A Forecasting Activity for a Large Introductory Meteorology Course

Douglas N. Yarger,* William A. Gallus Jr.,* Michael Taber,+
J. Peter Boysen,# and Paul Castleberry@

ABSTRACT

A large lecture introductory course at Iowa State University has used a forecasting activity since 1993 to actively engage students in doing science. This automatically scored Web-based activity requires students to evaluate selected weather parameters and to also select appropriate physical reasons for their values. Participants can select from more than 1000 cities in the United States for their forecast city. This activity engages students in doing what practicing meteorologists do. Further, forecast scores demonstrate increased understanding throughout the course. Design considerations were based on constructivist learning theory in order to address goals articulated by national panels; to promote problem solving, collaboration, and communication skills by being involved in scientific inquiry.

1. Introduction

The following is an actual response from a student and characterizes students' early encounters with Web-based instruction in a class of nearly 300 students that meets three periods a week in a large auditorium. Carol, majoring in animal ecology, is enrolled in an introductory meteorology class to fulfill a science requirement. This course has been restructured from a lecture-only course to one where almost half of the grade is based on a forecasting activity that requires her to use the computer to predict weather. Carol is scared. Although she is a junior, she is apprehensive about making a forecast and using the computer. The instructor counsels her not to drop the course and encourages her to use the computer help room that supports the course. A couple of weeks into the semester the instructor received this e-mail message from her:

"YES!!! I DID IT!!!! It may not be anywhere close to what is going to happen, but I found my way around and I know I'll learn. YIPPEEEEE!!!!!"

Carol's elation with overcoming insecurities relating to forecasting and computer use has been mirrored by scores of other students in this class. The forecasting exercise that is initially formidable has been selected as the most popular component of a large survey course in meteorology at Iowa State University for the five years it has been offered.

It is this motivating and authentic (as might be done in real practice) activity, weather forecasting, that can form the basis for a deeper study of the process of science. Prediction is a key goal of science and one that students eagerly embrace. They quickly realize that to improve their predictive skills they must develop additional skills of observation and hypothesis generation, testing, and analysis. Therefore, by developing a forecasting framework in which all activities have prediction as an underlying goal, students can form a recurring and authentic link to key scientific processes.

2. Background

The need for an integrated and motivating curriculum in introductory science courses is well known. The

*Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa.
+Department of Education and Social Policy, Northwestern University, Evanston, Illinois.
#Computation Center, Iowa State University, Ames, Iowa.
@Department of Agronomy, Iowa State University, Ames, Iowa.
Corresponding author address: Dr. Douglas Yarger, Department of Geological and Atmospheric Sciences, Iowa State University, 3010 Agronomy Building, Ames, IA 50011.
E-mail: doug@iastate.edu
In final form 2 July 1999.

Call to Action in the National Science Education Standards (National Research Council 1996) states:

> "All of us have a stake, as individuals and as a society, in scientific literacy. An understanding of science makes it possible for everyone to share in the richness and excitement of comprehending the natural world. Scientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society. A sound grounding in science strengthens many of the skills that people use every day, like solving problems creatively, thinking critically, working cooperatively in teams, using technology effectively, and valuing life-long learning. And the economic productivity of our society is tightly linked to the scientific and technological skills of our work force."

The processes involved in achieving scientific literacy have received national attention. The National Science Foundation report, Shaping the Future (National Science Foundation 1996) explains:

> "although there is disagreement about the meaning of the term 'science literacy' and doubt about whether agreement is possible on a list of facts everyone should know, there is no disagreement that every student should be presented an opportunity to understand what science is, and is not, and to be involved in some way in scientific inquiry, not just a 'hands-on' experience."

The importance of involving students in active scientific inquiry was also emphasized in another National Science Foundation report, Geoscience Education: A Recommended Strategy (National Science Foundation 1997):

> "students cannot learn to think critically, analyze information, communicate scientific ideas, make logical arguments, work as part of a team, and acquire other desirable skills unless they are permitted and encouraged to do those things over and over in many contexts."

Introductory science courses, as a whole, have not succeeded in meeting these goals for a scientifically literate population. Tobias (1992a,b) has summarized common problems with these courses (e.g., textbook-based knowledge transfer with emphasis on memorization and recall, passive students, uninteresting learning processes) and points out that even bright students are often discouraged from pursuing a degree in science.

The challenges then are to design a learner-centered course that promotes problem solving, collaboration, and communication skills, while at the same time being responsive to changing student demographics. To embrace the student of the next century we need to be responsive to student schedules, locations, and job requirements and to enable them to participate in life-long learning. These goals are becoming more realistic as computer and network technology are integrated with new and radically different theories of learning.

A large-lecture introductory meteorology course (MT206) at Iowa State University (ISU) has used Web-based course activities since 1993 to address many of these issues. Course goals include the following:

1) actively engaging students by making prediction an underlying motivation for understanding course materials;
2) emphasizing the scientific process of observation, hypothesis generation, and understanding of key concepts as a basis for making predictions;
3) providing context for class materials and deepening students' knowledge of underlying concepts and principles through application in an authentic activity;
4) encouraging students to be aware of weather events and providing opportunities for them to develop intuitive insights into weather processes; and
5) providing opportunities for students to develop confidence in their ability to understand and apply science.

One particular activity that has proven to be highly motivating and very effective in creating authentic situations for scientific inquiry when used in a large introductory meteorology course is a Web-based weather forecasting exercise. This activity has become the common thread for the course and serves as an ever-present opportunity to apply course concepts in real-world contexts.

Of the 300 students in the introductory course enrolled each semester to meet a science requirement, about 60% are freshmen and sophomores; enrollment is split nearly equally between males and females. The students have become increasingly more computer literate in the past few years but some of the class still needs initial assistance with using the Internet, which is provided through a help room. Participation in the forecast activity is required in the course and is weighted to be about half the course grade. The grading is not curved but students are only graded on their best 25 forecasts and can forecast each day during the semester if they wish. Nevertheless, apprehension is high at the beginning of the course among many of the students.

Weather briefings are included during some part of every class period and encouragement in the form of bonus points for entering a first forecast by a certain date, help sessions for "learning how," and undergraduate peer tutors all contribute to helping students overcome initial fears. A survey of student attitudes during the end-of-course evaluations shows that the forecast exercise becomes the most popular part of the course. In addition, students become more attentive during class periods and ask more insightful questions as a result of this activity.

During the spring of 1996, this forecast exercise was described in several press releases as a "cool Web activity" and interest from both the general public and K–12 schools prompted the redesign of the forecast exercise. The original forecast exercise was designed for only one city, Des Moines, since it is reasonably close to Iowa State University in Ames. Verification was initially done by hand. The new version needed to be designed to support many additional participants with interests in weather for a wide variety of cities without requiring a large commitment of resources for verification. The resulting automated forecast exercise has been designed to accomplish the primary class objectives for the ISU course and to support the application to other schools in different locations. The details of the design of the forecast exercise will be discussed more fully below.

3. Management (ClassNet)

In order to organize and manage the forecast exercise a Web tool called ClassNet[1] was developed (van Gorp and Boysen 1997). ClassNet also provides a suite of tools for managing Web-based course activities. These include registration, assignment design, automated evaluation, intraclass communication, and grade reporting. Central to ClassNet's design is a growing framework of assignment types in addition to weather forecasts. These include tests (consisting of multiple-choice, fill-in-the-blank, Likert or opinion-based multiple choice, essay, option lists, and list question types); surveys; student evaluations, and Java simulations. The assignment framework is extensible, allowing instructors to customize ClassNet to meet their individual class needs while still providing general administrative functionality. ClassNet assignments may also be used to track interactions with computer simulations for later replay by instructors or students. This has proven to be a very powerful utility for research relative to metacognitive and simulation design issues and simulation usage (Yarger et al. 1998).

The current system supports thousands of students worldwide, and in addition to forecast evaluation in meteorology it is used for assignments such as practice tests in geology, personality testing in psychology, simulation tracking in mathematics, and student counseling practice in counselor education. Students may access ClassNet anytime from anywhere to take tests, view class progress and see current scores. ClassNet is also capable of reading scores for assignments administered outside ClassNet or for reading tests into ClassNet. An expanded Java version called Ecademy is to be released in early 2000.

4. Design factors

The forecast exercise (Fig. 1) is designed to use characteristics of natural learning processes (Schank et al. 1995). Four fundamental features are identified that should be included in educationally sound multimedia software. (Italics have been added by the author.)

- Building *goal-directed* learning systems means creating engaging environments that engross students in their roles. It is important for both motivational and cognitive reasons for students to buy into the role and want to perform well in it. Multimedia can help by creating motivating settings (e.g., the White House or the space shuttle) and introducing scenarios in a compelling way.
- Making software *failure-driven* means creating situations that allow the student to make mistakes. The right time to present information to students is after they fail, and this is when a multimedia database of relevant information is needed, but only if it is indexed so that students can quickly find information when they need it.

[1]ClassNet is available without charge to educators. Instructions for accessing and using it can be found online at http://classnet.cc.iastate.edu.

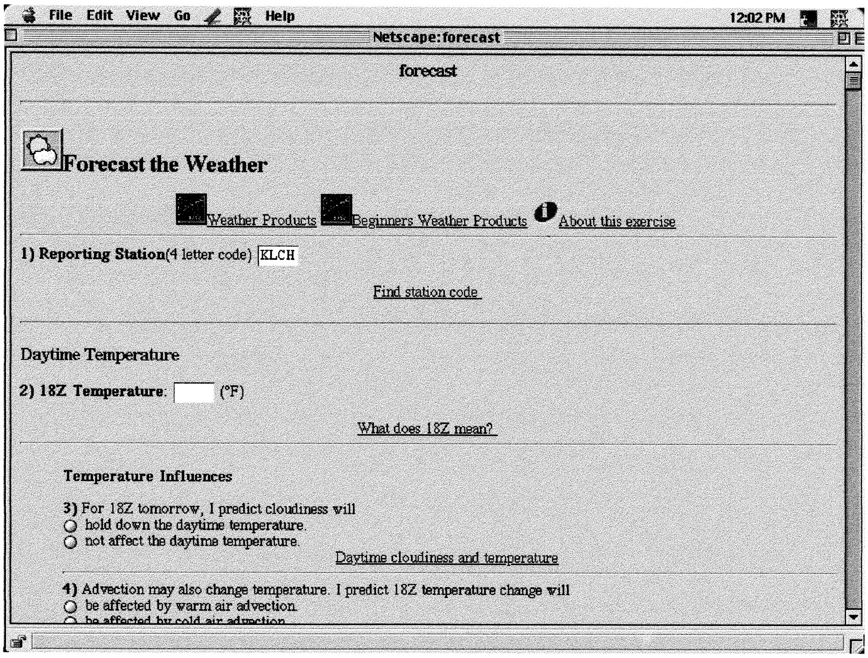

FIG. 1. Forecast exercise.

- Making software *case-based* means giving students access to expert opinions and stories that are relevant to the problem at hand. Digital video enables these experts' stories to be presented in an engaging and memorable way.
- *Learning-by-doing* means building simulated environments and multimedia can make these environments more realistic. Realism is important because it can make simulated worlds more authentic, helping students to connect the computer simulation to the real-life situation it represents.

The forecast exercise provides students repeated opportunities to test their understanding of various weather processes in a forum that is

- goal-directed (students are asked to predict various weather parameters and select the appropriate physical reasons such as advection impacting temperature);
- failure-driven (e.g., students now seek explanations for advection and ask how to estimate its influence on temperature changes);
- case-based (lecture discussions of advection processes now have context);
- learn-by-doing structured (each student must forecast a minimum of 25 times).

The forecast exercise requires that participants use available weather products to predict weather parameters for 1200 UTC and 1800 UTC the next day. These times were selected to correspond to early morning (and thus representative of nighttime conditions) and midday periods for cities across the United States. There are several versions of this activity that have been tested in the MT206 course at ISU.

1) The instructor can allow the participant to select any available city they desire to forecast weather conditions for the following day. The codes for available cities can be found by accessing the "Find

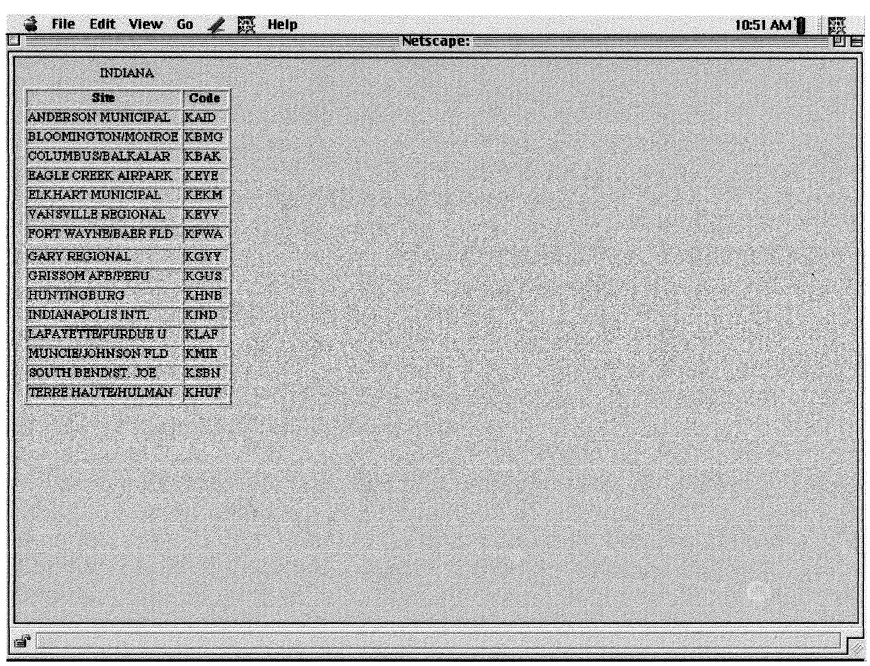

FIG. 2. City codes.

station code" option. For example, city codes for Indiana are shown in Fig. 2.

2) The instructor can specify a forecast city. Figure 3 shows a case where Nashville, Tennessee, was the forecast city for all students.
3) With the proliferation of weather-oriented Web sites it has become a concern that a portion of the student population may "mimic forecasts," which are provided for public use. Actually students are encouraged to use these for general class reference as sources of useful weather information. Because students are tempted to use forecasts found at these sites rather than doing their own thinking a forecast exercise that uses archived weather data was developed. Figure 3 is an example of this version of the forecast exercise where the forecast city (Nashville, TN) and the forecast day have been defined. The appearance of the forecast page is the same as before but now the weather data correspond to selected periods preceding the forecast times (Fig. 4).
4) Any of the versions of the forecast exercise can be modified to add or delete forecast questions. It has been helpful to use a restricted set of questions at various times in the course to focus attention on specific physical processes.

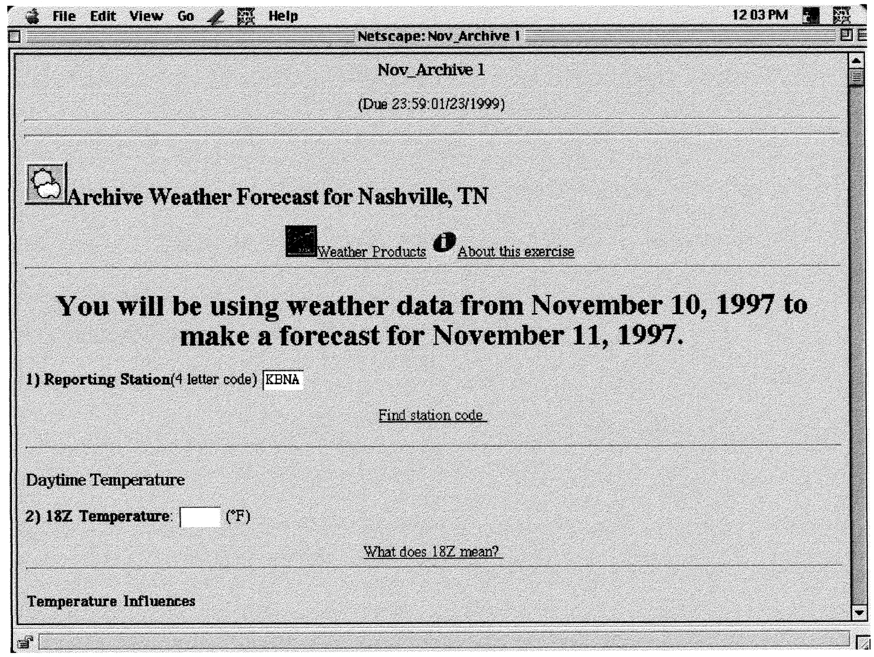

FIG. 3. Archive forecast page.

5. Scoring algorithms for forecast parameters

Participants in the forecast exercise are asked to provide supporting rationales for predictions of weather parameters. Temperature predictions are associated with a daytime period, selected to be 1800 UTC (Fig. 1; UTC is same as Z used in figures) and a nighttime period, selected to be 1200 UTC. Deeper understanding of weather processes is sought by requiring students to evaluate the influence of possible contributing factors. The acceptable range for the 1800 UTC temperature forecast has been selected to be ± 5°F although the instructor can select any range. The scoring weights we have used give students three points for a correct answer, one point for an answer outside the bound, and zero points for no submission. These also can be changed at the discretion of the instructor.

We identified several processes that could significantly influence temperature changes in the version of the forecast exercise used for the MT206 course. These are addressed in the questions on temperature influences (Fig. 5).

Daytime cloudiness is defined to have a significant influence on the 1800 UTC temperature based on the following algorithm. The reporting site is evaluated for the times 1500, 1600, 1700, and 1800 UTC to determine if two or more of these times report at least broken clouds (roughly 75% cloud cover). When this condition is met, clouds are said to have held down daytime temperature (since 1800 UTC is near midday in the United States).

For this exercise significant horizontal advection is defined to occur when at least a 1°F temperature change due to advection could occur in the 2-h period preceding 1800 UTC (i.e., the total change using the hourly observations 1700 and 1800 UTC is 1°F or more). This corresponds to a 10 mph wind oriented perpendicular to the isotherms with a spatial gradient of 10°F per 200 mi (approximate N–S dimension of Iowa) for a 2-h period.

Fronts can influence temperature in a variety of ways. These influences include cloud cover associated

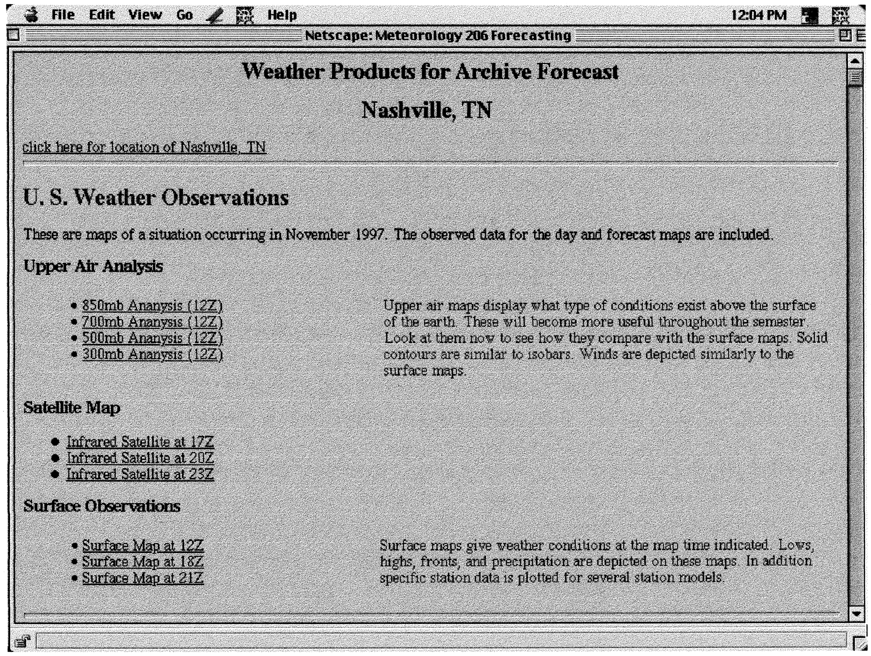

FIG. 4. Weather data for archive forecast exercise.

There are links after each question that provide students with specific information concerning the scoring algorithm and possible definitions and learning aids designed to enhance understanding. Question 6 (Fig. 5) is different since it was added during the part of the course when discussions of adiabatic processes were occurring. Students were asked to forecast in a mountain region (Reno, NV) to provide them with a practical application of this topic in a meteorology context. A Java-based simulation (http://www.pals.iastate.edu/simulations/Mtnsim/index.html) has been designed to engage students in exploring various factors that are associated with air motions on mountain slopes (Hsu et al. 1998).

The questions that are designed to motivate students to consider factors that affect nighttime temperature changes are similar to those for daytime (questions 3, 4, 5 in Fig. 5) except that cloud influences are now different. Clouds restrict cooling at night because they absorb longwave radiation emitted by the surface and

with specific frontal types, change of air mass as a result of frontal passage, and processes associated with precipitation. A rapidly moving cold front could cover about 90 mi in a 3-h period, thus the evaluation procedure checks for the appearance of a front in a 2° latitude—longitude grid containing the selected site during a 3-h period centered on 1800 UTC (i.e., 1700 UTC ± 30 min, 1800 UTC ± 30 min, 1900 UTC ± 30 min). This corresponds to determining whether a front is within 140 mi of the reporting site during the 3-h period centered on 1800 UTC. Warm, occluded, and stationary fronts are all evaluated using this same criterion. Although some subjectivity is involved in establishing the verification criteria, such as the distance over which a front improves precipitation chances, negative impacts are avoided by stating the criteria explicitly to the students. In fact, some of the more eager or brighter students are motivated to question the criteria, providing an opportunity to discuss meteorological processes in greater detail.

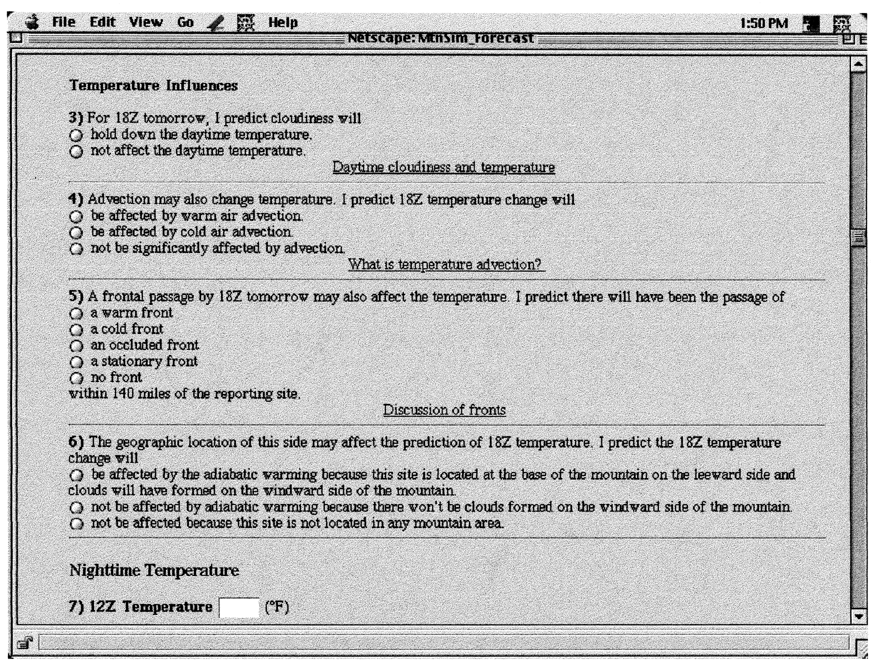

FIG. 5. Questions on temperature influences.

lower atmosphere and reemit a significant portion back. The criterion selected for defining significant restriction of radiation cooling is whether there will be three or more hourly observations of at least broken clouds (i.e., roughly 75% cloud cover) in the six hours preceding 1200 UTC (i.e., for 0700, 0800, . . ., 1200 UTC).

Although it is common to have a variety of precipitation categories for most forecast contests, for the MT206 class, if precipitation is reported (i.e., even a trace) during the 24-h period 1200–1200 UTC precipitation is defined to have occurred (Fig. 6). Three factors that may influence the occurrence of precipitation are moisture supply, frontal position, and atmospheric instability.

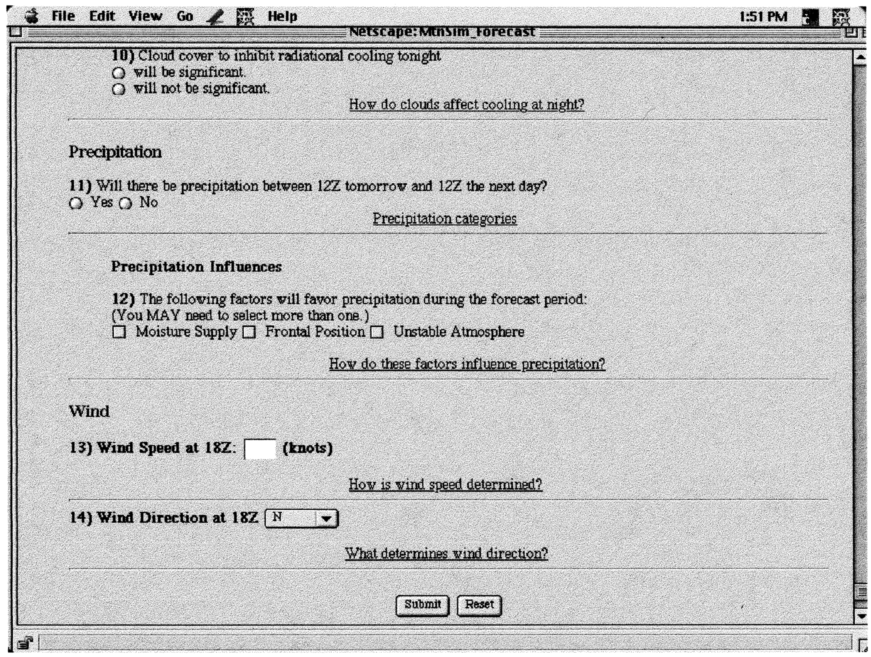

FIG. 6. Precipitation.

The algorithm that is used to evaluate whether the supply of moisture is adequate to favor precipitation is based on experience. A rule of thumb is that when the relative humidity is at least 70% at 850 mb, overcast conditions are usually observed. At a relative humidity of 90%, there is probably precipitation occurring, so 80% is somewhere in between and is defined to be a "favorable" value. The criterion is whether the relative humidity is equal to or greater than 80% at 850 mb at either 1200, 0000, or the following 1200 UTC time. Because the moisture supply is expected to change relatively slowly, evaluation at these times is considered representative for the 24-h period between 1200 and 1200 UTC. The 700-mb relative humidity analyses can be found in the "Weather Products" link at the top of the forecast page (Fig. 1). Although 700-mb humidities and 850-mb humidities are different, 80% relative humidities at 700 mb are also considered to be good estimates of moisture supply.

A grid area of 2° by 2°, about 140 mi by 140 mi, is associated with each reporting site for the purpose of evaluating the existence of fronts. If a front of any type is reported within this area during the 24-h period between 1200 and 1200 UTC, this will be defined to be a factor for favoring precipitation.

The algorithm that evaluates whether the atmosphere is sufficiently unstable so as to favor precipitation is based on the 850—500-mb temperature difference for the forecast city. A temperature difference between 850 and 500 mb that is at least 25°C is generally representative of conditional instability and may favor upward motion of cloudy air parcels and, thus, precipitation. The 850- and 500-mb maps with temperature analyses are provided in the weather products section at the top of the forecast page (Fig. 1).

The instructor can adjust the criteria for "correct" wind speed and direction predictions. For the MT206 course at ISU, a value within ± 5 kt of the reported wind speed is considered correct. A wind direction forecast is considered correct if it is within ± one octal of the reported value.

6. Use for meteorology majors

The forecast activity has also been used in a synoptic applications course taken by freshmen and sophomore majors in meteorology. In that course students were assigned to groups to forecast throughout the semester for one specific city. At the end of the semester, the groups would report their impressions of forecasting for "their city," along with any special challenges they encountered, whether it be the significant warming that occurred in Denver when westerly winds blew (downslope) or the precipitation occurring in Buffalo from lake effects.

A recently developed extension of the exercise to archived historical cases will be used in junior- and senior-level synoptic meteorology courses at ISU. As mentioned earlier, the exercise questions can be revised to suit more advanced students. Private forecasting firms have expressed their belief that graduating meteorologists rely too heavily upon numerical model forecasts, and have failed to sufficiently learn meteorological principles that would help them to be better forecasters. These firms have suggested that students experience forecasting without the assistance of numerical guidance for at least a portion of their educational experience. The forecast exercise that is based on archived data will allow this opportunity.

7. Student experiences

Students in the introductory meteorology course are graded on their best 25 forecasts. They may select any forecast days they wish during the semester although they are encouraged to begin early in the term. Figure 7 shows the improvement in skill with forecast experience for students who submitted 25 forecasts or more. The maximum number of points is 36 (3 points are awarded for each answer within the designated bounds or for selecting a correct reason). If a student tried all 12 questions and was wrong on each the minimum score is 12 since one point is given for trying. The total mean improvement of six points that occurred during the semester means that students on average got three additional questions correct by the end of the course. A score of 28 means the students have been graded correct on 8 of the 12 questions. The data indicate that after the first six forecasts, students have improved about four points, which means they are getting two additional questions correct on average. After that rapid improvement period additional progress is slower. These results are consistent with forecast skill trends noted for less experienced meteorology majors reported by Roebber and Bosart (1996), and are similar to the theoretical relationship between skill of forecasts and amount of information (Heideman et al. 1993).

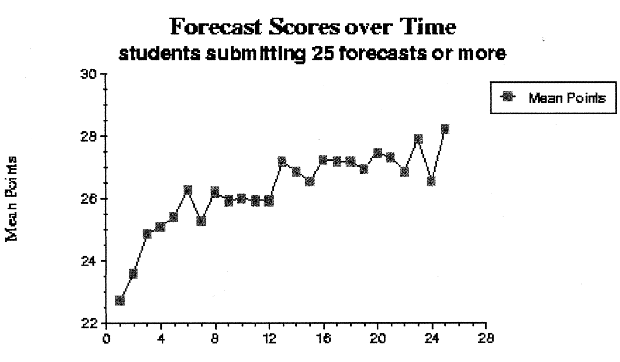

FIG. 7. Forecast scores.

A consequence of the forecast activity is that students now ask good questions about forecasting issues and challenge the instructor to explain why events happen and the rationale for specific questions to be scored the way they were. They ask for explanations for atmospheric behavior before it is addressed in the course and even beyond what would normally be addressed in an introductory course. For example, one student wondered,

> "How much does the temperature change if you notice a front moving in? I would like to know whether we use the wind speed at the surface or the 500-mb wind to estimate front speed, and how do we estimate the 500-mb wind from the surface wind?"

Another sent the following electronic mail message:

> "I'm not quite sure what I'm doing wrong on the forecast but I seem to have trouble telling when there is going to be advection—I know what it is, but I don't see when I look at the temperature map how to be sure. Also, I was wondering how to be sure a front is going to pass. Say that I see the cold front on the map, next to Iowa, with the arrows pointed at Iowa. What proves that it will pass or just stay put? Your advice would be appreciated, thanks."

Questions such as these provide opportunities to address these issues for all students. Course topics are routinely given context by reference to forecasting issues.

Although student-initiated questions and forecasting improvement are encouraging signals that the forecast exercise has a positive impact on student learning, caution must be used in evaluating the impact on student understanding. Fullen (1993) and Reeves and Okey (1996) have pointed out that some measures such as achievement tests are poorly matched to the goals of programs like the one described here. Our research supports this finding—students are not demonstrating better understanding on standard multiple choice questions typical of an introductory course.

However, Lehrer (1993) has found that constructivist educational activities (the forecasting exercise would be an example) do lead to pronounced improvement in long-term retention or application of material. Traditional longitudinal studies, which are typically used to document the long-term impact on student understanding, are beyond the scope of this project.

8. Summary

A forecast exercise has been described that has been a central component of a large introductory meteorology course at Iowa State University for the past five years. This activity has enabled this course to be transformed from a passive lecture-only course to a learner-centered course that promotes problem solving and collaboration in a learning-by-doing environment. This activity has been successfully transported to other institutions and is freely available to the academic community. Interested persons should contact the corresponding author.

Acknowledgments. The United States Department of Agriculture Higher Education Program Grants 94384110152 and 97384114269 provided support for this work.

References

Fullan, M., 1993: *Change Forces: Probing the Depth of Educational Reform.* Falmer Press, 162 pp.

Heideman, K.F., T.R. Stewart, W. Moninger, and P. Reagan-Cirincione, 1993: The Weather Information and Skill Experiment (WISE): The effect of varying levels of information on forecast skill. *Wea. Forecasting,* **8**, 25–36.

Hsu, Y., J. P. Boysen, D. N. Yarger, and C. Chen, 1998: The development of an exploratory simulation for constructivist learning—An example of Java application. Preprints, *USAWebNet 98—World Conf. of the WWW, Internet and Intranet,* Orlando, FL, Assoc. Adv. Comp. Ed., 1090–1092.

Lehrer, R., 1993: Authors of knowledge: Patterns of hypermedia design. *Computers As Cognitive Tools,* S.P. Lajoe and S.J. Derry, Eds, Lawrence Erlbaum Press, 197–227.

National Research Council, 1996: *National Science Education Standards.* National Academy Press, 262 pp.

National Science Foundation, 1996: Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology. National Science Foundation, NSF 96-139. [Available online at http://www.ehr.nsf.gov/ehr/due/documents/review/96139/start.htm.]

——, 1997: Geoscience Education: A Recommended Strategy. Natural Science Foundation, NSF 97-171. [Available online at http://www.nsf.gov/pubs/1997/nsf97171/nsf97171.htm.]

Reeves, T. C., and J. Okey, 1996: Alternative assessment for constructivist learning environments. *Constructivist Learning Environments,* B. Wilson, Ed., Educational Technology, 191–202.

Roebber, P.J., and L.F. Bosart, 1996: The contributions of education and experience to forecast skill. *Wea. Forecasting,* **11**, 21–40.

Schank, R. C., M. Korcuska, and M. Jona, 1995: Multimedia applications for education and training: Revolution or red herring? *ACM Comput. Surveys,* **27,** 633–635.

Tobias, S., 1992a: Reforming freshman science. *Tech. Rev.,* **95** (4), 70–71.

——, 1992b: Science education reform—What's wrong with the process. *Change,* **24** (3), 13–19.

van Gorp, M., and P. Boysen, 1997: ClassNet: Managing the virtual classroom. *Inter. J. Ed. Telecommunications,* 3/2, 279–292.

Yarger, D. N., J. P. Boysen, R. Thomas, and M. R. Marlino, 1998: Developing and implementing a constructivist learning environment: Translating theory into practice. Preprints, *10th World Conf. on Educational Multimedia and Hypermedia and Conference on Educational Telecommunications,* Freiburg, Germany, Assoc. Adv. Comp. Ed., 2116–2119.