Making Authentic Science Accessible to Students

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Abstract

Authentic activities are important in promoting inquiry because of the natural problem solving context they provide with high degrees of complexity. This study dealt with designing effective inquiry tasks through translating content, scientific thinking, and resources featured in scientists' authentic practices in order to help students develop deep inquiry about scientific knowledge. 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 four categories: prediction agreement, weather factors, explanation type, and scientific knowledge use. Results show students performed best when real world contexts closely mapped onto simple patterns whereas they had difficulty in real world contexts with naturally-occurring complex patterns. Key ideas discussed from the situated learning perspective include the importance of using authentic situations in developing scientific understandings and the design of activities 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 (T. S. 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. in press), 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?

The design and development of authentic science activities involve the translation of complex and ambiguous content, scientific thinking skills, and resources that support scientific

investigations. Because of the complexity of the translation, many researchers have prioritised a

selected part of the translation 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, we believe the translation of

content knowledge, inquiry skills, and resources should occur in concert. In this paper, we

provide evidence that not all authentic situations are beneficial towards students' development of

richer understandings about knowledge and abilities to perform inquiry due to the complicated,

uncharacteristic nature of some real world situations. We report how students' performances on

knowledge development and inquiry standards are affected by weather situations that require

them to execute different weather knowledge through real-time forecasting. From the situated

learning perspective, we discuss the importance of using authentic situations in developing rich

understandings about scientific knowledge and how to design activities that prepare students to

participate in social practices valued by the science community.

<div align="center">Related Research</div>

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 bears its meaning in a specific community of practice where it is constructed

and applied, it appears natural to assume that 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)

In the following we extend the concept of this situated learning to science education to

discuss the rationale and issues involved in the use of authentic activities practiced by scientists

for students' inquiry.

Why Inquiry for Science Learning?

Inquiry approaches stem from an idea that science teaching and learning should reflect

how scientific knowledge is constructed and revised. 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 (T. S. 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, content and thinking skills approaches often downplay the idea that knowledge is situated in context including a critical examination of how various context features influence knowledge or skill development (Perkins and Salomon 1989, Greeno 1998).

Inquiry and Authentic Activities

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 are '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). Unlike scientists' inquiry, students' inquiry requires a lot of guidance by more knowledgeable others from social and physical environments. In addition, students' inquiry is more constrained in terms of time and resources (Edelson et al. 1999). Current cognitive theory on the situativity of knowledge suggests that the retention and application of knowledge depend upon the context in which it 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 activities 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 mechanisms for adding authenticity to science activities. 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). Another example is to use a discussion forum to debate scientifically-oriented questions such as the extinction of dinosaurs and the travel of light (Bell and Linn 2000). 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 on video with rich audiovisual information by 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).

Translation of Scientific Inquiry for Students

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

Translating 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).

Translating 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.

Translating 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 a set of rich and up-to-date resources needed for open-ended investigations. These tools help students model (Spitulnik 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, S. Y. Lee and Songer in press), and evaluate relevant information (Bell and Linn 2000). Design principles that support inquiry 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 suggested adoption of somewhat complicated authentic activities for students' inquiry. The question becomes how to transform scientists' inquiry to students' inquiry successfully and what impacts it will create for student 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 promotes content-rich inquiry learning and thinking, the support of content and inquiry thinking simultaneously 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 tasks in inquiry will need to begin in the disciplinary context where they occur. This study focuses on how three real-time weather situations affect students' knowledge development and performances on inquiry standards in an authentic forecasting task to investigate what characteristics of authentic situations contribute to developing deeper inquiry about scientific knowledge, and which situations challenge the development of inquiry reasoning. This research connects to ongoing discussions of how to foster content-rich inquiry learning and thinking towards the goals advocated by the National Science Education Standards and others.

<div align="center">Kids as Global Scientists Curriculum</div>

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 translated into inquiry activities 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 activities that (Songer et al. in press):

- 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 for classroom inquiry in Inquiry and National Science Education Standards (NRC 2000) were adopted. These five features are (p. 25):

- 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 and students. In each activity students collect data and evidence to explain their answers to scientific questions. Students have opportunities to evaluate alternative explanations from students and meteorologists across North America. KGS provides two technological tools to use resources inside and outside the classroom efficiently: 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.

Insert figure 1 about here

Method

In this section subjects, forecasting task, and data collection and analysis are described in detail.

Subjects

Since 1992 KGS has been offered throughout the USA. In KGS 2000, 230 schools and 13 065 individuals participated. During eight weeks in February and March, students collaboratively learn about weather with students and scientists worldwide (Songer 1998). In this study we examined the forecasts of 59 students from three sixth grade science classes taught by Ms. Truman. Ms. Truman had been teaching middle school science for more than 13 years in an urban school district where 95% of students were African-American. Her school district and the University of Michigan were part of the Learning Technology in Urban Schools (LeTUS) project that sought to find ways to improve school science curricula through systemic reform in inner-city classrooms. Ms. Truman had one year of teaching experience with KGS prior to this study. Ms. Adams, the technology teacher, helped when KGS classes took place in the computer lab.

Forecasting Task

The real-time forecasting task was the culminating activity in the KGS curriculum. The task was posted on the message board during the last four weeks of the KGS curriculum and was open to the entire KGS schools. This activity 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 activity, a weather specialist provided a daily content insight on the focus city during the forecasting period. Designing the real-time forecasting task involved the translation of content knowledge, scientific thinking skills, and resources from meteorologists' forecasting practices towards a useful authentic learning task for students.

Translating content knowledge

The purpose of the forecasting activity was for students to develop rich understandings about weather systems in real-time weather situations. Throughout the forecasting period target cities were changed twice a week to see pattern changes associated with 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 for Denver, CO. Instead of accepting students' own forecasting statements, a prediction framework was provided to probe predictions on minimum and maximum temperatures, cloud condition, precipitation, and wind direction. These elements were chosen because they tend to change drastically while weather systems are passing. Students were asked to explain their predictions separately for temperature, cloud, and wind to see if they used proper evidence and knowledge to make forecasts.

Making sound forecasts requires students to consider local weather conditions and nearby weather systems. Weather systems are typically, but not always, associated with certain changes

in temperature, clouds, wind direction, and precipitation. However, the exact estimations of the

movement of weather systems and the change of their strength over time are difficult. In

addition, depending upon local geographies such as large bodies of water, high mountains, and

deserts, the same weather system can produce different weather conditions.

Insert figure 2 about here

Translating scientific thinking

Table 1 shows how the essential features of classroom inquiry suggested in the National

Science Education Standards document (NRC 2000) were manifested for the real-time

forecasting task. Two features such as using relevant evidence in the explanation and connecting

the explanation to scientific knowledge were highlighted and assessed in the forecasting task.

Other inquiry features were addressed to a lesser degree. This decision was based on the purpose

of the forecasting task.

Insert table 1 about here

Translating 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 like students would need to observe 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 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.

Data Collection and Analysis

Before the actual forecasting took place, the implementation of the activity was discussed with Ms. Truman and Ms. Adams. They agreed to an idea that forecasting would be a good opportunity for students to apply their knowledge about weather. As a result, they implemented the activity three times over three days, providing current forecasts for the cities of Dallas, Buffalo, and Denver in the USA. Prior to the forecasting activity, students learned about weather elements, fronts and pressure systems through hands-on experiments, KGS CD-ROM investigations, and message board communications. During the forecasting activity, Ms. Adams and Ms. Truman gave students several questions to ponder during the exploration of weather maps, and then asked them to make and justify their own predictions about the next day's weather in each of these cities. Two students were paired to explore weather maps on the KGS CD-ROM but made separate forecasts.

Figure 3 shows three weather situations students forecasted, each of which provided different challenges to students. On March 14 in Dallas, TX, a locally developed low pressure system occurred without accompanying fronts. March 16 featured a typical cold front passing over Buffalo, NY. On March 23 the weather for Denver, CO, was more complicating than previous two days because, without a dominant weather system, high and low pressures around Denver moved briskly and unexpectedly. Eventually, the high pressure near the Rocky Mountains affected Denver's weather. Among the three days, the weather specialist indicated that Denver was the most difficult case and Buffalo was the easiest case. Hereafter, weather

systems that affected actual weather in these three cities are used to refer to three forecasting

situations: low pressure for Dallas, cold front for Buffalo, and high pressure for Denver.

Each forecast consisted of four predictions for minimum and maximum temperatures,

cloud condition, and wind direction and three explanations for temperature, cloud, and wind. In

each weather element a multiple choice-based prediction question was paired with an open-

ended question for explanation. As shown in table 1, the forecasting framework was used to

probe two essential features of classroom inquiry: formulating explanations from evidence and

connecting explanations to scientific knowledge. Students' predictions and explanations were

coded for prediction agreement, weather factors, explanation type, and scientific knowledge use.

Table 2 shows a detailed coding scheme. Total scores for prediction agreement, weather factors,

and scientific knowledge use were calculated for each student by combining scores for

temperature, cloud, and wind parts. To compare differences among three weather situations,

ANOVA's were performed with total scores.

Insert figure 3 & table 2 about here

Results

In this section, two major findings are described: (1) how students' performances on

prediction agreement, weather factors, explanation type, and scientific knowledge use depended

upon weather systems students faced, and (2) how students applied their knowledge to

forecasting.

<u>Prediction Agreement</u>

Figure 4(a) shows how well students' predictions agreed with the actual weather data. It

shows that students' predictions were most accurate in the cold front case ($M = 2.11$, $SD = 1.13$)

compared to the high pressure case ($M = 1.13$, $SD = 0.92$) and the low pressure 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. Forecasting difficulty depended

upon how closely actual weather followed typical weather patterns caused by the dominant

weather system. 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

geography such as a large body of water in the Gulf of Mexico and the Rocky Mountains

contributed to the unusual weather system behaviour that made forecasting more difficult.

Weather Factors

As shown in figure 4(b), the average number of weather factors considered in each

forecast was highest in the cold front case, (M = 3.83, SD = 1.89) and lowest in the low pressure

case (M = 2.81, SD = 1.49), and in the middle in the high pressure case (M = 3.54, SD = 1.78).

This difference was statistically significant, F (0.05, 2) = 5.4, p < 0.01. The big increase occurred

between the low pressure and the cold front cases as confirmed by the Tukey's post hoc test, p <

0.01, in part because students were more visually attracted to the cold front than the low pressure

system that did not accompany any front. When students forecasted for the third time, students

began focusing more on the high pressure system indicated by the significant increase in the

number of weather factors between the low pressure and the high pressure cases, p < 0.05.

Insert figure 4 about here

Scientific Knowledge Use

Figure 4(c) shows the level of scientific knowledge expressed in explanations was highest

in the cold front (M = 2.27, SD = 1.73) and lowest in the low pressure (M = 1.27, SD = 1.06),

and in the middle in the high pressure (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 showed the significance occurred

between the low pressure and the cold front cases, $p < 0.001$. Scientific knowledge in students'

explanations appeared to improve as they repeated forecasting. Even though the high pressure

case was more difficult than the low pressure case as indicated by the weather specialist and the

prediction agreement score, students' explanations seemed to be more scientific in the high

pressure case than in the low pressure case.

Explanation Type

Figure 5 shows how students' explanations were classified. In the low pressure case,

system-based forecasts were rare for temperature (14 %), cloud (5 %), and wind (3 %). The

proportion of system-based forecasts increased for temperature in the next two forecasting days,

64 % for the cold front case and 42 % for the high pressure case. System-based cloud and wind

explanations also increased but not as much as system-based temperature explanations.

The type of explanation students provided was related to what type of weather factors

they considered. When students considered only a weather factor that was a part of their

prediction, i.e. temperature for temperature prediction, it was likely that making more forecasts

would not result in their ability to consider changes in 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 are formed and dissipated in the real world context though they commonly

cited the water cycle and the wind direction blowing from high to low pressures. Some students

offered explanations that were based on local signs. This type of explanations was different from

the system-based type of explanations because it often failed to recognize the relationships

between local signs that took place within the weather system.

Weather operates as a system. Even though three weather systems uniquely contributed to the changes in temperature, cloud condition, and wind direction, students did not always use them except in the case of the cold front. For pressure systems, temperature change can be estimated by considering the character of air from which the wind has been blowing. The wind direction should point away from the high pressure centre and towards the low pressure centre. Cloud conditions are also directly related to pressures. Around the low pressure centre the rising air facilitates the condensation process to make clouds. Around the high pressure centre the sinking air facilitates the evaporation process due to the temperature increase. These relationships are commonly known as a statement that 'Low pressure brings bad weather and high pressure brings fair weather'. So far, general patterns associated with real-time forecasting were presented. In the next section, more detailed descriptions of students' knowledge use in their explanations are discussed.

Insert figure 5 about here

Students' Knowledge Reflected in the Real-Time Forecasting Task

Several general patterns that demonstrate good and weak uses of evidence in the application of weather knowledge to forecasting were observed. Four are discussed here.

Weather systems

The aim of teaching weather systems was to show how weather elements were interacting within a system. When high and low pressure cells and cold and warm fronts were taught, students were expected to use these systems to predict temperature, cloud, and wind as necessary. However, students did not equally incorporate weather systems into their forecasting. Cold fronts were used more often by students to explain temperature, cloud and wind predictions as shown in the following examples:

Student A: 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 B: It will be partly cloudy because the cold front is pushing clouds. The high pressure creates winds that blow away clouds.

Student C: 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 the pressure distribution to estimate the wind direction such as 'because the wind is going from a high pressure that is going southwest' and 'the wind is going toward the low pressure'. However, most students rarely considered pressure to determine wind direction. Many students connected the wind direction with the movement of the cold front.

Relationships between weather elements

Some students used relationships between weather elements to predict the upcoming weather. An example of appropriate relationships was formed between cloud coverage and temperature change:

Student D: 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 was 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 packet rises, its density decreases, resulting in the lower pressure. Another misconception was to relate low (or high) temperature directly to cloud formation, '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 temperature reading is not a sole

indicator of cloud formation because clouds can form in any temperature range. More relevant

evidence for cloud formation was to consider dew point and humidity.

Weather system movement

Students in general had difficulty estimating the movement and strength change of

weather systems. Some students' forecasts were valid on the day they made forecasts not on the

next day. Other students thought weather patterns always moved from west to east. This

information was relevant to estimate the general movement of weather systems because of the

prevailing westerlies in the middle latitude. But this information created a problem that students

believed winds always blew from west to east in any place:

> Student E: 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 influence into their forecasting. Maybe this

was most difficult for them who were not familiar with the influence of local geographies on

weather. Large bodies of water affect weather due to the supply of humid air originated from

them. Mountains are important because they can force the air to go up or down depending upon

their slope. Rising (sinking) of the 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 F: 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.

<div align="center">Discussion</div>

Scientific inquiry is strongly advocated as a way to teach and learn science in k-12

classrooms by the National Science Education Standards (NRC 1996). Inquiry approaches intend

to develop deeper understandings about scientific knowledge by having students actively engage in how scientific knowledge is constructed. Authentic activities that are both faithful to science disciplines and relevant to students' everyday lives can be used for this purpose. Due to students' lack of knowledge, experience, commitment, and resources, their inquiry should be guided (Edelson 1998). To make scientific inquiry accessible to students, authentic practices of scientists need to be translated for students in terms of content knowledge, scientific thinking skills, and resources. The current research begins to look at the impact of authentic activities in improving conceptual understanding and developing inquiry skills. However, how authentic activities interact with the development of rich understandings about scientific knowledge is not well investigated other than the connection between performance improvement and motivational engagement (Rieber 1991).

This study investigated how sixth grade students performed on inquiry standards in real-time forecasting situations that required them to apply different content knowledge involving cold front, and high and low pressure systems. Results show a strong connection between forecasting situations and students' performance. Students performed best in the cold front whereas they had difficulty in the high and low pressures. Compared to the cold front situation, high and low pressure situations did not provide clear cases for such development because (1) the real situations were complicated by local geography and (2) the cold front concept was more flexible to be used in real situations than the pressure concepts. As a result, even though students learned about the impact of fronts and pressures on weather, they felt more comfortable applying the cold front concept to forecasting than the pressure concepts. In addition, students tended to apply weather systems more often with temperature predictions than cloud or wind predictions.

This study raises several issues regarding the utilization of authentic activities to develop rich understandings of scientific knowledge through inquiry.

Real World Situations That Map Closely to Students' Content Understandings

Real world situations are inherently complex even for professional scientists because they are ill-defined and contain so many uncontrollable factors. As a result, not all authentic real world situations can be used effectively for knowledge enrichment. Real world situations that closely match simple patterns in the knowledge students possess provide a better opportunity for them to apply their knowledge, i.e. cold front. When real world situations distantly resemble the way knowledge is previously acquired by students due to the involvement of factors other than what students have learned, i.e. local geography, they are likely to experience difficulty applying their knowledge or even resort to non-scientific reasoning such as intuition. Student performance in inquiry tasks is determined by two factors. One is the gap between the current status of students' knowledge and the knowledge requirement of the task (Linn 1982), and the other is ways students learn about the knowledge required in the task (Millar and Driver 1987). In order to make authentic situations accessible to students and contribute to the development of rich understandings about scientific knowledge, real world contexts should map closely from students' content understandings to the real world situations, i.e. cold front. Otherwise, the complexity of the situation will overwhelm students and reduce its effectiveness, i.e. low and high pressures.

Effective Scaffolds

Due to the lack of knowledge, scientific thinking skills, and resources (D. Kuhn 1989), learning about scientific knowledge in the realm of authentic real world situations can be difficult for students. Even though authentic tasks are characterized as ordinary practices of the culture of the science community, what scientists actually do cannot be directly used for students. Scaffolds at multiple levels are necessary for students to have meaningful experiences and practice scientific inquiry while they are engaged in authentic tasks. Content-rich inquiry

learning can happen when students are guided both conceptually to prompt what knowledge they need to activate and procedurally to prompt what ways knowledge should be used and improved (Davis and Linn 2000). Both social and physical environments can be sources for effective scaffolding. In the forecasting activity, the KGS CD-ROM provided weather maps and images organized to assist students in forecasting. Since this technological tool might not be optimally used every time students used it, a supportive network was created to connect the professional meteorologist, students, teachers, and the KGS research team through the web-based KGS message board. The help from the meteorologist was crucial in selecting the best possible cities for forecasting and explaining how the certain weather patterns occurred. The meteorologist's help reduced the burden that might be posed to teachers who did not have weather expertise and but still needed to explain the weather scientifically to students.

<u>Understanding Scientific Knowledge Beyond Simplistic Definitions</u>

The perceived value of authentic tasks is that they can help students achieve deep inquiry about scientific knowledge beyond simplistic definitions (NRC 1996). The power of scientific knowledge depends upon its applicability to a variety of problems. Similarly, robust and sophisticated scientific knowledge can be learned when students engage in a variety of settings, preferably in authentic situations, where knowledge is actually constructed and developed. Until recently the impact of authentic tasks on student learning of scientific knowledge was not explored due to difficulties associated with implementing authentic tasks in traditional science classrooms. In this study students were pushed to apply their knowledge about weather systems through real-time weather forecasting situations. Students' explanations about their predictions indicated a wide range of understandings about weather systems. Results showed students did not spontaneously apply knowledge about weather systems to forecasting clouds and wind direction and had difficulty applying high and low pressure concepts. Students demonstrated

misconceptions about relationships between meteorological entities, resulting in erroneous forecasting. Real weather situations can contribute to forecasting errors because factors such as local disturbances and geographies other than weather systems often strongly influence weather outcomes. Even though real world weather situations can complicate forecasting, they can also be used as opportunities for students to challenge and expand their understandings, recognize the need for in-depth understandings about weather knowledge, and experience uncertainty associated with current knowledge.

Implications for the Design of Authentic Tasks in Science

Developing higher order scientific thinking skills should be cultivated in the inquiry context. From the situated learning perspective, teaching scientific thinking skills to improve students' abilities to inquire is different from teaching them separately out of the inquiry context because of 'the relational interdependency of agent and world, activity, meaning, cognition, learning, and knowing' (Lave and Wenger 1991, p. 50). The acquisition of separate scientific thinking skills cannot guarantee that students will be able to perform scientific inquiry effectively with them and devour profound meanings of scientific knowledge. To create an inquiry context by using scientists' authentic practices, the translation of content knowledge, scientific thinking, and resources is necessary. The real-time forecasting activity presented in this paper was designed by applying the following sequence:

- Set learning objectives by reviewing national, state, and district standards and assessing students' needs.
- Select authentic practices of scientists that are relevant to achieving the learning objectives.
- Develop authentic tasks for students by examining the translation of content, scientific thinking, and resources used in scientists' authentic practices.
- Design iterative research on the translated products.
- Modify authentic tasks and resources based on outcome results towards balancing the tension between structured tasks and complexity involved in real world situations.

Results of this study suggest the modification of this activity. Even though what to consider in real-time forecasting was basically the same for all three cases such as interpreting weather maps and images, identifying weather systems, and considering geographical influences, students, in reality, did not exhibit equal performances because the knowledge required for each forecasting situation was different. If the learning objective is to see whether students are able to use front concepts in forecasting, then the cold front example will suffice this need. If it is to develop abilities to consider multiple factors in forecasting, then challenging examples like the high and low pressures will be appropriate.

<div align="center">Conclusion</div>

Unlike traditional teaching in science, inquiry approaches reflect how scientific knowledge is constructed, motivate students, and prepare them for lifelong learning. Inquiry approaches necessitate the use of authentic activities that are ordinary practices of the science community. Due to students' inexperience and lack of appropriate knowledge and inquiry skills, scientists' inquiry cannot be used directly. This study dealt with how to design effective authentic inquiry tasks for students to develop deep inquiry about scientific knowledge. Despite the complexity of real world contexts, authentic tasks can be effectively used for students' inquiry when they map closely from students' content understandings to the real world situations. Considering the growing enthusiasm towards using more authentic activities in science classes, further research on 'the contributions of learning activities to the learners' development of greater efficacy in their participation in valued social practices and to the development of their identities as capable and responsible learners' (Greeno 1997, p. 9) needs to be conducted to provide the best possible learning opportunities for students.

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Table 1. Inquiry Mapping

Essential features of classroom inquiry from table 2-5 (NRC, 2000, p. 25)	Inquiry manifested for real-time forecasting	Assessment
• 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)	
• 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)	
• Learner formulates explanations from evidence.	• Learner explains how temperature, cloud condition, and wind direction change with evidence.	• (Weather factors) 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 for 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
Weather Factors	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 that the future weather would be the same as the current weather.	Persistent: Tomorrow the wind will blow from southeast because the wind is coming from southeast today.
	• Local: The reasoning was based on the 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

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
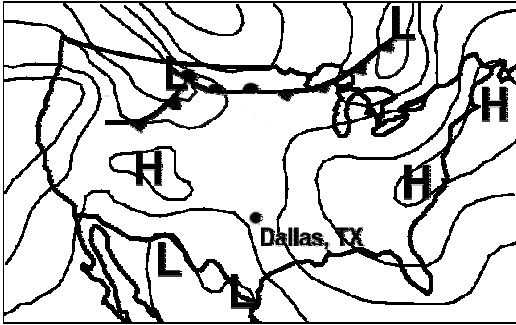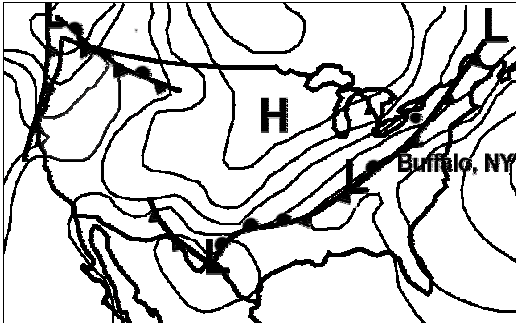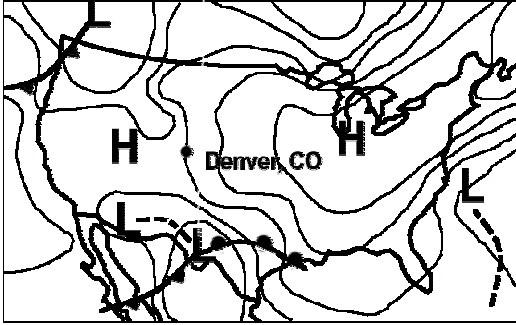
Figure 3. Three Days of Forecasting

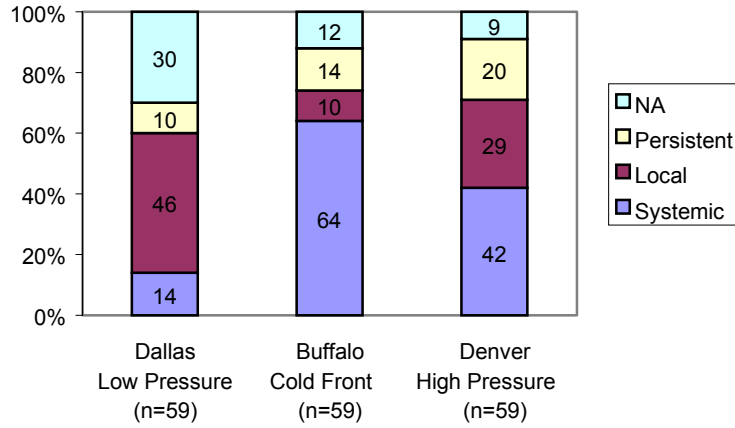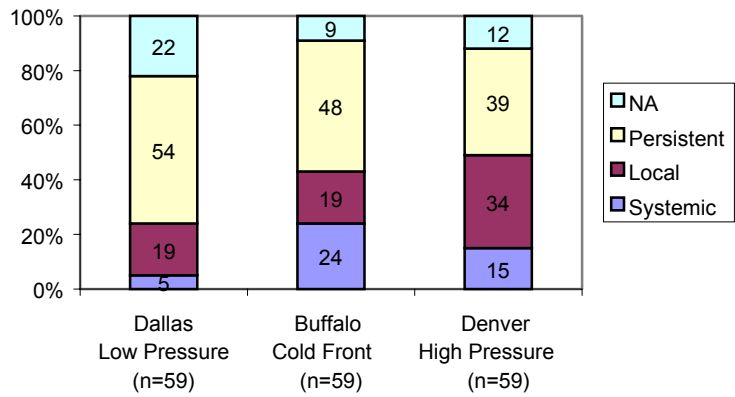| Weather situation when students forecasted	Major weather system	Knowledge for forecasting
03/14/2000, Dallas, TX 	On 03/14 a storm system was fuelled by the large amount of the warm and moist air from the Gulf of Mexico. As this system moved to Louisiana on 03/15, clouds gradually decreased toward 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) Weather Factors

(c) Scientific Knowledge Use
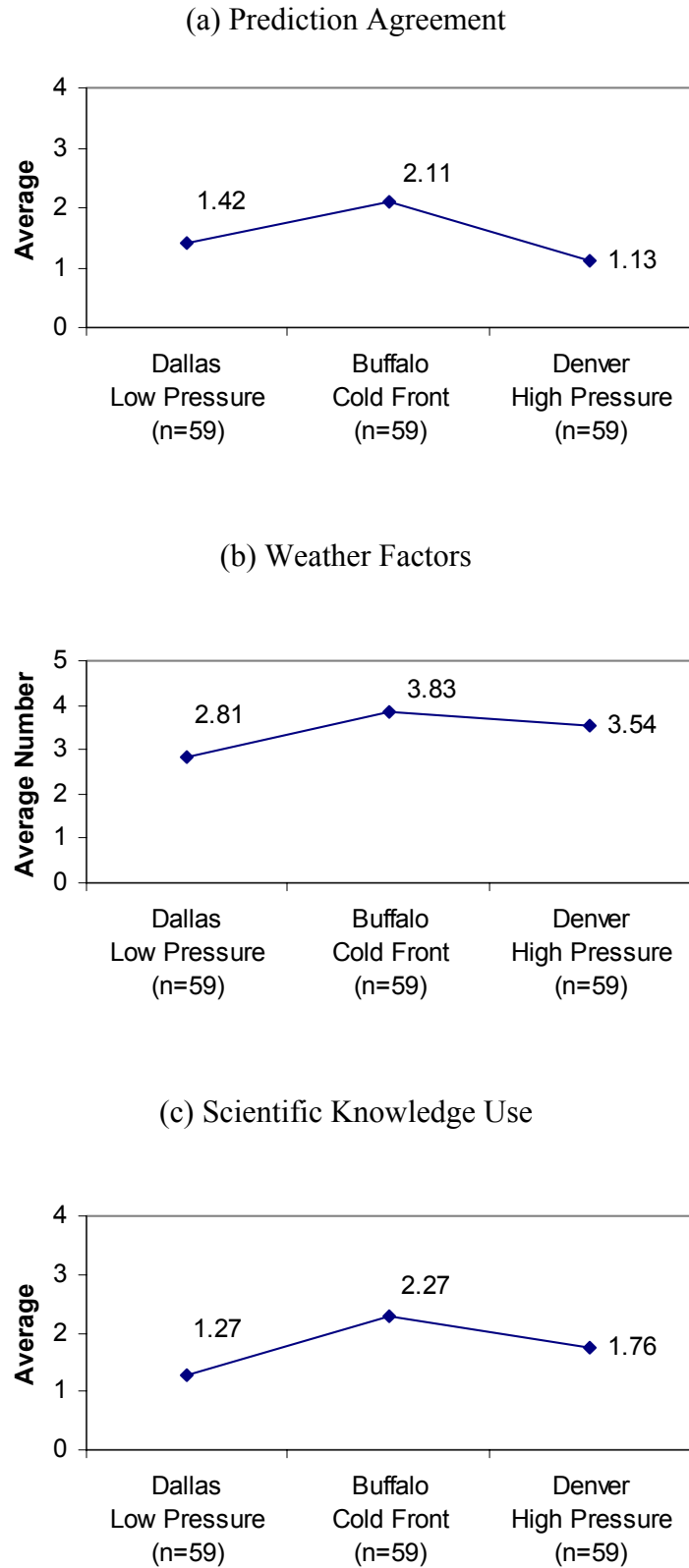
Figure 5. Explanation Type by Weather System

(a) Temperature

(b) Cloud

(c) Wind