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A Severe Weather Laboratory Exercise for an Introductory Weather and Climate Class Using Active Learning Techniques

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ABSTRACT

This paper describes a new severe weather laboratory exercise for an Introductory Weather and Climate class, appropriate for first and second year college students (including nonscience majors), that incorporates inquiry-based learning techniques. In the lab, students play the role of meteorologists making forecasts for severe weather. The exercise is designed to teach students how to identify the atmospheric conditions that promote severe weather and how to prepare a severe weather forecast. We utilize collaborative learning in the lab exercise where students are encouraged to work in teams to accomplish the class assignment. Working in teams teaches students about how modern interdisciplinary science is conducted, as well as creates accountability for students to learn the material and complete their share of the work. Our results show that important content knowledge is maintained in comparison with a traditional lab and that students found the new lab more engaging. © *2011 National Association of Geoscience Teachers*. [DOI: 10.5408/1.3543917]

INTRODUCTION

Introductory Weather and Climate laboratory sections are frequently used to supplement the regular lecture section by providing opportunities for more "hands on" experience. Many of these classes rely on a laboratory manual that accompanies the textbook used in the lecture section. Unfortunately, the structure of the class using the manual often results in a laboratory section that begins with a lecture and ends with students taking a "cookbook" approach in working through the problems. The students, largely comprised of nonscience majors in their first or second year of college, receive very few opportunities to take an active approach to learning and rarely must think beyond simply finding the correct answer to a problem in the laboratory manual.

Student feedback we have collected over recent years indicates that the laboratory section is merely an extension to the lectures with traditional homework assignments, rather than a typical physical science lab where students conduct experiments with instruments and perform observational analysis and hypothesis testing. The result is that students are less enthusiastic and engaged in the material, which can hamper the overall learning and retention process. In order to help improve student-learning among the younger, more technologically driven student body, laboratory sections in Introductory Weather and Climate classes must foster and enhance student engagement and learning by adapting a curriculum that combines scientific, inquiry-based approaches with contemporary techniques (Prensky, 2006; 2001). Hands-on approaches in meteorology classes have been developed and implemented for weather forecasting (Cervato *et al*., 2009; Hilliker, 2008; Kahl *et al*., 2004; Kahl, 2001; Knox, 2000; Yarger *et al*., 2000) but to our knowledge there are no similar exercises for studying severe weather.

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This paper presents student perception and learning outcomes from the implementation of a new laboratory exercise on severe weather that incorporates inquiry-based learning methods with modern analytical techniques. In inquiry-based learning, students are encouraged to more actively participate in the learning experience by asking logical hypothetical questions and analyzing actual data in order to justify their findings. Our exercise utilizes two particular techniques to enhance the learning experience. First, it puts students through a process that mirrors what scientists do (Bhattacharjee, 2005; George and Becker, 2003; Flower *et al*., 1997). The focus is on scientific reasoning and application instead of only factual knowledge (Bhattacharjee, 2005). Second, students are divided into teams to work on projects. This "cooperative learning" encourages teamwork, while "peer pressure" leads to student accountability in terms of learning the material and performing their share of the work on the project (Leech *et al*., 2004; McKeachie, 2002; Johnson *et al*., 1991).

The goal of this lab is to apply active learning techniques to make the exercise more engaging for the students while maintaining rigorous content. It is important to consider that many students enrolled in this course are nonscience majors who may never take another science class. Thus, introductory science courses like this one may provide one of the few opportunities to teach them about scientific inquiry. This exercise is designed to teach students how to identify the atmospheric conditions that promote severe weather and how to prepare a severe weather forecast.

SEVERE WEATHER EXERCISE

Initial Preparation for Lab

At the beginning of class, the lab instructor divides the students into groups. The size of the groups depends on the class size and the number of available computers. Our classes typically have between 15 and 30 students, and we found that groups of 4 or fewer were ideal because this size encourages students to work closely and participate in the activity. In addition to the positive learning outcomes reported in Leech (2004), we like the group approach because it teaches students how modern interdisciplinary scientific work is so commonly done (Ackerman, 2007).

As will be discussed in the following sections, each group is then tasked to play the role of a professional severe-weather forecast team whose job is to look at various surface and upper-air atmospheric maps, examine the necessary atmospheric variables conducive for thunderstorm development (e.g., instability, moisture, lift), interpret the potential for severe weather (e.g., wind shear analysis), and to accurately communicate this information via different forecast products. We felt that by simulating the "real world" experience of a professional severe-weather forecast team, students are given a sense of relevance, which in turn can help promote improved student engagement and learning.

Our experience is that a successful outcome depends on properly teaching the laboratory instructor how to conduct an inquiry-based exercise. It should be made clear that part of the exercise is for the students to solve problems on their own. Also, some students who are used to more structured exercises may find their initial experience with an inquiry-based exercise frustrating or confusing. Thus, while the instructor should let the students work, he/she should be attentive to questions and help guide the students to the correct answer.

Background Information for Students

The lab is designed to build upon previous assignments, in which the students are expected to integrate their understanding of atmospheric stability, atmospheric motion, and midlatitude cyclones into severe-weather forecasting. Prior to beginning the lab, however, students are given some background information on the elements of severe weather forecasting via a short lecture. First, students are instructed about the mission of the Storm Prediction Center (SPC) (http://www.spc.noaa.gov) and the different forecast products they offer. Some of the SPC products include convective outlooks that consist of probabilistic categorical risk of thunderstorm activity, the mesoscale discussion (MD) of developing severe weather, and severe weather watches and warnings. The students then learn how these predictions are used to convey the threat of severe weather and how this information is disseminated by the SPC for public notification and awareness (e.g., Internet, National Weather Service office, local radio, television, etc.).

Next, the class is introduced to various fundamental variables that are used in assessing the atmospheric conditions for guidance in issuing a severe weather forecast. These include (but are not limited to) different atmospheric stability indices such as convective available potential energy (CAPE), lifted index (LI), severe weather threat index (SWEAT), total totals index (TT), as well as wind shear and storm-relative helicity (SRH) (details on these indices may be found at NWS, 2008). To aid the students, we provided the NWS severe weather checklist table that characterizes conditions for weak, moderate, and strong possibility for severe thunderstorm activity (Table I), (NWS, 2008).

TABLE I. Characteristic Conditions for Weak, Moderate, and Strong Possibility for Severe Weather After NWS (2008).

Parameter	Weak	Moderate	Strong
Surface			
Surface pressure	>1010 mb	1010–1005 mb	<1005 mb
Surface dew point	<55 °F	55–64 °F	≥65 °F
850 mb			
850 mb temperature axis	East of moist axis	Over moist axis	West of moist axis
850 mb dew point	<8 °C	8–12 °C	>12 °C
850 mb jet	<25 kts	25–35 kts	>35 kts
700 mb			
700 mb dry intrusion	Weak or no winds	Winds from dry to moist at ≥ 15 kts	Winds from dry to moist at ≥ 25 kts
500 mb			
500 mb wind speed	≤35 kts	36–49 kts	≥50 kts
500 mb vorticity	None	Moderate PVA	Strong PVA
Jet stream			
300–200 mb jet	≤65 kts	66–85 kts	>85 kts
Shear			
850–500 mb speed shear	15–25 kts	26–35 kts	>35 kts
850–500 mb directional shear	20–30°	30–60°	>60°
Helicity (0–3 km)	150–300 $m^2 s^{-2}$	300–450 $m^2 s^{-2}$	>450 $m^2 s^{-2}$
Indices			
CAPE	800–1500 J kg^{-1}	1500–2500 J kg^{-1}	>2500 J kg^{-1}
LI	>−2	−3 to −5	≤−6
SWEAT	<300	300–500	>500
Total totals	<50	50–55	>55

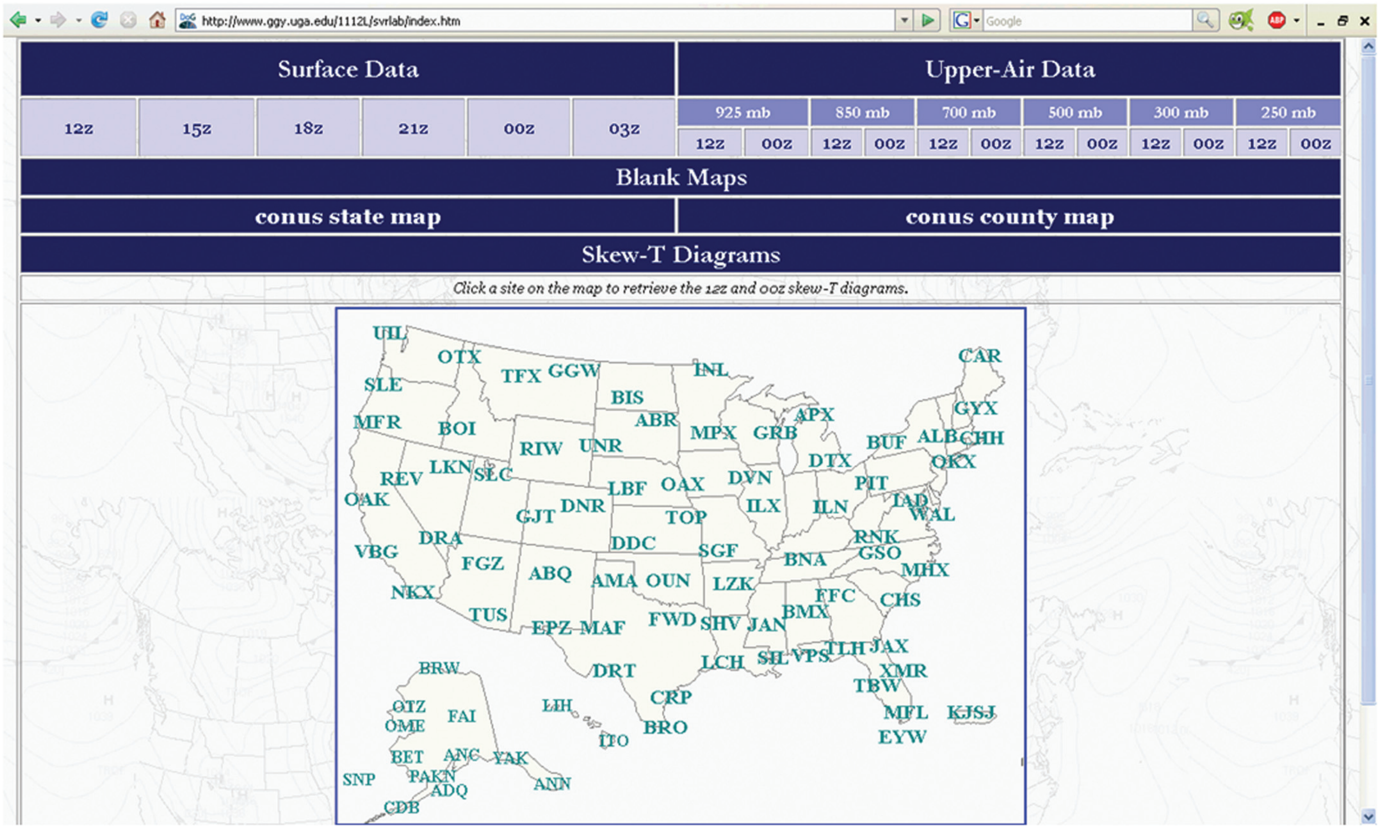

FIGURE 1: (Color online) Interface for accessing meteorological maps.

Forecasting Activity

After students receive the background information on severe weather forecasting, they are asked to play the role of a forecaster for the SPC and analyze various meteorological data for a severe weather event. We provide the groups with a suite of maps, including surface and upper-level data, and radiosonde soundings that are available online at http://www.ggy.uga.edu/1112L/svrlab/index.htm (Figs. 1 and 2). The data are provided in a chronological series during a 24-h period to simulate the evolution of the event. In order to assemble a severe weather forecast, the students must combine their previous knowledge of thunderstorm formation and general forecasting with their new understanding of severe weather, including information provided in Table I.

The groups are asked to provide diagnostic and prognostic discussions of the atmospheric environment and the potential for severe weather with the aided support of their analyzed maps and written discussions. Specifically, the teams are responsible for providing a series of four severe weather analysis and forecast maps (Table II). These analyses require students to identify geographically where severe weather is likely to occur and to provide a meteorological justification for their choices. We provide examples of each map (Fig. 3 and Table II) so that instructors can explain and discuss them. Also, instructors should indicate that much of the information (e.g., shear and stability indices) that students will need is available by selecting the appropriate station under Skew-T diagrams on the main interface page (Fig. 1). Finally, proper guidance by the instructor is very important. For example, if a student mentions that he/she does not understand how to make Map 1, the instructor should guide the student to the answer by asking a series of questions such as "What conditions are necessary?" and "Do you see any of those conditions anywhere on the map?". Below, we describe in detail how students construct each of the four maps.

Map 1 is a general thunderstorm outlook map that shows the risk of thunderstorm activity (i.e., slight, moderate, or high) across the continental U.S. [Fig. 3(a)]. The students create a general thunderstorm outlook map by analyzing the 12z surface and upper-air conditions (including the skew-T diagrams) and consulting the severe weather checklist in Table I to outline areas with weak, moderate, or strong possibility for severe weather is likely.

Map 2 is the mesoscale discussion [Fig. 3(b)]. The SPC issues mesoscale discussions that highlight specific areas where severe weather conditions are becoming more favorable for storm development, usually within a few hours of initiation. In order to highlight a probable area of severe weather in this exercise, the students must examine the evolution of the three-hourly surface data, and compare the 12z and 00z upper-air and skew-T data. Using the severe weather checklist (see Table I), the students must identify an area that has evolved toward a greater probability for severe weather and support their finding with a brief discussion of their analysis.

Map 3 is the severe weather or tornado watch box. A severe weather or tornado watch will be issued, usually within an hour or two prior to storm initiation, if the area highlighted in the mesoscale discussion continues to maintain conditions or evolves towards a greater probability for

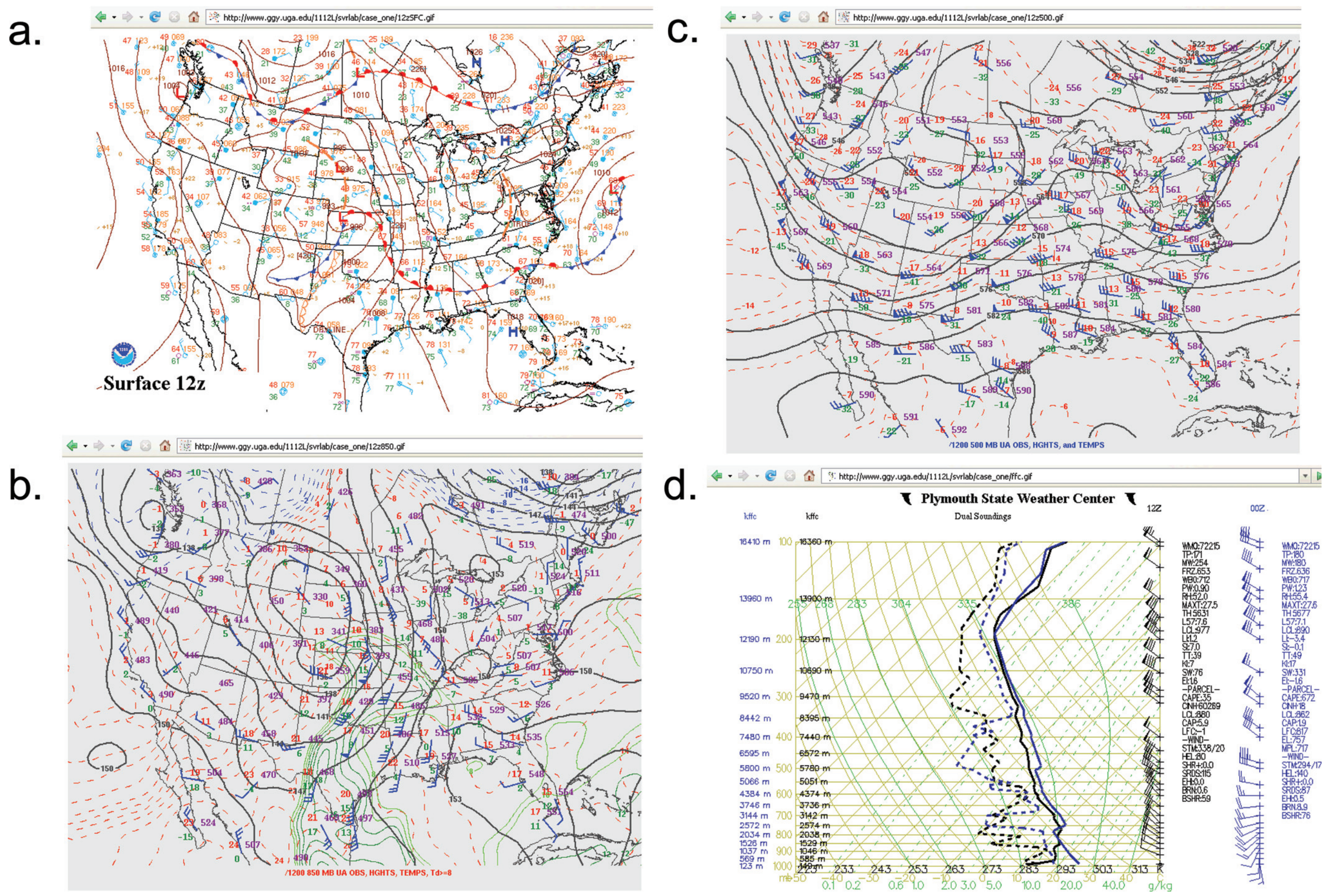

FIGURE 2: (Color online) Sample meteorological information, including (a) surface map, (b) 850-mb height map, (c) 500-mb height map, and (d) sounding.

severe weather [Fig. 3(c)]. For this map, the students must decide if their diagnostic mesoscale discussion is still valid (e.g., moderate at 12z and 15z) or if conditions have strengthened over time (e.g., moderate to severe from 12z to 15z) using the next three-hourly surface data plot in conjunction with thresholds listed in Table I. If conditions are consistent or even more favorable for severe weather over time, then the student needs to issue either a severe thunderstorm or tornado watch. In making the distinction between these two watches, students should focus on the "shear" and "indices" categories in Table I. For a tornado watch, students should look for moderate to strong shear categorical values as well as strong instability using stability indices such as CAPE, LI, SWEAT, and TT. Moderate or strong shear variables and instability should be widespread for the greatest likelihood for a tornado.

Finally, students are asked to predict where tornadoes will appear in map 4 [Fig. 3(d)]. A helpful hint to students is that the counties should be within or extremely close proximity to the watch box [Fig. 3(d)]. The purpose of this map is to have the students consider the final outcome of their forecast analysis. In reality, this type of forecast is extremely challenging and thus, not operational. However, this activity forces the students to scale their forecast from the general thunderstorm outlook (relatively easy), to precise locations (relatively difficult) with an expectation of the final outcome based on their analysis of the data. Moreover, this portion of the exercise demonstrates the great difficulty in severe weather forecasting.

The primary objective for the students is to determine the area(s) where the atmospheric conditions have the highest probability of severe weather. When evaluating student work, it is important to recognize that the atmosphere rarely, if ever, provides the "perfect" environment conducive for severe weather. Further, it is not uncommon for clear weather to be present even though the atmospheric conditions are favorable for severe weather. Therefore, students are not expected to identify the actual location of severe weather events but rather to locate areas where severe weather is plausible. In this particular event, for example, there are several areas where data suggest severe weather is possible. Some groups identified east Texas and Louisiana in their convective outlook as locations with a probable severe weather threat because of relatively high instability in the area [Fig. 4(a)]. Other groups, however, recognized that the overlap of variables that contributed the greatest potential for severe weather was located farther to the north [Fig. 4(b)]. The region identified in Fig. 4(b) is closest to where severe weather occurred and is therefore the more accurate forecast. We accepted both forecasts for our classes, composed mainly of nonscience majors, as each group used logical approaches in their predictions. An instructor in a class with many Atmospheric Science majors, for instance, may want to apply a

TABLE II. Severe Weather Analyses and Forecast Maps. Links are Provided for Real-Time Maps and Archived Maps of Severe Weather Events.

Map 1	• A general thunderstorm outlook map that shows the risk of thunderstorm activity (i.e., slight, moderate, or high) across the continental U.S. • A meteorological description of the key atmospheric constituents that may promote organized severe thunderstorms should be included.
	Real-time: http://www.spc.noaa.gov/products/outlook/ Archived: http://www.spc.noaa.gov/products/outlook/archive/2004/day1otlk_20040430_2000.html http://www.spc.noaa.gov/products/outlook/archive/2005/day1otlk_20050604_1200.html http://www.spc.noaa.gov/products/outlook/archive/2005/day1otlk_20050609_1300.html
Map 2	• An MD and geographical outline of the area of concern highlights areas where severe weather conditions are becoming more favorable for development. • The MD should include a meteorological description of the key atmospheric constituents that may promote severe weather in the next few hours.
	Real time: http://www.spc.noaa.gov/products/md/ Archived: http://www.spc.noaa.gov/products/md/2004/md0517.html http://www.spc.noaa.gov/products/md/2005/md1169.html http://www.spc.noaa.gov/products/md/2005/md1266.html
Map 3	• A severe weather and/or tornado watch box is indicated, usually within an hour or two of storm initiation, if the highlighted area in the MD maintains conditions or evolves towards a greater probability for severe weather. • Similar to the MD, the students must provide a meteorological description of the type of severe weather to be expected given the current atmospheric conditions (e.g., widespread severe storms with damaging winds, hail; tornadoes, etc.).
	Real-time: http://www.spc.noaa.gov/products/watch/ Archived: http://www.spc.noaa.gov/products/watch/2004/ww0133.html http://www.spc.noaa.gov/products/watch/2005/ww0401.html http://www.spc.noaa.gov/products/watch/2005/ww0447.html
Map 4	• Students make an educated guess as to the location and total number of tornadoes during the event. • Students shade in the counties where tornadoes may have occurred.
	Actual results are presented in Fig. 3(d) and are available at: http://www.ggy.uga.edu/1112L/svrlab/Verification/

somewhat more stringent assessment strategy that recognizes the combination of factors pointing to severe weather is greater in some locations [e.g., Fig. 4(b)] than others [e.g., Fig. 4(a)].

At the end of the assignment, the students use storm report data (available at http://www.ggy.uga.edu/1112L/svrlab/Verification/) to evaluate the accuracy of their predictions. They are asked to discuss whether their forecast was accurate and if not, what may have confounded it. As mentioned above, students should be assessed on the quality and thoughtfulness of their explanation and not only on whether their forecast was indeed accurate.

LEARNING OUTCOME ASSESSMENT

Our assessment examined the degree to which students found the new lab engaging and also if students gained key content knowledge about severe weather. We collected data, including demographic information, from University of Georgia students enrolled in Introduction to Weather and Climate laboratory sections. The demographic data included year in school, major, and gender. The majors were aggregated into categories representing the arts, social sciences, physical and life sciences, and professional programs like business, journalism, and education.

Laboratory class sections were randomly assigned to serve as comparison or experimental groups prior to the first class meeting. Also, all laboratory sections were taught by one of the coauthors to insure a consistent level of instruction among classes. The comparison class was taught using a severe weather laboratory exercise provided in a commonly used laboratory manual. The comparison section mainly involved an exercise that consisted of conceptual depictions of the evolution of thunderstorms and severe weather, along with some maps illustrating surface and upper-air observations. The instructor discussed the supplementary text provided in the exercise with the students and the class was provided a series of questions based on the conceptual framework and weather maps discussed above. These questions are geared for either short answers (e.g., one or two sentences) or fill-in-the-blank (e.g., station temperature, dew point, wind direction, etc.). The comparison section did not contain questions that pertained to problem-solving or application of data.

The assessment of student engagement involved a total of 91 students with 40 in the comparison class and 51 in the experimental one. The demographic profiles of the students in the two groups were very similar. Each group was almost evenly divided between male and female students, and a large percentage of students were in the social sciences or business. Neither group had many students in the sciences. Finally, most students in both groups were in their first or second year of college (Table III).

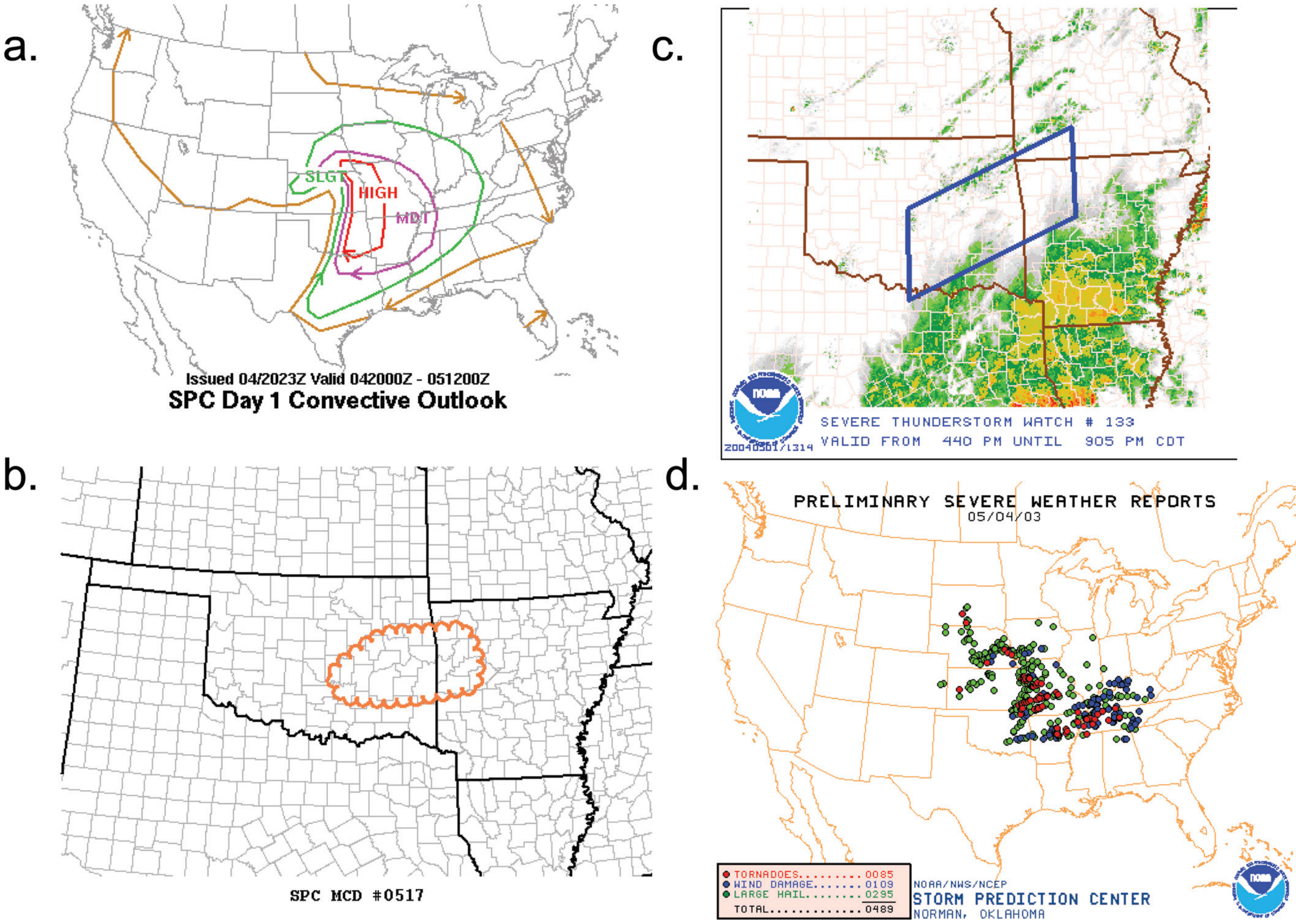

FIGURE 3: (Color online) Examples of output maps, including (a) thunderstorm outlook, (b) mesoscale discussion area of concern, (c) severe thunderstorm watch box, and (d) severe weather reports.

Both quantitative and qualitative methods were used in the assessment, including anonymous comments from student evaluations. The student questionnaire included two questions, with rankings from 1 (highest) to 5 (lowest), as well as space to make written comments:

1. How much did you enjoy the lab?
2. How much do you feel you learned in the lab?

Results suggest that the students reacted positively to the changes (Table IV). The students enjoyed the experimental laboratory exercise more than the one based on a laboratory manual and even felt they learned more. Average scores were 2.25 for the experimental compared to 3.18 for the comparison sections on question No. 1. There were similar findings for question No. 2 with scores of 2.33 for the experimental lab versus 2.90 for the comparison lab. In both cases a student's t-test indicated that the differences in scores between classes were statistically significant at the $p \leq 1\%$ level.

We used anonymous written evaluations to clarify the reasoning behind the above results. Samples that are representative of the broader collection of comments are presented in Table V. The students indicated that they liked the experimental lab, even if it seemed difficult, because it gave them the opportunity to apply their knowledge. They clearly did not like the comparison format that involved filling in answers from the laboratory manual. Many felt that it involved too much lecture and repeated material already covered in the lecture section of the course.

After identifying how the students felt about the new lab, we assessed learning outcomes. Here, we divided two classes of 24 students each into comparison and experimental sections. The classes had nearly identical student populations with similar proportions of male and female students, a large percentage of students in their first year of college, and many students in the social sciences, business, and journalism (Table III). Also, the student population in these two classes is similar to those used for assessing student engagement, particularly in terms of year in school and distribution of majors outside of the physical sciences. Both the old and new labs cover similar material on the factors that promote thunderstorm activity and severe weather but there are some differences in content such as a focus on operational forecasting and associated forecast products in the new lab. Thus, the assessment used two questions that represented basic content knowledge covered in each class on the respective quizzes:

1. Name at least three ingredients that encourage thunderstorm development and give an explanation for each.
2. What is wind shear and how does it help generate tornadoes?

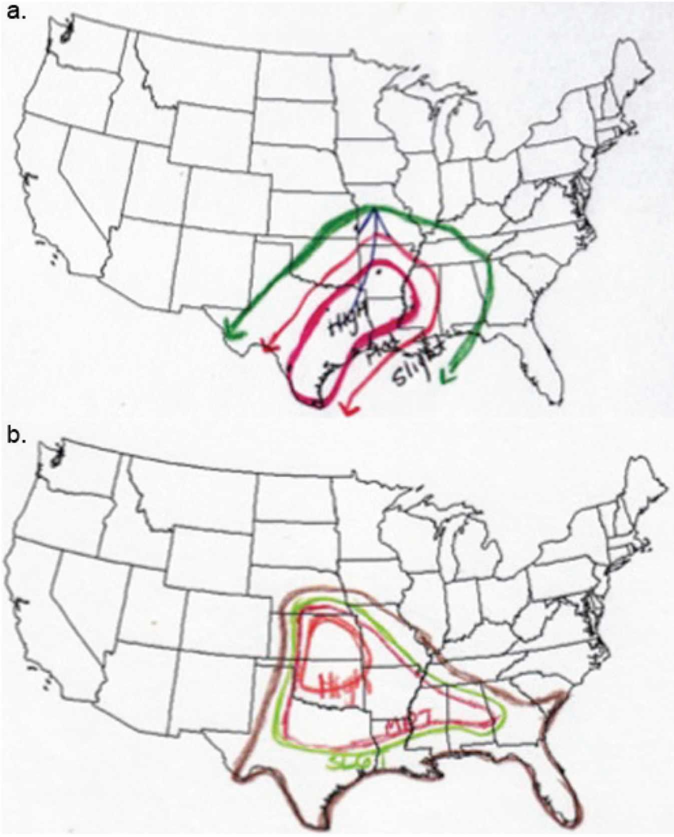

FIGURE 4: (Color online) Sample thunderstorm outlook forecasts from groups who highlighted (a) the southeast Texas region and (b) the eastern Oklahoma and Kansas regions for the greatest probability for severe weather.

The results indicate no statistically significant difference in performance on the quiz (Table VI). While the sample size is not large, it does suggest that the new lab format does not detract from basic content knowledge.

CONCLUSIONS

Students often take Introductory Weather and Climate classes because of their interest in severe weather. Many of these students, however, lament that the laboratory exercises for severe weather simply repeat what was covered in lecture. This paper presented a new laboratory exercise on severe weather that is appropriate for first and second year college students and is designed to augment topics covered in the lecture section of the class. Additionally, the objective is to get the students more involved in the learning process by allowing them to play the role of a severe-weather forecaster. In this exercise, they learn about how forecasts for severe weather are developed, the “ingredients” that foster conditions favorable for severe weather and how information on the threat of severe weather is communicated to the public through various forecast products.

Our assessment of the new laboratory exercises, using 91 students, showed positive outcomes regarding student interest and participation. Further, we found that while the new lab was more enjoyable, it did not harm acquisition of essential content knowledge. Finally, our lab provides information on the operational aspect of severe weather forecasting unlike many severe weather exercises in commonly used laboratory manuals.

The assignment we use at the University of Georgia is publically available (http://www.ggy.uga.edu/1112L/svrlab/severe_lab.doc) and should be widely adaptable for use in Introductory Weather and Climate courses at other schools. Ultimately, we hope that this lab helps to fill a gap in hands onexercises for severe weather.

TABLE III. Demographic Profile of Student Populations in Comparison and Experimental Sections Using in the Survey of Student Engagement and Outcome Assessment.

		Survey		Outcome Assessment	
		Comparison (%)	Experimental (%)	Comparison (%)	Experimental (%)
Gender	Female	50	52	43	47
	Male	50	48	57	53
Year	Freshman	56	83	82	77
	Sophomore	29	14	9	15
	Junior	9	3	9	4
	Senior	7	0	0	4
Major	Arts	6	2	5	4
	Humanities	6	5	5	4
	Social Science	33	19	24	12
	Physical Science	6	0	0	4
	Life Science	3	0	0	8
	Business	30	38	33	28
	Education	0	14	0	0
	Journalism	12	7	24	28
	Other	3	16	10	12

TABLE IV. Results from Anonymous Student Questionnaires. Ranking is from 1 (Highest) to 5 (Lowest).

	Q1		Q2	
	Experimental	**Comparison**	**Experimental**	**Comparison**
Count	51	40	51	40
Average	2.25	3.18	2.33	2.90
Median	2.00	3.00	2.00	3.00
Standard deviation	0.91	1.03	0.89	1.10
p-value	0.00002		0.00797	

TABLE V. Representative Student Comments from Anonymous Questionnaires.

Comparison Lab
■ It was difficult to understand because we did not get to do anything
■ I feel like I learned less compared to the other labs
■ I would have preferred more hands-on activities.
■ Geography 1112 (lecture) already covered tornadoes
■ The lab was pretty boring…because I just read the material and answered questions and did not see how it works.
■ Long and it was all lecture
■ It was not very fun, just answering questions (out of the lab book)
■ Not very interesting compared to other labs
■ The lab is fairly boring because we do not have any visuals or in class activity, just a workbook
Experimental Lab
■ Forced me to apply my knowledge
■ It was kind of hard to do but it was better than learning by lecture
■ It helps to visually look at a map and figure stuff our for yourself
■ It was fun working with a group
■ The lab helps you to apply things instead of just using book information.
■ It really helped me to understand what all affects a storm
■ It was good to apply my knowledge to a real life example and work as a team
■ It was applying a lot of information I already learned but never used in an example like this
■ It is easier to learn by doing and working with other people helped a lot
■ Improvements: having a computer for each group member, clearer instructions

TABLE VI. Quiz Results for Experimental and Comparison Classes. Scoring is from 1 to 5 Points.

	Q1		Q2	
	Experimental	**Comparison**	**Experimental**	**Comparison**
Count	24	24	24	24
Average	3.26	2.96	2.82	2.61
Median	3.00	3.00	3.00	3.00
Standard deviation	1.14	0.82	1.11	0.84
p-value	0.30		0.46	

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