Making Authentic Science Accessible to Students

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Abstract

Authentic activities are important in promoting inquiry due to the natural problem solving context they provide with high degrees of complexity. This study dealt with designing effective inquiry tasks through transforming content, scientific thinking, and resources featured in scientists' authentic practices. This study investigated how fifty-nine inner-city sixth grade students performed in real-time forecasting situations involving fronts and pressure systems. Forecasts were evaluated in terms of prediction agreement, meteorological entity consideration, explanation type, and scientific knowledge use because these four categories reflected inquiry features emphasized in the forecasting task. Results show real world situations that closely mapped onto students' content understandings, rather than those with naturally-occurring complex patterns, helped students perform inquiry. Key ideas discussed in this paper include the importance of using authentic situations to develop rich understandings about scientific knowledge and the design of tasks that prepare students to participate in social practices valued by the science community.

Introduction

Even though science has been an important part of secondary school curricula since the turn of the 20th century (DeBoer 1991), it is still controversial how school science should be taught to deliver the essence of science to students. Science is a human endeavour striving towards a better way of explaining scientific phenomena through experimental and theoretical investigations (Kuhn 1970). The vehicle that advances science is scientific inquiry, which involves both in-depth understandings of scientific knowledge and rigorous applications of scientific thinking processes. Current science education reform documents (NRC 1996, 2000) prioritise scientific inquiry as a way to teach and learn about science in k-12 classrooms.

A lot of effort has recently been devoted to finding ways to promote scientific inquiry in classrooms (Krajcik et al.1998, White and Frederiksen 1998, Edelson et al. 1999, Songer et al. 2002), particularly within authentic learning situations. Brown, Collins, and Duguid (1989) describe authentic activities as the ‘ordinary practices of the culture’ where their ‘meanings and purposes are socially constructed through negotiations among present and past members’ (p. 34). Traditional learning situations that utilize lectures and demonstrations rarely challenge students to practice particular activities of the culture of the science community such as asking questions, planning and conducting investigations, drawing conclusions, revising theories, and communicating results. Often, real world science is not accessible to students because authentic activities that are interesting to students are too open-ended and require content knowledge and scientific thinking students do not have the supports to realize (Edelson 1998). How can we design inquiry learning that both emulates inquiry in science disciplines and is accessible to students?

Design and development of authentic science activities involve the transformation of complex and ambiguous content, scientific thinking skills, and resources that support scientific investigations. Because of the complexity of the transformation, many researchers have prioritised a selected part of the transformation such as the development of scientific thinking skills in the inquiry cycle (White and Frederiksen 1998), the selection of knowledge for study (Linn and Songer 1991), the technology resources needed (Edelson et al. 1999) or the benefits ideally present in authentic learning situations (CTGV 1992). Despite the complexity, the transformation of content knowledge, inquiry skills, and resources should occur in concert.

In this study, an authentic science task was created through simultaneous transformation of content, scientific thinking, and resources for sixth grade students. The purpose of this study is to investigate what kinds of authentic situations are beneficial towards students' knowledge-rich inquiry. Results of this study indicate students' performances on the development of knowledge and inquiry depend upon the complexity of authentic situations. From the situated learning perspective, this paper deals with the importance of using authentic situations to develop rich understandings about scientific knowledge and how to design science tasks that prepare students to participate in social practices valued by the science community.

Related Research

Situated learning provides a theoretical foundation to implement scientific inquiry in science classrooms. Lave and Wenger (1991) define learning as:

> becoming able to be involved in new activities, to perform new tasks and functions, to master new understandings. Activities, tasks, functions, and understandings do not exist in isolation; they are part of broader systems of relations in which they have meaning, these systems of relations arise out of and are reproduced and developed within social communities, which are in part systems of relations among persons. (p. 53)

What is important in situated learning is to understand interrelationships among learners, activity, and world that are defined in a community of practice. Lave and Wenger (1991) identify that 'a community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage' (p. 98).

Since knowledge is defined in a specific community of practice, knowledge taught in the school setting may not reveal its profound meaning. Brown et al. (1989) point out that:

> Too often the practices of contemporary schooling deny students the chance to engage in the relevant domain culture, because that culture is not in evidence. Although students are shown the tools of many academic cultures in the course of a school career, the pervasive cultures that they observe, in which they participate, and which some enter quite effectively are the cultures of school life itself. (p. 34)

From the situated learning perspective, the following sections illustrate the importance of inquiry learning in science education, the role of authentic activities in inquiry learning, and transformation of scientific inquiry for students.

Importance of Inquiry Learning in Science Education

Inquiry approaches stem from an idea that science teaching and learning should reflect how scientific knowledge is constructed. Scientific knowledge should not be considered as self-evident facts or mere empirical verifications because it is continuously revised and reorganized through theoretical and empirical investigations (Kuhn 1970). To conduct scientific investigations, scientists are involved in a wide range of activities: reviewing what is already known, planning, making observations, hypothesizing, experimenting, collecting and analysing data, proposing explanations, and communicating results to name a few. However, describing scientific inquiry neither as a series of four or five step processes nor a general thinking skill is an accurate portrait of scientific inquiry (Millar and Driver 1987). There is no one way of carrying out scientific inquiry across scientific disciplines because each science community accepts specific ways to carry out inquiry in its own discipline (NRC 2000).

Since scientific knowledge and thinking are intertwined in science, curriculum developers are sometimes faced with a difficult challenge; whether to prioritise content or thinking skills (DeBoer 1991). Some educators think these two goals are competing rather than complementary (Edelson 2001). Programs that prioritise content focus on teaching science as a body of organized knowledge. Programs that prioritise thinking skills focus on developing scientific modes of thought such as the scientific method, critical thinking, reflective thinking, and problem solving.

Both approaches have been criticized from science, teaching, and learning perspectives. From the science perspective, neither content nor thinking skills depict science as it happens. Schwab (1962) criticizes content approaches by arguing that students ‘are shown conclusions of enquiry as if they were certain or nearly certain facts. Further students rarely see these conclusions as other than isolated, independent “facts”. Their coherence and organization-the defining marks of scientific knowledge-are underemphasized or omitted’ (p. 31). Millar and Driver (1987) disagree with thinking skills approaches because too much attention is given to the inductive or empirical nature of science. From the teaching perspective, teachers have difficulty teaching students to transfer what they learn, either knowledge or thinking skills, to other applicable situations (Bransford and Schwartz 1999). From the learning perspective, both approaches often downplay the importance of the knowledge acquiring context so that a critical examination of how various context features influence knowledge or skill development becomes unnecessary (Perkins and Salomon 1989, Greeno 1998).

Role of Authentic Activities in Inquiry Learning

The idea of fostering inquiry in science education is hardly new. Bybee (2000) and others find the origin of the idea as early as Dewey (for example, Dewey 1938). Schwab (1962) advocates the use of scientific inquiry as a pedagogical strategy to achieve inquiring science classrooms that offer ‘not only the clarification of inculcation of a body of knowledge but the encouragement and guidance of a process of discovery on the part of student’ (p.66). The National Science Education Standards (NRC 1996) make it clear that scientific inquiry should not be interpreted as only one way of doing science such as hands-on experimentation or reading about science. Rather, scientific inquiry is defined as ‘diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work' (p.23). In addition, 'inquiry is a step beyond "science as a process" in which students learn skills, such as observation, inference, and experimentation. The new vision includes the processes of science and requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science' (NRC 1996, p. 105).

It is apparent that distinctions should be made between scientific inquiry scientists pursue in their professions and scientific inquiry students can pursue in their classrooms. These differences include: (1) the inquirer's knowledge, experience, attitude, and scientific thinking and (2) the inquiry context (Bransford et al. 2000). In addition, students' inquiry is more constrained in terms of time and resources (Edelson et al. 1999). Unlike scientists' inquiry, students' inquiry requires a lot of guidance. The concept of scaffolding is firmly based on Vygotsky's Zone of Proximal Development that refers to the gap between the actual level the student can develop without assistance and the potential level the student can reach with assistance from more knowledgeable others (Vygotsky 1978). Scaffolding for multi-step inquiry tasks need to address novice inquirers' lack of subject matter knowledge, sophisticated strategies, and self-monitoring skills (Bransford et al. 1989, Chi et al. 1989, Clement 1991, Lewis and Linn 1994). Scaffolding by more knowledgeable others can be accomplished through many different means. Some examples of scaffolding include reciprocal teaching (Palincsar and Brown 1984), modeling (Krajcik et al. 2000), prompting (Davis and Linn 2000), self-assessment (Barron et al. 1998), and reflective assessment (White and Frederiksen 2000). Studies demonstrate that these various kinds of scaffolding mechanisms improve students' conceptual understanding (White and Frederiksen 1998), reading comprehension (Palincsar and Brown 1984), and knowledge integration (Davis and Linn 2000).

The situated cognition theory suggests that retention and application of knowledge depend upon the context in which knowledge is acquired. In the case of scientific inquiry, students need to be involved in the culture where scientific inquiry is possible. Traditional practices in science classrooms such as lectures, demonstrations, and cookbook lab experiments rarely support a culture of inquiry and often instead promote the culture of schooling. Authentic tasks are believed to support the culture of science in classrooms. Even though there is still no consensus on what constitutes authentic science tasks and how to create them, authentic activities are defined as ‘ordinary practices of the culture’ (Brown et al. 1989, p. 34) or what students face in the real world (NRC 1996). The former definition promotes the adoption of scientists’ practices by helping students learn attitudes, tools, techniques, and social interactions held by scientists (Edelson et al. 1999). The latter definition promotes the use of everyday problems in order to draw students’ enthusiasm and develop attitudes for lifelong learning (Linn and Muilenburg 1996).

There are several ways to add authenticity to science tasks. First, authenticity is addressed by using real world problems scientists face (Edelson et al. 1999). For example, The Scientists in Action Series developed by the Cognition and Technology Group (CTGV) at Vanderbilt consist of several activities that utilize real world problems such as a chemical spill by an overturned tanker on the highway and the rescue of bald eagles in the wild. After watching video episodes, students answer questions similar to what professionals address (Goldman et al. 1996). CTGV emphasizes video as ‘anchors’ to stimulate students’ enthusiasm and generate multiple opportunities to study complex problems (CTGV 1992). Second, authenticity is obtained through students’ solutions of problems from their own lives. Problems are pursued in students’ own projects (Blumenfeld et al. 1991, Krajcik et al. 1998) or are presented to students by the curriculum (Barron et al. 1998). Third, authenticity is obtained by linking students and scientists through data sharing, critiquing and direct communication (Pea 1994). In the Kids as Global Scientists project, students interact with professional quality-data and imagery and analyse live events through direct communication with scientists (Songer 1998). Fourth, authenticity is added when science tasks address what scientists do to reach common understandings including argumentation (Bell and Linn 2000), presentation, and communication (Scardamalia and Bereiter 1991). Socially constructed understandings about scientific knowledge among students can happen in communities formed inside the classroom (Brown et al. 1993) or across classrooms (Scardamalia and Bereiter 1994, Bell and Linn 2000).

Transformation of Scientific Inquiry for Students

To create authentic tasks for students, the deliberate transformation of content knowledge, scientific thinking skills, and resources is necessary. Some key findings from studies that investigated these transformations are as follows:

Transforming content knowledge

As scientists develop more powerful and parsimonious theories that explain a wider range of phenomena, the body of scientific knowledge essential to them shifts. Because the fundamental knowledge underlying such theories becomes complex and extensive, more powerful and parsimonious theories are often abstract and hard for students to learn. Linn and Songer (1991) examined whether more abstract molecular-kinetic models are better for eighth grade students to learn about heat and temperature concepts than heat transfer models. Even though molecular-kinetic models explain thermodynamic phenomena more precisely, heat transfer models that map directly to real world problems are more powerful models for students' explanation of natural world situations (Linn and Muilenburg 1996). Thus, it is important to note that students can benefit from using models of phenomena that map to familiar contexts even though abstract models are more widely accepted in the science community.

Transforming scientific thinking skills

Despite the disagreement with defining scientific inquiry as a series of processes (Millar and Driver 1987), since the 1960s several activity sequences have been proposed to simplify and generalize the scientific inquiry process (Karplus 1977). In one good example, White (1993) proposed a sequence of inquiry activities consisting of prediction, experimentation, formalization, and generalization to facilitate students' construction of a set of conceptual models through scientific modelling. White and Frederiksen (1998) later refined this sequence towards an inquiry cycle that consists of question, predict, experiment, model, and apply, in order to emphasize the modelling aspect of scientific inquiry within computer-generated microworlds. To increase students' awareness of the inquiry cycle, White added a reflective assessment component that encourages students to reflect on their performance at the end of each cycle. This inquiry cycle approach with reflection led deeper conceptual understandings about force and motion than what had been achieved before (White and Frederiksen 1998).

Transforming resources

Authentic learning necessitates the use of tools and resources to enable students to form questions, plan and perform investigations, and communicate results. As part of scientific inquiry it is important to experience the changing nature of science (Schwab 1962). Traditional textbook-based resources rarely support this kind of inquiry because students tend to perceive what is written in the textbooks as unchanging truths. Recently, telecommunication technologies are increasingly used to offer students rich and up-to-date resources needed for open-ended investigations. These tools help students model (Spitulnik et al. 1998), visualize data (Edelson et al. 1999), collect and analyse data (Mokros and Tinker 1987, Nachmias and Linn 1987), communicate ideas (Scardamalia and Bereiter 1994), and evaluate relevant information (Bell and Linn 2000). Design principles for these technological tools deal specifically with learning objectives based on current learning shortcomings. However, most research concludes that these resources are not used optimally due to students and teachers' lack of knowledge and experiences.

What is Necessary?

Taking the position of situated learning leads to the adoption of somewhat complicated authentic activities for students' inquiry. The question becomes how to transform scientists' inquiry to students' inquiry successfully and what kinds of impacts it will create for learning. Greeno (1997) discusses this complexity when he raises the question of 'which combinations and sequences of learning activities will prepare students best for the kinds of participation in social practices that we value most and contribute most productively to the development of students' identities as learners?' (p. 9). Although the National Science Education Standards encourage content-rich inquiry learning and thinking in authentic contexts, the nature in which features of the authentic contexts should be transformed to support inquiry thinking is still far from understood. Since authentic activities are by definition unique to each science discipline, an investigation leading to greater characterization of the role of authentic activities will need to begin in the disciplinary context. Therefore, this study investigated what characteristics of authentic situations contribute to the development of knowledge-rich inquiry. Findings in this research will give valuable insights on how to foster knowledge-rich inquiry for students through very complicated and challenging authentic science problems.

Method

In this section the Kids as Global Scientists curriculum, subjects, forecasting task, and data collection and analysis are described in detail.

Kids as Global Scientists Curriculum

Kids as Global Scientists (KGS) is an eight-week, inquiry-based weather curriculum for middle school students (Songer 1996). Some parts of what meteorologists do are transformed into inquiry tasks in the KGS curriculum such as collecting local data, comparing weather data from geographically different regions, interpreting real-time weather maps and images, and making forecasts. KGS consists of inquiry tasks that (Songer et al. 2002):

- foster deep fundamental knowledge and a strong conceptual framework.
- build on and foster natural problem solving abilities.
- work directly with students' own ideas, beliefs, and conceptions.
- provide effective guidance and modelling for students' own queries.

In incorporating inquiry in the KGS curriculum, five essential features of classroom inquiry (NRC 2000, p. 25) were adopted. These five features are:

- Learner engages in scientifically oriented questions.
- Learner gives priority to evidence in responding to questions.
- Learner formulates explanations from evidence.
- Learner connects explanations to scientific knowledge.
- Learner communicates and justifies explanations.

Each curricular activity engages students in scientifically oriented questions initiated by the curriculum as well as students. In each activity students collect evidence to explain their responses to scientific questions. Students have opportunities to evaluate alternative explanations from students and meteorologists across the US. KGS provides two technological tools for students to utilize resources inside and outside the classroom: the World Wide Web message board for an organized online communication and the KGS CD-ROM, as shown in figure 1, for an access to real-time weather data and imagery used by professional scientists.

Since 1992 KGS has been offered throughout the US. Teachers register their classes on the project website (http://www.onesky.umich.edu) to receive curriculum materials, access to online resources, and teacher support. During eight weeks in February and March each year, students collaboratively learn about weather with students and scientists (Songer 1998). In KGS

2000, 13 065 individuals from 230 schools in 35 states participated. Unlike other similar technology-rich science programs that target a small number of well-supported, privileged schools, KGS has been adopted in less idealistic settings. For instance, the KGS 2000 statistics indicated 40 % of 230 schools were located in urban settings.

Insert figure 1 about here

Forecasting Task

The real-time forecasting task was a culminating activity in the KGS curriculum. The task was posted on the online message board during the last four weeks of the KGS curriculum and was open to the entire KGS schools. This task satisfied two authentic activity criteria described in the National Science Education Standards: simulating the culture of what scientists do (Ahrens 1994) and providing problem solving activities that are accessible to students in their daily lives (Ault 1994). To model and support the prediction-making task, a weather specialist provided a daily content insight on the focus city on the message board during the forecasting period. Designing the real-time forecasting task involved the transformation of content knowledge, scientific thinking skills, and resources from meteorologists' forecasting practices towards a useful authentic learning task for students.

Transforming content knowledge

The purpose of the forecasting task is to develop rich understandings about weather systems in real-world weather situations. Throughout the forecasting period target cities were changed every three days, which allowed students to see changes during the passage of weather systems including cold, warm, stationary and occluded fronts and high and low pressure systems. Figure 2 shows an example of forecasting questions posted on March 22, 2000, for Denver, CO. Instead of making their own forecasts on any meteorological entity, students were guided to make predictions on minimum and maximum temperatures, cloud condition, precipitation, and wind direction in a multiple choice format. These four meteorological entities were chosen because they tend to change drastically during the passage of weather systems. Students explained their predictions separately for temperature, cloud, and wind in the open-ended format.

Making scientifically sound forecasts requires students to consider local weather conditions as well as nearby weather systems. If weather systems are the dominant influence on weather outcomes, the results are somewhat predictable. However, in most cases weather systems interact with several other influences including geography such as large bodies of water, high mountains, and deserts, resulting in more inexact estimations of changes over time.

Insert figure 2 about here

Transforming scientific thinking

Table 1 lists how five essential features of classroom inquiry were transformed for the meteorologists' real-time forecasting task and which inquiry features were assessed in this study. In transforming inquiry for forecasting, two inquiry features were emphasized: the formulation of explanations from evidence and the connection of explanations to scientific knowledge.

Insert table 1 about here

Transforming resources: KGS message board and CD-ROM

The web-based KGS message board system allowed participation of the weather specialist and students from different locations. Each day a city was selected from the weather specialist's choices and announced on the KGS message board. The forecasting cycle took three days to complete. On the first day students in small groups logged onto the KGS message board to view the forecasting questions. They explored various resources including the KGS CD-ROM and other weather-related web sites to answer the questions. Students' predictions of temperature change, cloud condition, and wind direction were posted and justified. At the end of the second day actual data were collected and posted on the message board. The weather specialist also posted explanations of the previous day's weather situation. On the third day students compared their predictions with the actual data and the specialist's explanation.

The KGS CD-ROM shown in figure 1 was used to enable students to explore real-time weather data, maps, and images effectively. Weather maps and images the user chooses are shown in the display area at the centre. If the user locates a city, the current information on that city appears in the right data column. The user can view the data in metric or American units. Five base map choices are infrared and visual satellite images, humidity, temperature, and wind chill. A base map covers the entire display area. Overlay map choices are pressure, precipitation, winds, and fronts. These maps can be displayed as many as the user applies and can be overlaid on a base map. The user also can draw and erase with the editing tools on the weather map.

Many features in the KGS CD-ROM were designed to accommodate what meteorology novices would need to observe real-time weather effectively. Lowe's work (1988, 1993, 1996) on the differences between professional weather forecasters and undergraduates in the cognitive processing of weather maps articulates major considerations made in the development of the KGS CD-ROM. Lowe (1996) identified that undergraduates generally had difficulties in visualizing weather systems beyond the weather map and in estimating the change of weather patterns over time. On the KGS CD-ROM the magnifier allows students to view weather maps over a specific region as well as over an entire continent. In addition, students can view still images of current weather and animated images of weather over a 24 hour or 4 day period. Lowe (1996) also found that, due to the lack of knowledge in meteorology, undergraduates focused on external visuo-spartial aspects of weather maps without understanding meteorological relationships. On the KGS CD-ROM, two or more weather maps can be overlapped to allow students to test the relationships between weather elements. Lowe (1988) recommended explicit visual cues to foster making connections between information on the weather maps and personal experiences. On the KGS CD-ROM, the clothing of the bunny, the weather outside the window, and the thermometer facilitate the connections between everyday experiences and scientifically visualized information.

Subjects

The forecasting data were collected on the KGS message board from distant locations as well as from local classrooms. During the four weeks of the forecasting period 251 forecasts from 20 schools in eight states were collected. The schools consisted of five elementary schools, ten middle schools, three high schools, and two home schools. The total number of forecasting posts from each school varied, ranging from one post to ninety-six posts. This variation occurred because the KGS curriculum did not specify how many times students needed to forecast online. For this study, the forecasts from one focus school were selected for detailed analysis. This local school was selected because it was necessary to collect detailed observations on the classroom practices associated with forecasting as well as the forecasts in order to have a comprehensive understanding of the data.

The local school was located in an urban school district where 95% of the students are African American and 70% are on free or reduced lunch. This school has been involved with various technology-rich projects mainly because of the enthusiasm of Ms. Adams, a technology teacher. KGS has been implemented by various science teachers in this school since 1997. Ms. Adams and Ms. Truman partnered for the teaching of technology-rich science. Ms. Truman had been teaching middle school science for more than 13 years and had one year of teaching experience with KGS prior to this study. Ms. Adams helped Ms. Truman when the KGS classes took place in the computer lab.

Data Collection

The implementation of the real-time forecasting task was discussed with Ms. Truman and Ms. Adams. They agreed to an idea that forecasting would be a good opportunity for students to apply the knowledge they obtained about weather. They implemented the forecasting task three times, providing current forecasts for the cities of Dallas, Buffalo, and Denver in the US. Prior to this task, students learned about meteorological entities and weather systems through hands-on experiments, KGS CD-ROM investigations, and message board communications. During the forecasting task, Ms. Adams and Ms. Truman gave students several questions to ponder for the exploration of weather maps. Two students were paired to explore weather maps on the KGS CD-ROM but made separate forecasts. Three weather situations students forecasted were shown in figure 3.

Insert figure 3 about here

In summary, three forecasting situations provided different challenges to students. On March 14 in Dallas, TX, a locally developed low pressure system occurred without accompanying fronts. This quickly became a problem to students who were familiar with cold and warm fronts attached to the low pressure system, not the one without them. This low pressure system was caused by the heating of a large body of water in the Gulf of Mexico, not by the meeting of the cold air and the warm air. March 16 featured a cold front passing over Buffalo, NY, that exactly followed a textbook example (Ahrens, 1994). On March 23 the weather for Denver, CO, was more complicating than the previous two days because, without a dominant weather system, high and low pressure systems around Denver moved unexpectedly.

Eventually, the high pressure system near the Rocky Mountains affected Denver's weather. As the high pressure system moved from the high mountains to Denver, the air heated up adiabatically. Among the three forecasting situations, the weather specialist indicated that Buffalo was the easiest case and Denver was the most difficult case because of the influence of local geography on the weather outcomes. Hereafter, three forecasting situations will be referred to their city name.

Data Analysis

This research investigated how the complexity of authentic real-time weather situations affected students' development of knowledge and inquiry. As shown in table 1, the development of knowledge and inquiry was assessed in students' explanations for temperature, cloud condition, and wind direction in terms of meteorological entity consideration, explanation type, and scientific knowledge use. In addition, prediction agreement with actual data was assessed based on students' responses to four multiple choice predictions on minimum and maximum temperatures, cloud condition, and wind direction.

Insert table 2 about here

Prediction agreement

Students' predictions on minimum and maximum temperatures, cloud condition, and wind direction were scored by comparing them with actual weather data as shown in table 2(a). For each weather element, one point was given if students' prediction agreed with actual data. A total prediction agreement score on a particular day was calculated by combining the scores of four weather elements, ranging from zero to four points. ANOVA's were performed to compare total prediction agreement scores across three forecast situations.

Meteorological entity consideration

This coding category looked at how many meteorological entities were incorporated into students' explanations. This decision was based on Lowe's study (1996) that, compared to non-experts, professional weather forecasters provided rich explanations about weather phenomena because they were able to consider more meteorological entities. Lowe (1996) defined meteorological entities as constituents of the weather map such as temperature, pressure, humidity, wind, and fronts. Each day's total number of meteorological entities was calculated by combining the scores for the number of meteorological entities presented in temperature, cloud, and wind explanations. A higher score meant more meteorological entities were incorporated into explanations. ANOVA's were performed to compare the total number of meteorological entities students considered in their explanations for the three forecasting situations.

Explanation type

Depending on the reasoning students provided, their explanations were categorized as persistent, local, and systemic as adapted from Ahrens (1994). 'Persistent' explanations assume that future weather is the same as current weather. 'Local' explanations use local measurements of meteorological entities such as temperature, pressure and wind. 'Systemic' explanations include weather systems. Systemic explanations were considered to be the strongest because weather systems are the dominant influence on weather outcomes. The intercorder reliability was 0.95.

Scientific knowledge use

Students' explanations were coded on a scale of zero to two based on the consistency and sophistication of scientific knowledge. Zero points were assigned if students (1) restated their answers to multiple choice-based predictions, (2) cited current weather without mentioning why this projection was possible, or (3) did not use any weather concepts. One point was assigned if students used the relationships between weather elements and/or weather systems but their explanations were incomplete or inconsistent. Two points were given if students used relationships between weather elements and/or weather systems appropriately, and their explanations were consistent and scientifically elaborated. To calculate a total scientific knowledge score for each day, three knowledge scores for temperature, cloud, and wind explanations were combined for a possible score of six. The intercorder reliability was 0.90. ANOVA's were performed to compare the total knowledge scores across three forecast situations.

Results

In this section, two major findings are described: (1) how students' performances on prediction agreement, meteorological entity consideration, explanation type, and scientific knowledge use depended upon weather situations students faced, and (2) how students applied their knowledge to forecasting. Results of data analyses are presented by each coding category with examples of student work.

Prediction Agreement

Figure 4(a) shows how well students' predictions agreed with the actual weather data. Students' predictions were most accurate in the Buffalo case (M = 2.11, SD =1.13) compared to the Denver case (M = 1.13, SD = 0.92) and the Dallas case (M = 1.42, SD = 0.91). This pattern was statistically significant, F (0.05, 2) = 15.1, $p < 0.001$. This tendency agreed with the weather specialist's forecasting difficulty rating as explained earlier. Forecasting difficulty depended upon how closely actual weather followed typical weather patterns caused by the dominant weather system. Similarly, Ahrens (1994) indicates that cold fronts in the Northern Hemisphere during the winter, like the one in the Buffalo case, are most predictable. In the other two cases, local geographies such as a large body of water in the Gulf of Mexico and the Rocky Mountains contributed to the unusual weather system behaviours that made forecasting more difficult.

Meteorological Entity Consideration

One of the differences between professional meteorologists and novice learners is experts' ability to process many meteorological entities towards more accurate forecasts. As shown in figure 4(b), the average number of meteorological entities considered in each forecast was highest in the Buffalo case, (M = 3.83, SD = 1.89) and lowest in the Dallas case (M = 2.81, SD = 1.49) with the Denver case in the middle (M = 3.54, SD = 1.78). This difference was statistically significant, F (0.05, 2) = 5.4, $p < 0.01$. The largest differences occurred between Dallas and Buffalo cases as confirmed by the Tukey's post hoc test, $p < 0.01$. These differences occurred because more students incorporated weather systems information into their explanations in the Buffalo case to explain the noticeable cold front. Results also indicate that students considered more entities with time and experience. Significant differences existed in the number of meteorological entities in explanations between Dallas and Denver cases, $p < 0.05$. In general, consideration of more meteorological entities resulted in stronger scientific explanations. However, mere consideration of more meteorological entities did not always result in scientific explanations and accurate prediction as shown in the following examples from student temperature predictions for Dallas:

> Student A: There will be cold air. It is going to move to Dallas because the coverage of the clouds is going to affect the temperature. The wind is medium so it [the maximum temperature] may be cold and the temperature at night [the minimum temperature] will be cool also.
>
> Student B: The maximum temperature is [going to be] higher. The reason I think it's going to be hot [is] because the warm air mass is coming from the south [the Gulf of Mexico].

Student A's explanation includes more meteorological entities, e.g. cold air, clouds, and winds, than Student B's explanation, e.g. warm air, but Student A's explanation is scientifically incomplete because she did not elaborate how cloud coverage affected temperatures. As a result, Student A’s explanation was scored high in the meteorological entity consideration category and low in the scientific knowledge use category while Student B’s explanation was scored in the opposite way. Scientifically productive forecasting requires students to consider salient meteorological entities that would affect the next day’s weather instead of every meteorological entity the weather map provides.

Insert figure 4 about here

Explanation Type

Figure 5 shows the classification result of students’ explanations for temperature, cloud, and wind predictions. In the Dallas case, system-based forecasts were rare for all cities including temperatures (14 %), clouds (5 %), and winds (3 %). The proportion of system-based forecasts increased for temperature in the next two forecasting days (64 % for Buffalo and 42 % for Denver). System-based cloud and wind explanations also increased but not as much as system-based temperature explanations.

Explanation type was related to what type of meteorological entities students considered in explaining their predictions. When students considered only a meteorological entity that was going to be predicted, i.e. temperature for temperature prediction, it was unlikely that making more forecasts would improve their ability to consider changes caused by the weather system. For example, a student predicted maximum temperature would be steady ‘because today is 35 degrees F and the temperature will not change’. For wind prediction ‘tomorrow will be NW because today is NW’. Figure 5 shows that persistent forecasts like these were common for cloud and wind predictions regardless of weather situations. This indicated that students had difficulty understanding how clouds and winds influence predictions in a real world context. Other students offered explanations that were based only on local signs. This type of explanations was different from the system-based explanations because it often failed to recognize the relationships between local signs that took place within the weather system.

Forecasting experts recognize that weather operates as a system. Unlike experts, students did not often consider weather systems except the cold front system in forecasting. Students did not easily connect an idea that pressure systems are strongly related to temperature change, wind direction, and cloud formation. From which direction winds blow can determine temperature. In Dallas, the Southwest winds brought warm air from the Gulf of Mexico resulting high temperatures. The distribution of high and low pressure systems can indicate the wind direction because winds blow from the high pressure centre and towards the low pressure centre. Cloud formation is associated with rising air above low pressure systems and cloud dissipation is associated with sinking air above high pressure systems. Students often cite ‘Low pressure brings bad weather and high pressure brings fair weather’ without knowing this relationship between cloud formation and pressure systems.

Scientific Knowledge Use

Figure 4(c) shows that the level of scientific knowledge expressed in students’ explanations was highest in the Buffalo case (M = 2.27, SD = 1.73), lowest in the Dallas case (M = 1.27, SD = 1.06), and in the middle in the Denver case (M = 1.76, SD = 1.19). This difference was statistically significant, F(0.05, 2) = 14.75, $p < 0.001$. Tukey’s post hoc test shows significance between the Dallas and the Buffalo cases, $p < 0.001$. Scientific knowledge in students’ explanations appeared to improve as they repeated forecasting because, even though the Denver case was more difficult than the Dallas case.

Insert figure 5 about here

Among students' explanations, several general patterns that demonstrate good and weak uses of evidence were observed. Four are discussed here.

Weather systems

The goal of teaching weather systems was to show how meteorological entities interact within a system. When weather systems such as high and low pressure cells or cold fronts were addressed for the purpose of forecasting in the curricula, students would use these systems to predict temperature, cloud, and wind patterns. However, students did not equally incorporate various weather systems into their forecasting. Cold front systems were used more often by students to explain temperature, cloud and wind predictions than other systems:

> Student C: Minimum and maximum temperatures will be much lower than today because the cold air is pushing clouds away so it will be cold because there are no clouds to keep Buffalo warm.
>
> Student D: It will be partly cloudy because the cold front is pushing clouds. The high pressure creates winds that blow away clouds.
>
> Student E: The wind direction will be Northwest because it is the cold wind coming behind the cold front and the cold front which just passed through Buffalo, NY.

Some students considered pressure distribution to estimate wind direction such as 'the wind is going from a high pressure' or 'the wind is going toward the low pressure'. However, most students rarely considered pressure to determine wind direction. Many students connected wind direction with the movement of the cold front.

Relationships between meteorological entities

Some students used relationships between meteorological entities to predict upcoming weather. The following example illustrates the consideration of a relationship between cloud coverage and temperature:

> Student F: The minimum temperature will be steady because the clouds in the sky are keeping it warm so it will stay the same all night because the clouds keep it warm at night just like our blankets and the clouds are moving.

One of the common mistakes was relating high (low) temperature to high (low) pressure such as ‘the clouds will keep themselves warm which will move the pressure go higher’ and ‘I think the temperature will go up a little bit because of the pressure will go up’. The relationship between temperature and pressure in weather systems is not the same as the relationship between temperature and pressure in thermal physics. As a container half filled with water is heated, the pressure of the container increases due to the increased movement of gaseous molecules. In the atmosphere as the heated air rises, its density decreases, resulting in lower pressure. Another misconception is the relationship between low (or high) temperature and cloud formation such as ‘I think it will be partly cloudy because the temperature is going to be low and when the temperature is low sometimes the clouds come out’. The consideration of dew point or humidity provides more relevant evidence for cloud formation.

Weather system movement

Students in general had difficulty estimating changes in the movement and strength of weather systems. Some students made forecasts assuming that all weather systems would stay in the same places for the next day. Other students thought weather systems always moved from west to east. This overgeneralization occurred because of the general movement of weather systems due to the prevailing westerlies in the middle latitude. As a result, some students thought winds always blew from west to east:

> Student G I think the wind is coming from west. The reason why is that the wind is blowing in a rounded or boxed path basically. The wind goes around and now it is blowing from the west. The wind is pushing from the west because it blows in a circle path. The winds are blowing around in a circle all around the earth.

Geographical features

Students rarely incorporated geographical influences into their forecasts. Perhaps students did not consider geography because they were not familiar with its influence on weather. Large bodies of water affect weather due to the supply of humid air. Mountains are important because they can force the air to go up or down depending upon their slope. Rising (sinking) air is related to cooling (heating) of the air, resulting in cloud formation (dissipation). No students considered mountains to forecast the weather of Denver, while several students mentioned the influence of the Gulf of Mexico on the weather of Dallas.

> Student H: The temperature will be higher because the water from the Gulf of Mexico is carrying moisture and the water evaporated and makes clouds and more and more clouds keeps the earth warm.

Discussion

National Science Education Standards (NRC 1996) put a strong emphasis on scientific inquiry for k-12 science classrooms because of the emphasis on rich understandings of scientific knowledge beyond simplistic definitions. Scientific inquiry presented in scientists' authentic practices can be used for students' inquiry if the situation is transformed so that it is accessible and relevant to students' lives. For this research, a real-time forecasting task was developed through the simultaneous transformation of content knowledge, scientific thinking skills, and resources and implemented in sixth grade urban middle school classrooms. This study investigated whether students' development of knowledge and inquiry differed due to the scientific complexity involved in authentic forecasting situations. Results show that the scientific complexity of forecasting situations influenced students' explanations for their predictions as well as their forecasting accuracy. When forecasting situations closely matched their content understandings about weather systems, students were better able to use scientific knowledge and evidence in their explanations. In addition, results show students did not always spontaneously apply knowledge about weather systems to forecasting. Students applied the cold front system better than the high and low pressure systems because they acquired the cold front system through a curricular activity where they explored how weather patterns change as the cold front system moves over a region. Students more actively exercised their understandings about weather systems for forecasting temperatures than clouds or winds. Students' forecasting difficulties resulted from both their misconceptions about relationships among meteorological entities and real-world weather situations complicated by local geography.

While National Standards and policy documents advocate the use of authentic contexts for problem solving and scientific experimentation, this study shows that not all authentic situations are appropriate for the development of students' understandings of scientific knowledge. The following section outlines three guidelines for the development and transformation of science activities that utilize authentic contexts for student inquiry.

1. Real world situations must map closely to students' content understandings and curricular activities.
2. Authentic science tasks should be developed through the simultaneous transformation of content knowledge, scientific thinking and resources.
3. Students need specific guidance for the use of transformed products towards inquiry learning goals.

Real World Situations Must Map Closely to Students' Content Understandings and Curricular Activities

Real world situations are inherently complex even for professional scientists because they are ill-defined and contain so many uncontrollable variables that influence outcomes. As a result, some authentic real world situations cannot be used effectively for students. Real world situations that closely match simple patterns in the knowledge students possess provide a better opportunity for the application of students' developing knowledge. When real world situations distantly resemble the way knowledge is previously presented to students, they are likely to experience difficulty applying their knowledge and often resort to non-scientific reasoning.

A real-time forecasting activity in this study was created for students so that they could predict future weather using current weather information. Results of this study demonstrate that weather situations should be carefully selected to enable students to practice inquiry about weather systems. The Buffalo case served as a perfect example for students to apply the cold front concept because the cold front featured in this case behaved exactly as experienced earlier by students. However, Dallas and Denver cases were much more difficult because students needed to incorporate understanding of local geography towards predicted outcomes.

Authentic Science Tasks Should Be Developed through the Simultaneous Transformation of Content Knowledge, Scientific Thinking and Resources

Developing scientific knowledge through scientific inquiry can have cognitive, motivational, and epistemological benefits because of ‘the relational interdependency of agent and world, activity, meaning, cognition, learning, and knowing’ (Lave and Wenger 1991, p. 50). The development of scientific knowledge distinct from contexts of use is long thought to be a problem of traditional science instruction. To create inquiry tasks for students based on scientists’ practices, transformation of content knowledge, scientific thinking, and resources is necessary due to the fundamental differences between scientists and students in their domain specific knowledge, sophisticated strategies, and resources (Kuhn 1989). In addition, this transformation needs to occur in concert to support curricular learning goals effectively. A good way to achieve this result is to employ a team of specialists in areas of science, education, and technology in developing curricular activities.

One example of transformed resources is the KGS CD-ROM. The real-time forecasting task asked students to make 24-hour forecasts on temperature, cloud condition, and wind direction in a city. These meteorological entities were chosen because their changes were strongly associated with the passage of weather systems. With the KGS CD-ROM students could explore three meteorological entities in real-time, 24-hour animation, and 4 day animation formats. Real-time weather maps on the KGS CD-ROM allowed students to evaluate current weather conditions for any city. Animated weather maps and images were useful for students to estimate how fast weather systems move and how their strength changes over time. Moreover, to enable students to examine changes in these three meteorological entities, the KGS CD-ROM also provided fronts and pressure maps. The transformation and presentation of specific content in specific formats connected to student inquiry activities illustrates the importance of resource transformation that is aligned with learning goals. Without the specific transformation of content and resources in the KGS CD-ROM, student inquiry through forecasting would not be possible.

Students Need Specific Guidance for the Use of Transformed Products Towards Inquiry Learning Goals

Developing scientific understandings through authentic inquiry is challenging because students do not often possess the background knowledge or thinking skills to reduce the complexity of the authentic inquiry situations. In the KGS curriculum, several supports were present to guide students appropriately. Relevant weather background knowledge was provided through both the weather map presentation and weather specialists. Features on the KGS CD-ROM interface organized the presentation of weather maps and images, e.g. only certain maps could be overlaid on others, to guide students towards salient weather features (Songer and Samson 2000). On the web-based KGS message board, weather specialists provided daily weather updates and explained certain weather patterns outcomes. Experts' weather knowledge also reduced the burden that might be imposed on teachers allowing easier guidance of students' thinking.

This study also demonstrates that in two of the three forecasting cases the transformation of content knowledge, scientific thinking and resources into a real-time forecasting task did not result in a simple authentic earning experience for all students. While the current curricular supports specifically reduced some of the unnecessary complexity so that students could more easily focus on salient problem features, they did not provide all of the necessary information such as information on local geography.

Conclusion

Unlike traditional laboratory tasks which are often used to foster inquiry, authentic inquiry tasks provide opportunities for students to experience knowledge development in actual contexts of use. As students often lack much of the necessary background knowledge and inquiry skills required to build successful explanations in these contexts, educators need to carefully organize the resources, content and activities into transformed products that make inquiry accessible. This study provided a case for the transformation of resources, content and thinking into a science activity that capitalizes on authentic contexts and data towards knowledge-rich inquiry understandings. Authentic activities are important in promoting inquiry because they can provide opportunities for students to develop ‘identities as capable and responsible learners’ (Greeno 1997, p. 9), but they sometimes provide unnecessary complexity. Simultaneous transformations can reduce the complexity of real world contexts towards the learning benefits available with authentic science.

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Table 1. Inquiry in the KGS Forecasting Task

Essential features of classroom inquiry from table 2-5 (NRC, 2000, p. 25)	Forecasting task organization according to inquiry features	Forecasting coding categories
• Learner engages in scientifically oriented questions.	• What will tomorrow's weather be like in ____ (city name)? • Learner is guided what to forecast through a series of sub-questions. (See table 2)	Not assessed. (Question provided for learner).
• Learner gives priority to evidence in responding to questions.	• Learner uses the KGS CD-ROM and other real-time web resources to explore weather situations around the city. (See figure 1)	Not assessed. (Students guided to collect evidence).
• Learner formulates explanations from evidence.	• Learner explains how temperature, cloud condition, and wind direction change with evidence.	• (Meteorological entity consideration) How many meteorological evidences do students consider? • (Explanation type) What kind of reasoning students provide from the evidence?
• Learner connects explanations to scientific knowledge.	• Learner's explanation reflects the level of understanding about his/her knowledge on weather systems.	• (Scientific knowledge use) How consistent and sophisticated are students' forecasts in conjunction with scientific knowledge?
• Learner communicates and justifies explanations.	• Learner compares his/her explanations with other students' explanations and weather expert's. • Learner compares his/her forecast results with actual data.	• (Prediction agreement) How well do students' forecasts match what actually happened?

Table 2. Coding Scheme

(a) Actual Data to Code Prediction Agreement

Date	Max. Temp*	Min. Temp*	Cloud Condition	Wind Direction**
March 15	Higher (+8.1 F)	Steady (+1.1 F)	Mostly cloudy	E (SE-NE)
March 17	Lower (-22.0 F)	Lower (-5.0 F)	Partly cloudy	NW (N-W)
March 23	Higher (+18.0 F)	Higher (+8.0 F)	Partly cloudy	NW (N-W)

Note. * The values in the parentheses were the actual temperature differences between the day students forecasted and the following day.
** We allowed +/- 45 degrees from the actual wind direction for a correct response.

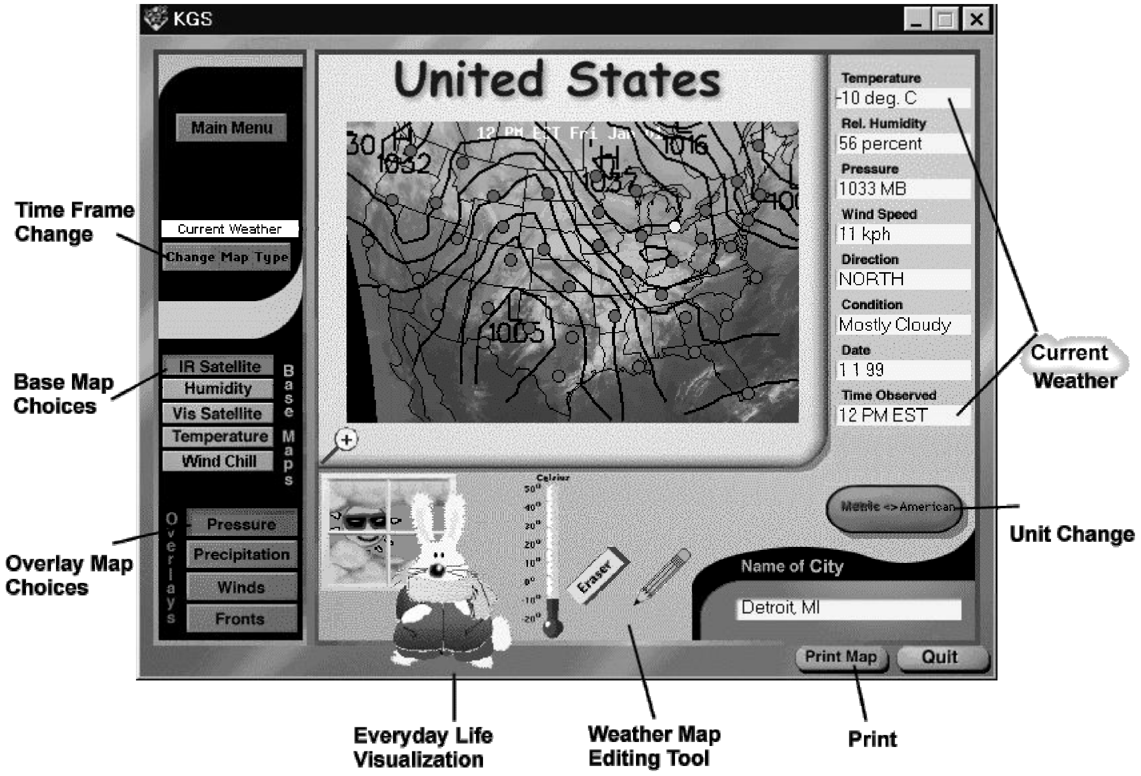
(b) Evidence into Explanation

Coding Categories	Criteria	Examples
Meteorological Entity Consideration	Count the number of meteorological entities cited in the explanation such as temperature, pressure, wind, precipitation, cloud, humidity, fronts, pressure systems, air mass, etc.	(for cloud prediction) Because of the front and the temperatures around Buffalo and the temperatures today, and I chose partly cloudy because scattered clouds are moving north of Buffalo coming from the south. (Three meteorological entities in this explanation)
Explanation Type	• Persistent: The reasoning presented in the explanation was based on a consistency between current weather and future weather.	Persistent: Tomorrow the wind will blow from southeast because the wind is coming from southeast today.
	• Local: The reasoning was based on predicted relationships between measurement-based entities without referring to the weather system.	Local: It will be a lot lower than today because you can see all of the cold winds coming from the east.
	• Systemic: The reasoning was based on the behaviours of the weather elements within the weather system.	Systemic: it is going to be a lot lower from today because the cold front is moving out from Buffalo.

(c) Scientific Knowledge Use

Score	Criteria	Examples
0	• Students restated their prediction. • Students cited the current weather without mentioning why this projection would be possible. • Students did not use weather.	• I think Dallas, TX, will have a slight steady change for maximum. • Tomorrow will be partly cloudy because it is not that cloudy in Denver [right now]. • I saw it from the computer.
1	• Students used the relationships between weather elements and/or weather systems but their explanations were somewhat incomplete or inconsistent.	• Min and max temperatures will be higher because the cold fronts and winds are coming from the northwest. • It is going to be colder because of the low pressure system is close by Denver and it will be a lot lower.
2	• Students used the relationships between weather elements and/or weather systems appropriately, and their explanations were consistent and scientifically elaborated.	• I think the maximum temperature will go down because if the clouds stay for a long period of time, it’s going to block the sun that heats it up.

Figure 1. KGS CD-ROM



Temperature: -10 deg. C
Rel. Humidity: 56 percent
Pressure: 1033 MB
Wind Speed: 11 kph
Direction: NORTH
Condition: Mostly Cloudy
Date: 1 1 99
Time Observed: 12 PM EST
Name of City: Detroit, MI
Current Weather

Figure 2. Forecasting Questions on March 22

Hi KGSers, Today is the last day to forecast tomorrow's weather in Denver, CO. After more than 24 hours of light snow that just ended yesterday afternoon, do you think people in Denver will enjoy a warm and sunny weather? What kind of weather system is coming to Denver? Is it fast enough to get there in time for your forecasting? Remember you make your own forecast for the weather in Denver at 3:00 PM, MST.

Question 1: We think tomorrow's maximum temperature for this city will be

- A lot lower than today: -10 F (-5 C) or more change
- Moderately lower than today: -3 to -9 F (-2 to -4 C) change
- Steady or slight change: -2 to 2 F (-1 to 1 C) change
- Moderately higher than today: 3 to 9 F (2 to 4 C) change
- A lot higher than today: 10 F (5 C) or more change

Question 2: We think tomorrow's minimum temperature for this city will be

- A lot lower than today: -10 F (-5 C) or more change
- Moderately lower than today: -3 to -9 F (-2 to -4 C) change
- Steady or slight change: -2 to 2 F (-1 to 1 C) change
- Moderately higher than today: 3 to 9 F (2 to 4 C) change
- A lot higher than today: 10 F (5 C) or more change

Reasons for our prediction on Question 1 & 2 are

Questions 3: We think the weather in this city tomorrow around 3:00 PM will be

- Sunny (0-10 % cloud coverage)
- partly cloudy (20-50 % cloud coverage)
- mostly cloudy (50-90 % cloud coverage)
- overcast without precipitation
- overcast with rain
- overcast with snow

Reasons for our prediction on Question 3 are

Question 4: We think that, around 3:00 PM, the wind will blow from

North Northeast East Southeast
South Southwest West Northwest No wind

Reasons for our prediction on Question 4 are

Figure 3. Three Days of Forecasting

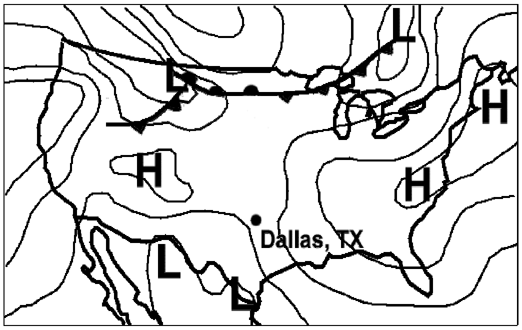
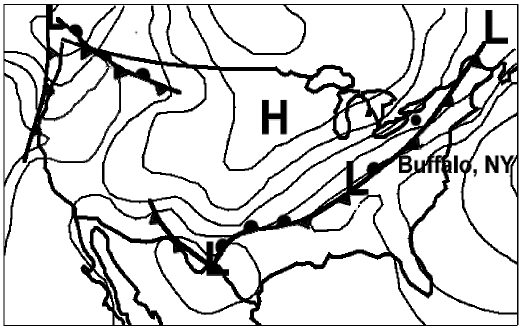
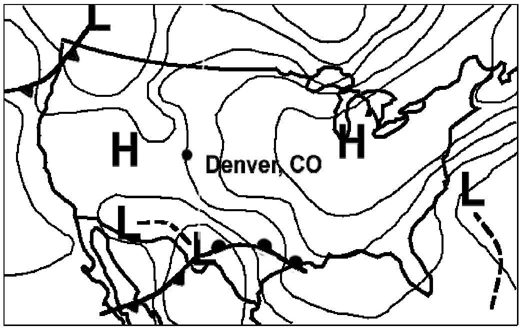
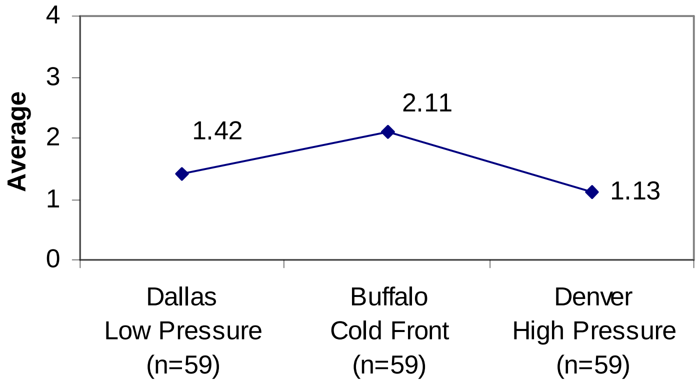
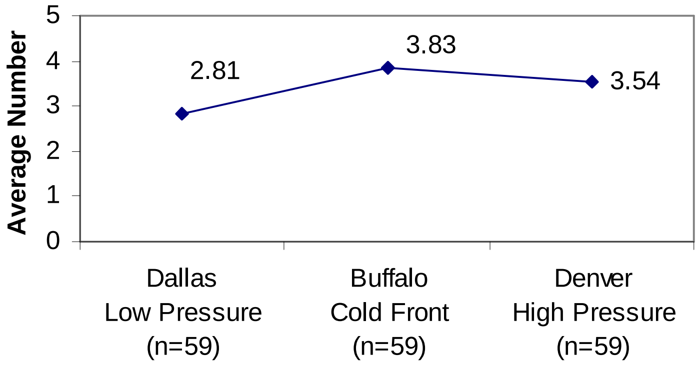
Weather situation when students forecasted	Major weather system	Knowledge for forecasting
03/14/2000, Dallas, TX 	On 03/14 a storm system was fuelled by the large amount of the warm and moist air from the Gulf of Mexico. As this system moved to Louisiana on 03/15, clouds gradually decreased toward the afternoon. Actual data on 03/15 • Max. temp.: moderately higher • Min. temp.: steady • Cloud: mostly cloudy • Wind direction: east	• Low pressure system that does not accompany fronts • Cloud coverage • Geographical influence of the Gulf of Mexico
03/16/2000, Buffalo, NY 	On 03/17 as the cold front had passed, the temperature dropped significantly. The high pressure cell behind the cold front caused north-westerly wind and clear skies. Actual data on 03/17 • Max. temp: a lot lower • Min. temp: moderately lower • Cloud: partly cloudy • Wind direction: northwest	• Cold front • High pressure system
03/22/2000, Denver, CO 	On 03/23 the high pressure near Denver caused winds to blow from W-NW. Due to the high mountains these winds were down slope winds, which made the moving air heat up adiabatically. Around the high pressure the cloud cover was not extensive. Actual data on 03/23 • Max. temp.: a lot higher • Min. temp.: moderately higher • Cloud: partly cloudy • Wind direction: northwest	• High pressure system • Cloud coverage • Geographical influence of the Rocky Mountains

Figure 4. Forecasting Patterns by Weather System

(a) Prediction Agreement



(b) Meteorological Entity Consideration



(c) Scientific Knowledge Use

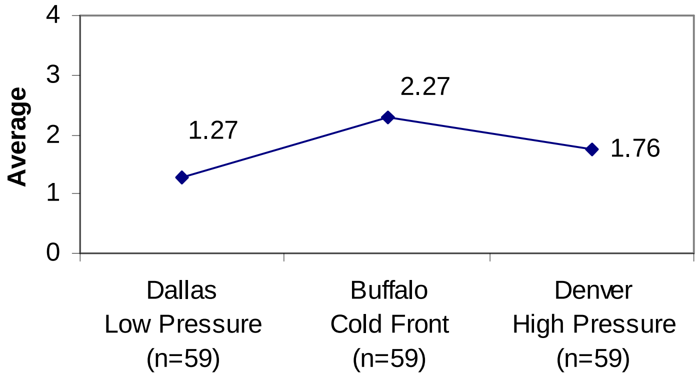
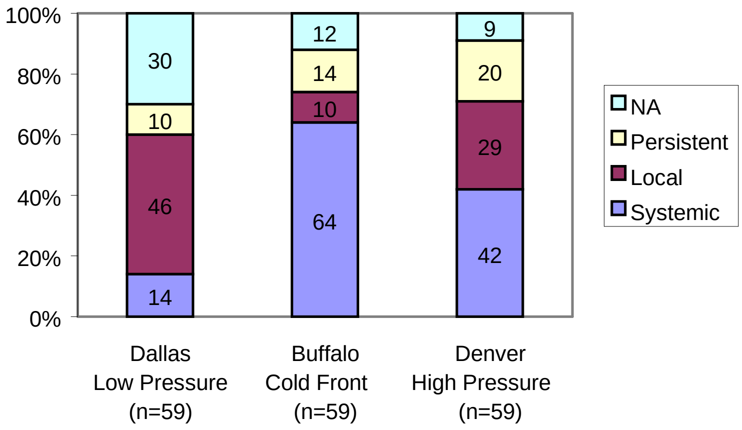
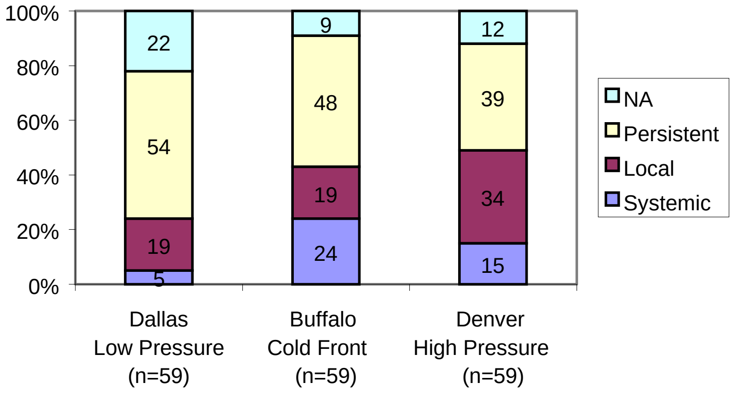


Figure 5. Explanation Type by Weather System

(a) Temperature



(b) Cloud



(c) Wind