

Linking meteorological education to reality:
A prototype undergraduate research study of public response to
Hurricane Rita forecasts

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Abstract

After the 2005 hurricane season, several meteorology students at Texas A&M University became interested in understanding Hurricane Rita's forecasts and societal impacts in greater depth. In response to the students' interest, we developed a collaborative student research study at Texas A&M associated with an undergraduate course in the spring semester of 2006. The study included a meteorology component and an interdisciplinary component, in which students performed an in-person survey of Texas Gulf Coast residents. Students were involved in multiple phases of the research, from design to implementation to dissemination of results. This collaborative research model engaged and motivated the students, providing substantial educational benefits. The study and class linked the students' classroom knowledge to reality while generating new knowledge about societal aspects of Hurricane Rita and other hurricanes. This paper reviews key aspects of the study and class, presenting a prototype integrated research/education model for others interested in incorporating active learning, collaborative inquiry, and interdisciplinarity into undergraduate classrooms. The model can be implemented at both colleges and research universities, for a variety of topics of interest to students, teachers, the research community, and society.

1. Introduction

In 2005, four major hurricanes made landfall in the U.S., causing more than 2000 deaths and \$100 billion in damage (NCDC 2006). Especially destructive were Hurricane Katrina and the subsequent levee failures in New Orleans, which generated widespread devastation, disruption, and suffering reported around the world. Although hurricane forecasts, warnings, evacuation, and damage have been actively discussed in the meteorology and hazard management communities in recent years, Katrina and the 2005 hurricane season launched these issues onto the national stage, opening a window of opportunity for the meteorological community to articulate and reevaluate its role in preventing such disasters.

One month after Katrina, in August 2006, Hurricane Rita threatened much of the Texas/Louisiana Gulf Coast, prompting large-scale evacuations and causing over \$10 billion damage at landfall (Zhang et al. 2007). At Texas A&M University, approximately 200 km from the Gulf, students and staff watched as Rita threatened their region and, for some, affected their hometowns. This experience interested several Texas A&M meteorology students in understanding Rita's forecasts and societal impacts in greater depth. In response to the students' interest, we developed a collaborative student research study at Texas A&M associated with an undergraduate "directed studies" course in the spring semester of 2006. Seven undergraduates and three graduate students participated, along with the two authors as principal investigators (PIs).

The research study included a meteorology and an interdisciplinary component. The meteorology component was an investigation of uncertainties in forecast of Rita, through three small group projects. The interdisciplinary component was an investigation of the public's perceptions of hurricane risk and their use and perceptions of Rita forecasts, through an in-

person survey of Texas Gulf Coast residents. Students were involved in multiple phases of the research, from study design and implementation through analysis and dissemination of results. The class included exposure to new meteorology and interdisciplinary concepts; collaborations among undergraduates, graduate students, faculty, and other researchers; classroom and web-based discussion; written and oral presentations; and field work communicating with members of the public. Together, the research study and class generated new knowledge about societal aspects of Hurricane Rita and other hurricanes, along with substantial educational benefits for the students.

The study and class described here are connected to broader conversations about how meteorology education, as well as science and undergraduate education more generally, can and should evolve. In recent years, changes in meteorological technology, knowledge, and careers have prompted discussion of how well current undergraduate meteorology curricula meet the needs of students and the discipline (e.g., Croft and Binkley 1997). Such discussion has motivated atmospheric scientists to develop applied meteorology classes and programs (e.g., Changnon 1998, 2004; Carr et al. 2002), explore teaching techniques that better link theory with applications (e.g., Roebber 2005), provide research experiences for undergraduates (e.g., Cortinas et al. 1996; Pandya 2005), and incorporate inquiry and interdisciplinary experiences into classrooms (e.g., Pandya et al. 2004). A similar movement to enhance inquiry-based, collaborative, interdisciplinary learning is also building in scientific and undergraduate education as a whole (e.g., NRC 1996, 1999; Boyer Commission 1998; González 2001; Wood 2003; Lawler 2004; CUR/NCUR 2005). The study and class we developed illustrate one way that undergraduate teachers can link theory to applications and incorporate collaborative inquiry, active learning, and interdisciplinarity into meteorology classrooms, while motivating students

and preparing them for a range of future opportunities. The prototype is applicable at both research universities and smaller colleges, for a broad range of topics.

This study and class are also linked with broader trends in atmospheric science and related fields. Although weather- and climate-related predictions and projections have improved in recent years, such information cannot, on its own, prevent negative societal outcomes — as the climate change debate and disasters such as Katrina clearly illustrate. This realization, along with budgetary pressures and other factors, has motivated the atmospheric science community to discuss how weather- and climate-related information is used in societal decision making and how our community can better meet society's needs (e.g., Pielke and Kimple 1997; Stern and Easterling 1999; Morss et al. 2005; NRC 2006; USCCSP 2006). The in-person survey we performed addresses some of these questions, in the case of Hurricane Rita and hurricane forecasts (see sidebar for highlights and Zhang et al. 2007 for more detailed results). This illustrates how research and education can be integrated in interdisciplinary investigations that simultaneously engage students in the learning process and generate new knowledge that helps the atmospheric science community better serve society.

[Sidebar: Highlights of results from survey of Texas Gulf Coast residents

- *As Hurricane Rita approached, most of our respondents obtained hurricane forecasts frequently, and the vast majority obtained forecasts from several sources. Many used this forecast information, in conjunction with other information, to evaluate the risk that Rita posed for them and their family and to decide whether and how to prepare and/or evacuate.*
- Only about 15% of responding evacuees said the primary reason they evacuated was an evacuation order. The remaining respondents offered a variety of other reasons for their

evacuation decision. This indicates that while effectively communicating forecasts to emergency management officials is important, the meteorologists should also collaborate with social scientists and emergency management officials to improve communication of hurricane forecasts and hurricane risk to different segments of the public.

- *Approximately 10% of respondents who evacuated from Hurricane Rita said that Hurricane Katrina was their primary reason for evacuating.* More than half of respondents stated that Hurricane Katrina influenced their evacuation decision.
- *Although many evacuating respondents experienced significant traffic and minimal damage to their property and communities, most would evacuate again next time.* Most evacuating respondents who would do something different next time said they would leave earlier or prepare better. This suggests that occasional “false alarms” do not reduce many residents’ willingness to evacuate in future hurricanes; in fact, such experiences may help people plan for future evacuations, if needed.
- *The majority of respondents anticipate evacuating for a future Category 3-5 hurricane, but the majority do not anticipate evacuating for a Category 1-2 hurricane.* This indicates that respondents understand that hurricane risk generally increases with increasing classification on the Saffir-Simpson scale. However, different people had different thresholds for evacuation, and a few respondents living near the coast said they would not evacuate even for a Category 5 storm. People may also need more detailed forecasts of potential maximum wind speeds, storm surge, fresh-water flooding, and impacts in their area to make informed evacuation decisions.
- *Overall, most respondents reported high confidence in Hurricane Rita forecasts, and most were very satisfied with the forecasts’ timeliness and quality.*

Although one cannot generalize from our survey of 120 residents to the general population, these results (together with those from previous related research) identify important issues for meteorologists to consider when developing and communicating hurricane forecasts. They also raise questions for more in-depth interdisciplinary investigation in future work. For further details and discussion, see Zhang et al. (2007).

[end sidebar]

The important issues society faces related to hurricane evacuations and damage and other areas of atmospheric science cannot be addressed without interdisciplinary research and training. Studies and classes such as that described here promote this needed integrated perspective, helping the next generation of meteorologists understand how weather and climate information — and science in general — interact with society. This knowledge will serve our discipline and the students well, whatever career path they choose. Thus, we believe that the education-research paradigm we successfully implemented can serve as an example for enriching undergraduate curricula and student research experiences in meteorology and other disciplines.

2. Implementation of research study and class

The study and class had several overlapping goals. First, we sought to explore uncertainty in forecasts of Hurricane Rita and societal aspects of Rita and its forecasts. Second, we aimed to give the students experience with the full research process, including development of research questions, collection and analysis of data, and presentation of results. Third, we wanted to connect the students' classroom-derived knowledge with reality, by providing them with first-hand exposure to real-world problems. In the process, we sought to enhance the

students' oral and written communication skills and prepare them for future careers, all in a collaborative environment.

To meet these goals, the PIs developed the class around two research components, both collaborative. The first component was a meteorology project overseen by the Texas A&M PI. Depending on their experience and interests, students worked in one of three small groups: group 1 examined deterministic and probabilistic aspects of the National Hurricane Center's real-time forecasts of Rita; group 2 examined forecast uncertainties by performing numerical simulations of Rita with the Weather Research and Forecast (WRF) model (Skamarock et al. 2001); and group 3 examined media coverage of Rita's forecast and damage. The second component was an investigation of public response to Hurricane Rita and related issues, overseen by both PIs. To give the students an opportunity to learn from the public first-hand and allow the study to be conducted within a semester, we decided to structure this component as an in-person survey of Texas coastal residents, performed by the students. Because the survey research component is more novel for meteorology curricula, the remainder of this section focuses primarily on this component and the structure of the class, as a brief guide for others interested in implementing similar efforts. Further details on the survey are available in Zhang et al. (2007) or upon request from the authors.

The survey questionnaire was developed through collaborations among the students and PIs, via discussion at class meetings, on a class-maintained weblog, and over e-mail. Specifically, the students helped the PIs brainstorm potential questions, decide how to phrase the questions, and select which questions to include in the final questionnaire. As the questionnaire was being developed, students received one-and-a-half hours of interview training from a researcher at the Texas A&M Hazard Reduction and Recovery Center (HRRRC). Each student

then conducted at least two practice interviews to obtain experience and to pretest the questionnaire. The questionnaire was finalized based on recommendations from the students following their pretests. Approval for implementing the survey with human subjects was obtained through the Texas A&M Institutional Review Board (IRB); filing the IRB application and taking the online IRB training course required about 10 hours of the Texas A&M PI's time.

The questionnaire included both closed-ended questions, to facilitate data collection and allow the students to participate in formal quantitative analysis of the results, and open-ended questions, to give students opportunities to learn first-hand about people's perceptions of hurricane risk and their hurricane experiences. The questionnaire was designed to last approximately 15 minutes, although some interviews lasted much longer when respondents provided extended responses. Much of the survey was structured as a closed-ended (yes/no, numerical, or short-answer format) question followed by an open-ended question to gather richer, more detailed information. We found that this format worked well because it struck a balance between being easily implemented by the students (who had limited interview training and experience) and providing the students with an interesting educational experience.

Given limited time and resources, we implemented the survey in three Texas Gulf Coast regions: Galveston, Port Arthur, and Houston. The seven undergraduates and one graduate student who participated in this component of the study divided into three groups, with each group traveling to one of the three areas for a day or weekend to conduct the interviews. Students used a convenience sampling strategy, approaching respondents in a variety of locations. The students followed the structured questionnaire, recording responses on the interview sheets and, for about half of the interviews, on digital voice recorders. The students

conducted 120 interviews used in analysis, with most students conducting more than 10 interviews each.

Students coded the responses from their interviews into computer data files based on a standard format developed by the PIs. These files were verified against the interview sheets by one of the graduate students, and the PIs performed basic quantitative and qualitative analysis of the results. These results were then discussed with the students, who incorporated their interpretations of these findings and their own qualitative impressions from the interviews into their final class reports. After the semester was over, the PIs completed analysis of the data and wrote a manuscript discussing the results with the students as co-authors (Zhang et al. 2007), obtaining feedback from the students on the manuscript draft. The students therefore participated in every component of the survey research project, from design to implementation to dissemination of results.

The class associated with the research study was 3 credit hours and met once per week. The research team held smaller group meetings as needed and frequently communicated with each other through e-mails and a class-maintained webpage. Because one of the PIs is located in Colorado, most of the classes were conducted by the Texas A&M professor; the other PI traveled to Texas A&M towards the end of the semester to discuss the survey results with the students. One of the three graduate students served as the official class teaching assistant. Each graduate student also played a “teaching assistant” role for one of the three meteorology group projects.

To augment the interdisciplinary educational component of the class, the students were assigned several readings discussing societal aspects of hurricanes. They also had two class meetings with Texas A&M HRRC researchers who study hurricane evacuation and response: one for interview training, and a second to discuss the survey results. In addition, each student

had at least three opportunities to give class presentations, and each student wrote a final report discussing their educational experience and results from both research components. As a further experience with disseminating scientific results, several undergraduates presented two posters on the study at the 2007 American Meteorological Society Student Conference.

From the beginning, the research was framed as a collaborative effort among the students and the PIs. To set this collaborative tone, the class was discussion- rather than lecture-based, and students were engaged early on in helping design the research study. The Texas A&M PI also motivated the students by telling them they would be co-authors on a manuscript discussing the survey results if significant findings were obtained. This collaborative framing ensured substantial discussion and sharing of experiences throughout the project, benefiting the students, the PIs, and the research.

Based on our experience, there are several aspects of the class that we would probably implement differently next time. First, we began planning the class less than a month before the semester started, based on the students' interest in examining a recent event. Several months' additional planning time would have helped us scope the research components and class content, navigate and fulfill the IRB approval process, entrain more local expertise in societal aspects of hurricanes, and obtain additional funding to implement the study and facilitate in-person interactions with the non-local PI. Second, with two research components, the class was quite broad. To better merge the educational content, we would likely focus the class around societal aspects of Rita and implement only the survey component of the research. Such a focus would allow us to provide more interdisciplinary training and discussion, based on additional readings, more in-depth inquiry, and more extensive interaction with social scientists.

3. Educational benefits

By participating in the research study and class, the students gained substantial educational benefits, which we describe using material from the students' final reports. This discussion is necessarily anecdotal, given the small number of students involved. The benefits we found are complementary to those reported in other studies of undergraduate research and related inquiry-oriented educational experiences (e.g., CUR/NCUR 2005).

The first major benefit for students was learning about the research process — including its rewards, challenges, and limitations. As one student explained, the class allowed the students “to experience what research truly entailed.” The inquiry-based format also motivated several students to identify additional research questions (meteorological and interdisciplinary) that they were interested in exploring further. We believe that these benefits were enhanced by two aspects of how the research study was framed: first, by students' active participation in all aspects of the research process; and second, by the collaborative nature of the study, with undergraduates, graduate students, and experienced researchers working together. Providing this end-to-end, collaborative research experience for the students made the study more time-consuming for the PIs, compared to a more typical PI-directed model for research. However, doing so also made the process more enjoyable for the PIs and improved the research project by incorporating the students' ideas. The collaborative framing of the project also motivated the students and engaged their interest, promoting active learning.

Because the study and class involved significant collaborative work and peer learning, students also benefited by applying and enhancing their leadership and teamwork skills. One student said: “the survey phase of the project gave me the opportunity to utilize many skills I have acquired throughout past leadership positions and to apply them to a real life scenario ...

Though [I do not perceive research as a] typical field involving leadership and teamwork, working with others was crucial in accomplishing our goals.” Another student “learned that group work is essential in scientific research projects.” A related benefit was learning the value of peer review in research and, more generally, the importance of critiquing and being critiqued. One student noted that “developing the questions on the survey [was] my first experience with ‘peer review’ ... After my experience with this, I realize how necessary this review process is.”

Furthermore, by talking directly with members of the public, students learned first-hand how a variety of people perceive hurricanes and hurricane forecasts. The students also discovered how learning about people’s perceptions can help meteorologists improve communication with the public — a major audience for weather forecasts — and other forecast users. One student explained:

“This project allowed me to see opinions of Hurricane Rita as well as future hurricanes of 16 different people. These 16 people came from different backgrounds, ages, and ethnicities. Seeing these people’s points of view ...will allow me to better understand what ordinary citizens need when it comes to hurricane forecasting. As meteorologist[s], if we know what information the public is looking for when it comes to hurricane forecasting, then we can be better in the job we do.”

This experience helped the students connect their meteorology and forecasting knowledge gained from other classes with the real world, where that knowledge is interpreted and applied by non-meteorologists. Such experiences are rarely provided in meteorology curricula, although they are an important aspect of training future meteorologists to understand the societal implications of their work and communicate effectively with stakeholders.

Through the collaboration, group work, presentations, and final report involved in the class, students also further developed their written and oral communication skills. In addition, participating in the research process enhanced students' problem-solving and analytical skills. These benefits, along with those discussed above, helped students prepare for a variety of future careers. Several students developed an interest in further research, while others' career plans were enhanced by "learning and understanding [about] one field that a meteorology major can get into." Whether the students pursue a career in research (meteorological or interdisciplinary), forecasting, forecast applications, management, or another area, the knowledge and skills they gained through the class will benefit their future endeavors.

Overall, the students appreciated the unique opportunity to work and learn outside the classroom setting. Although the project was challenging, they found tremendous value in applying their classroom knowledge and linking it to reality. As three students summarized:

"My research experience was great, but not in the way I expected. This project tested me mentally, physically, and socially. It proved to be very beneficial, though at times, it was very tough and demanding. I got to learn that there were many advantages, as well as [a few limitations], associated with this research project. I learned many things that could not be taught in a classroom, and that can only be learned through experience."

"Overall this project was an awesome learning experience. I have finally gotten the chance to start applying some of the knowledge from my classes, but more importantly I enjoyed getting out of the classroom and exploring areas of weather prediction not necessarily focused on previously. This was just a taste of what actual

research consists of; hopefully future opportunities will arise where I can dive head first into the unknown, in hopes of further self enlightenment.”

“This research project was a very important educational experience ... I would recommend an undergraduate research experience to anyone who asks me.”

4. A prototype for enhancing undergraduate meteorology education

The survey study and class we implemented were successful from both research and educational perspectives. They also promote broader goals in meteorological, scientific, and undergraduate education, by providing a prototype for collaborative, interdisciplinary, inquiry-oriented learning that links classroom knowledge to the real world. Such learning engages students in acquiring knowledge and skills, and it prepares them, in their careers and as citizens, to address a range of future problems in our increasingly interconnected world. Thus, we propose that our class can be used as a teaching model to provide other students with opportunities to experience the research process and learn first-hand about how people perceive and use scientific information. Such classes can be implemented at both research universities and liberal arts colleges, complementing related efforts such as PI-mentored undergraduate research programs, applied meteorology classes, problem-based instruction, and interdisciplinary seminars.

The class we developed focused around Hurricane Rita and public response to Texas Gulf Coast hurricanes because that was a topic of current interest to the students and in the Texas A&M region. The basic educational model can, however, be applied to a variety of other topics, depending on the region and the interests of students and teachers. Classes could focus, for example, around other recent weather- and climate-related events of local interest, such as

hurricanes, tornados, floods, droughts, or winter storms. Other possible topics include use of everyday weather forecasts, perceptions of climate change, mitigation policies for floods or other natural hazards, local environmental issues, and so on. As a research method, we found that in-person interviews with members of the public gave the students a particularly rich educational experience. However, the research component could also be implemented through interviews with other information users or stakeholders (such as local public officials), analysis of socioeconomic and hydrometeorological data using geographical information systems, or other interdisciplinary methods appropriate for the questions of interest. The research might generate results leading to a peer-reviewed publication or student conference presentations, as our study did, or it might serve primarily as a learning experience for the students.

While developing the interdisciplinary component of the research, the PIs consulted with two professors with survey experience who suggested that implementing a study such as ours with undergraduates would be challenging, if not impossible. They suggested that we make the study less ambitious, e.g., by having the students talk with emergency management officials rather than members of the public. Because the students were most interested in learning about the *public's* response to Rita, however, we decided to focus on that. We found that the students were sufficiently motivated to learn about the public's opinions that they met the challenge of helping develop a questionnaire and interviewing strangers, and the study was successful. This illustrates that undergraduate students are capable of contributing to such research efforts, if they are sufficiently engaged in the topic and process.

Based on our experience, we offer several recommendations for others interested in implementing similar educational efforts:

Choose a timely, local or regional problem of interest to the students. Focusing on such a problem will engage the students and enhance the classroom-to-applications link.

Enlist the students' ideas in developing research questions, and use those questions as a focal point for designing the research methodology and class. Doing so will bring new ideas into the research, match the class to the students' interests, and engage the students in the inquiry process.

Expose students to as many aspects of the research process as possible, from design through dissemination of results. For a one-term class, this will require participation from students before the term, to provide input for a general research and class design, and possibly after the term, as analysis and communication of results is completed.

Frame the study and class around collaborative work, including collaborations among peers, students with different levels of knowledge and experience, and students and researchers/faculty. Such a collaborative framing will motivate and challenge the students, improve their leadership and teamwork skills, and promote both peer-to-peer and mentor-mentee learning.

Entrain additional interdisciplinary expertise as needed to help develop interesting research questions, apply appropriate methods, and interpret results. Doing so will ensure that questions, methods, and results are relevant from appropriate disciplinary and interdisciplinary perspectives, and it will expose the students to cross-disciplinary discussion and ideas. Such expertise can be obtained at the institution where the class is being taught or another regional college or university. Or, as in this effort, one can leverage research or practitioner expertise available outside the traditional undergraduate education community.

Take advantage of local expertise when possible. In-person interactions with different experts enhance the interdisciplinary learning experience for the students. Where non-local collaborations are used, as in this effort, obtain funding for in-person interactions with the students to the extent possible and supplement with in-person discussions with local experts.

Remain flexible. Remaining open to new ideas and allowing the study to evolve gives students a more realistic picture of the research process. In our experience, it worked well to start the semester with a general plan but adapt to the students' interests and abilities as the semester progressed. We found that undergraduates can be quite capable if motivated, challenged, and made partners in the research. We also found that remaining flexible enhanced the learning experience for the PIs and benefited the research by entraining new ideas from the students.

We also identified three key elements for success with such efforts. The first is a small group of interested students. The second is at least two researcher/teachers with different (but overlapping) expertise who are willing to invest the time needed before, during, and possibly after the semester to design and implement the study and class. Although a similar effort could be performed with a single professor, we found that the interdisciplinary interaction substantially benefited the research, the students, and the PIs. Developing and teaching the class required additional time for the research component, but less time than a regular course for material preparation and homework grading. Thus, overall the class took approximately the same amount of the Texas A&M PI's time as a regular course, not counting the time required for IRB training (a one-time process) or the research time used to analyze and write up the results. The key third element is departmental support, to sanction the class, endorse the students' and professors' involvement, and provide teaching assistant and minor financial support as needed.

Interdisciplinary training and research to enhance understanding of science-society interactions continues to grow more important, for atmospheric science as a discipline, society, and students. Classroom-based efforts such as this one, while not appropriate for every research study or educational goal, can both address important research questions and provide a unique educational experience for students. In doing so, such efforts can advance interdisciplinary understanding and enhance undergraduate education, in both the short-and long-term. Thus, we encourage others to consider how the educational paradigm proposed here might be adapted to fit other environments, problems, and regions, and how such efforts might contribute to undergraduate education.

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