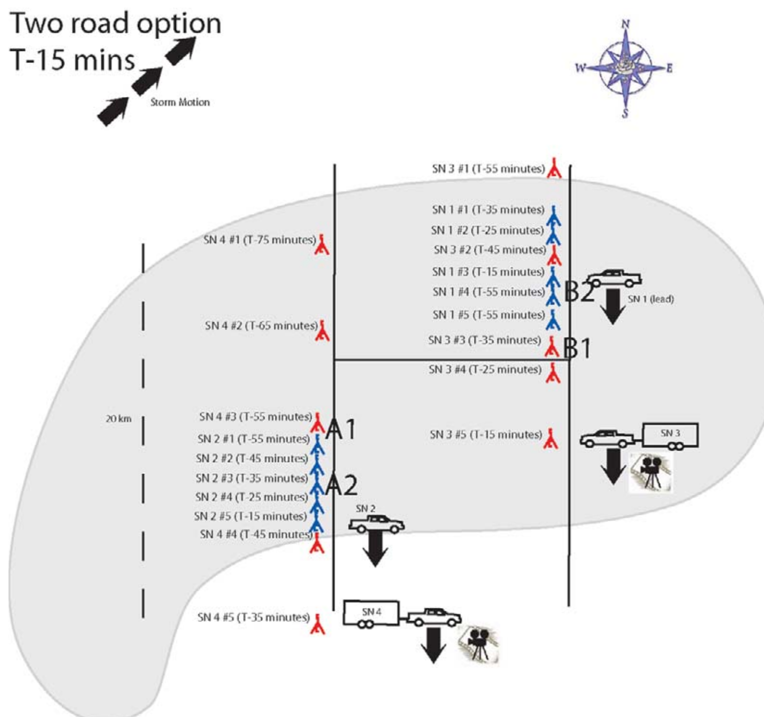

Fig. 2. Example of an experimental plan developed during the 2007 course offering of ATMO 5353, Meteorological Field Experiments. The planned two-road deployment of StickNet platforms to collect data from an approaching supercell (forward-flank precipitation is shaded) is shown using four coordinated transport vehicles. Estimated storm motion is indicated, and individual platform deployment timelines are indicated with respect to the time (T) the tornado crosses the array. Reference points A1, A2, B1, and B2 are determined by a field coordinator and relayed to each transport vehicle.

Many institutions maintain a course where students travel to the field in an organized effort to observe thunderstorms under the guidance of a faculty member, but rarely is a field research component effectively involved. The third graduate course (initiated in 2004 and taught every year), Meteorological Field Experiments (ATMO 5353), leverages the available observational technologies to complete research-relevant field experimentation. Students gain an understanding of how to design, plan, and execute scientifically relevant atmospheric field research. To accomplish this goal, the class develops field strategies based on science objectives and available instrumentation, and attempts to execute the experimental plans, remaining intimately involved in every aspect of the field campaign.

For the 2007 course offering, open questions regarding kinematic and thermodynamic gradients within the forward-flank region of supercells, and their potential importance to tornado genesis and maintenance, were posed to the class. Additional background information on the existing mobile mesonet and StickNet platforms was also provided. The students and faculty, working together through an open, iterative process, then developed experimental strategies (e.g., Fig. 2) to use the available observational technologies to acquire scientifically relevant observations that contributed toward answering the open science questions.

The students prepared the observational platforms (Fig. 3) for use, and provided mass platform tests (Fig. 4) to identify instrument malfunction and instrument bias. Students also installed and checked the functionality of other required infrastructure (laptops, GPS equipment, software applications, radios, etc.).

Fig. 3. Photograph of a graduate student working on a mobile mesonet rack. Mobile mesonet probes were used to acquire near-surface kinematic and thermodynamic characteristics of rear-flank downdrafts.

Daily forecast discussions were initiated, focusing on the probability of supercell occurrence within the experimental domain. Students and faculty discussed potential deployment opportunities, considering not only the predicted atmospheric conditions, but also budgetary (travel and fuel expenses), personnel, and time (project duration) constraints.

Upon activation, the group caravanned to the predicted area of interest. The instructors served as field coordinators, but students were also tasked with various leadership roles. The group then attempted to execute the experimental plan given that the predicted deployment opportunity materialized. Students were also tasked with completing numerous other daily responsibilities, including downloading and validating data, making platform repairs, troubleshooting radio performance, monitoring the travel and fuel budgets, etc. Each time the group returned from field operations, data were inspected further, in-depth maintenance was performed, and the experimental and logistical plans were discussed and modified based on the newly acquired field knowledge.

EXAMPLES OF CLASSROOM PROJECTS. A recent student challenge was to develop a relatively inexpensive instrument platform, termed StickNet, which could be quickly deployed (1–2 minutes). A mass of these relatively inexpensive platforms could then be placed in the direct path of a landfalling hurricane or downstream of a supercell thunderstorm to provide a wealth of near-surface meteorological information in locations where manned mobile mesonet probes cannot be sent. The student design process yielded a host of reasonable approaches. The designs were presented and reviewed in an open setting by faculty and students. After significant classroom discussion on the advantages and disadvantages of each design, two prototypes were selected, built, and tested. Subsequent classes constructed 22 additional platforms (Fig. 5), with each new edition improving on the previous. These StickNet platforms are now available to serve in future field campaigns.

Another class assignment was the development of a LabVIEW application to provide an informative graphical user interface to the occupants of a mobile mesonet platform. This application is important if thermodynamic and kinematic gradients are to be realized in real time. The application interfaces a laptop with the mobile mesonet's Campbell Scientific datalogger using a serial port and provides plots of temperature, pressure, dew point, equivalent potential temperature, virtual potential temperature, wind speed, wind direction, and indicators for other useful information (such as car location, speed, direction, etc.). The application was developed by each student, with the best approach being formalized into what is currently employed in TTU's field research operations.

STUDENT PARTICIPATION AND RESPONSE. It is important to note that while all three graduate courses are offered in the ATMO curriculum at TTU, students from other disciplines (typically engineering) enroll and actively participate in the courses. In fact, two of the three courses have

Fig. 4. Photograph of graduate students working to complete a mass test of newly constructed StickNet platforms.

actually been populated with a majority of students from tangential disciplines. This multidisciplinary environment is especially active in the Meteorological Field Experiments course, since it is a required core course for the NSF-sponsored Integrated Graduate Education Research and Traineeship (IGERT) degree program in WISE.

The advantage of the various academic backgrounds working together toward a common goal is magnified in field campaigns and design projects. In a recent class project, ATMO students benefited from the input of engineers who used their expertise to provide wind load calculations for StickNet designs. At the same time, the engineering students benefited from the meteorological knowledge of the ATMO students, particularly as related to the science supporting the field project. This diversity in academic background leads to a healthy exchange of ideas and knowledge that benefits all students who take the courses.

Pre- and post-course surveys have been administered and have yielded significant feedback to judge student development. The survey responses (based on 26–37 student responses in each course) indicate that all respondents find the hands-on design projects, in-class examples, and field experience especially useful and a strong supplement to the ATMO curriculum. The surveys also indicate that while some students (19% of respondents) tend to arrive in graduate school at TTU with some experience with sensors, only 5% of respondents understand how to interface with them. The course surveys also serve as a mechanism for anonymous student feedback to the instructor, which has led to course modifications/improvements in subsequent semesters.

Students who have completed all three courses have provided strong statements concerning the comprehensive value of the experiences. One commented: "The opportunities provided to me here at TTU have been invaluable to my growth as a researcher. Having access to state-of-the-art facilities and observation systems, combined with a unique ability to create and develop independent research projects, has given me first-hand exposure to field research." Another responded: "The three courses combined give students tremendous exposure to all aspects of meteorological observation and data analysis." ATMO faculty have also noted a sharp increase in the ability of the general graduate student body to complete more independent, observationally based research projects since the laboratory and associated coursework was established.

Fig. 5. Photograph of a student team working together to construct a new StickNet instrument platform.

SECONDARY IMPACTS. What truly makes the efforts described herein unique is the student access to the existing observational capabilities and active participation in the design and construction of new technologies. When the platforms and software applications are assembled over time through student participation, the integration of research, education, and technology is complete. At the same time, the research capabilities of the university slowly expand through their efforts. Beyond the major goals and impacts already discussed, several secondary tangential impacts have also been recognized.

LabVIEW programming is an important component to the measurements course. LabVIEW has successfully been integrated by other science and engineering disciplines into a classroom setting, but has not been incorporated to a large degree into ATMO courses. LabVIEW uses "G," a graphical programming language, which differs significantly from the standard text-based languages such as C or FORTRAN. Incoming graduate students typically maintain some level of text-based programming knowledge acquired during the pursuit of their undergraduate degree, yet even students with significant programming experience benefit from recognizing the LabVIEW "dataflow" programming paradigm. A clear increase in subsequent text-based programming skills has been observed.

The Meteorological Field Experiments course is typically composed of mainly Ph.D. students. Students are encouraged to think independently and question everything, developing their own ideas and concepts for new instrument platforms and/or projects. The laboratory setting and existing observational capabilities then provide a means to test their theories and ideas through experimentation. For example, students in a recent class questioned the effect of platform motion on data acquired from a propeller vane anemometer mounted on a mobile mesonet rack. Discussion ensued, which led to an experiment where a sonic anemometer was mounted adjacent to a propeller vane anemometer on a mobile mesonet unit. The DAQ system and associated software were modified to incorporate the signals from the sonic anemometer. Data were then collected, analyzed, interpreted, and discussed.

Students and instructors have benefited from the data acquired in the field experiments course. Instructors have leveraged the pilot datasets for future science proposals, and students have used the resulting data toward the completion of their theses or dissertations.

CONCLUSIONS. Our science demands measurements to validate and extend our numerical and theoretical efforts. While providing classroom access to observational facilities can be a challenge, it has been shown that a seamless integration of research assets into a multidisciplinary educational environment can be beneficial to student development and the continued growth of the research infrastructure itself. Student participation in the finer details of field projects and instrument design decisions results in a rich educational environment that, when coupled with science objectives, completes the discovery process. The students, institution, and society benefit greatly from this integration.

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FOR FURTHER READING

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