# Science for Conceptual Understanding in an Inquiry-Based Learning Environment

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# Abstract

We created an inquiry-based learning environment where science was represented as inquiry and teaching and learning was also represented as inquiry. We understand science as a process of continuous inquiry seeking for better scientific knowledge which can more accurately explain scientific phenomena. In our program, One Sky, Many Voices: Hurricanes ’97, twenty-three elementary school students constructed their own meanings of Hurricanes through a variety of activities which hurricane scientists use in their process of inquiry. They benefited from coordinated activities, multiple representations, and the thematic organization of activities in our program while constructing the meaning of the Coriolis Force as a reason for hurricane formation and a determinant for wind direction inside a hurricane.

# Introduction

The National Science Education Standards (1996), as well as many others, proclaims scientific literacy for all Americans as a goal for science education in public schools. Scientifically literate citizens will be able to “use scientific information to make choices that arise every day and engage intelligently in public discourse and debate about important issues of science and technology”. Above all, they “deserve to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world”. (National Research Council, 1996, p.1). Scientific literacy requires a person to have a comprehensive understanding of the nature of science, not only the scientific knowledge itself but also the dynamic process that creates, modifies, and refutes scientific knowledge. To accomplish this goal of science education, the most popular approach in recent years has been inquiry-based science through which students can construct knowledge on their own by posing questions, experimenting, developing concepts and principles, and communicating with others.

Science is a process of continuous inquiry: “utilizing changing concepts, producing continuous reorganization and revision of its knowledge,” rather than a collection of dogmatic hierarchical knowledge (Schwab, 1962). The process of inquiry results in creating new knowledge or refining old knowledge. Unlike traditional science in the classroom where students passively receive scientific knowledge from the teacher, inquiry-based science claims to incorporate this dynamic feature of science into the science classroom where students participate as active learners in constructing their knowledge and applying that knowledge as a yardstick and inquiry as a process to problem solving situations in everyday life.

In preparing an inquiry-based learning environment for young students, the greatest difficulty lies in how to translate scientific knowledge into the process of inquiry in feasible ways which students can deal with. Due to complexity and abstraction, most scientific knowledge as scientists held by is intellectually challenging for students to conceive. It is even harder for students to learn scientific knowledge in ways that scientists discover it because scientists' inquiry process is not as linear as it appears in the process of questioning, hypothesis building, data gathering, data interpreting, hypothesis testing, and reflecting. Furthermore, scientists' inquiry process takes a long time to reach conclusions and needs sophisticated, reliable equipment to experiment. Therefore, without providing teachers and students with a thoughtfully designed inquiry-based learning environment, it would be almost impossible for students to follow scientists' inquiry process because of their cognitive, temporal, and resource limitations.

In this paper, we present our version of an inquiry-based science learning environment, One Sky, Many Voices: Hurricanes '97. We intentionally recreate an environment where students followed activities in ways that mimicked hurricane scientists' inquiry. Since new knowledge construction is one of the consequences of the inquiry process, we measured students' conceptual development in our program as a means of measuring the effect of our program on student learning. We choose the Coriolis concept for this purpose because it is relatively unknown to elementary school students, but it is critical in the scientific understanding of hurricanes. Based on our experiences, we will discuss implications for creating inquiry-based learning environment at the end of this paper. Before our approach in inquiry-based learning is taken into account, science learning in the context of inquiry in the literature will be examined.

## Inquiry Approach in Science Education

Inquiry has been in great favor among science educators for last couple of decades. In earlier years, inquiry has referred to either the outcome or the means of science instruction. The former approach focuses on delivering the inquiry process of science to students by providing facility in the scientific way of thinking and an accurate picture of the way scientific knowledge is generated in the past, and developing basic scientific attitudes. The latter is a teaching strategy where students construct their own knowledge in a specific area by following the inquiry process as an active learner. For classroom use of inquiry in science, we integrate these two views about inquiry instruction: students are learning science in an environment where science is portrayed as inquiry and teaching and learning are carried out as inquiry. As a result, students will be able to use inquiry in their everyday life.

## Science as Inquiry

Science has been developed in pursuit of scientists' inquiry in order to understand natural phenomena they observed, experiments they conducted, and theoretical inferences they made. Previous scientific knowledge gives scientists a tentative hypothesis for explaining natural phenomena or planning for their experiments. Scientists gather and interpret data to confirm or refine their previous knowledge, or they might end up creating new knowledge that explains more accurately than did the old. The new knowledge or refined knowledge gives another opportunity for scientists to follow their intellectual inquiry. The methods scientists use in data gathering and analyzing in the process of inquiry are standardized in their field of science. Scientific inquiry, therefore, is a driving force for scientists to construct and develop scientific knowledge and is carried out with scientific methods.

Inquiry is not a universal method or logic. “It is only a generic envelop for a plurality of concrete enquiries. Each one arises in relation to a specific subject matter and the essence of each lies in its own substantive conceptions, its own data, and its own questions asked and answered. It is enquiries in their plurality and concreteness with which we are concerned” (Schwab, 1962, p.103). For example, scientists may only redo the data collection part leaving hypothesis and data analyzing methods unchanged.

In relation to science education, “the treatment of science as enquiry is not achieved by talk about science or scientific method apart from the content of science. On the contrary, treatment of science as enquiry consists of a treatment of scientific knowledge in terms of its origins in the united activities of the human mind and hand which produce it; it is a means for clarifying and illuminating scientific knowledge.” (Schwab, 1962, p. 102)

## Teaching and Leaning as Inquiry

Since science itself is inquiry, teaching and learning science in the classroom should be perceived as inquiry. The traditional didactic teaching method would be adverse to inquiry-based instruction because students passively receive the products of science in fragmented, fixed nature, not in the dynamic feature. Also, teaching and learning inquiry does not mean that teaching and learning particular skills related to inquiry. Decontextualized inquiry skills from the substantial content will limit their application to real life (Millar & Driver, 1987).

Similar to scientific inquiry in the knowledge context as Schwab said, the *National Science Education Standards* (1996) emphasizes understanding scientific knowledge in the process of inquiry in science class:

**Knowledge and Understanding**

> Implementing the National Science Education Standards implies the acquisition of scientific knowledge and the development of understanding. Scientific knowledge refers to facts, concepts, principles, laws, theories, and models and can be acquired in many ways. Understanding science requires that an individual integrates a complex structure if many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events. Understanding encompasses the ability to use knowledge , and it entails the ability to distinguish between what is and what is not a scientific idea. Developing understanding presupposes that students are actively engaged with the ideas of science and have many experiences with the natural world. (National Research Council, p. 23)
>
> **Inquiry**
>
> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.
> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (National Research Council, p.23)

Recognizing importance of inquiry in science education, researchers developed projects with an effort of incorporating inquiry into the science classroom. In the Project-Based Science approach, students, on their own, made questions in science units, designed investigation procedures, and carried out investigations, and answered their questions. In doing this students construct the knowledge of their interest by following the inquiry process (Krajcik, Blumenfeld, Marx, & Soloway, 1994). As an inquiry-based learning approach, Tinker favors this project-oriented science curriculum for further student inquiry and investigation (Tinker, 1996). Brown & Champion (1994) take a middle-ground approach of didactic teaching and discovery learning (guided discovery) realizing that students are not able to enjoy the full authority of discovering and rediscovering ideas in science. Rather, questions and methods are guided by the teacher who will select appropriate areas of science and orchestrate the discovery process. (Brown & Champione, 1994). The difficulty of leaving responsibilities to students in knowledge construction process is also noticed by Magnusson & Palinscar. They recommended guided inquiry by the teacher for elementary school students from grade one to five. (Magnusson & Palinscar, 1995)

From all those approaches for inquiry learning in science class, several elements are in common. In inquiry-based classrooms, students, first, are active learners to develop their own understandings of scientific knowledge. Second, the role of a teacher becomes more sophisticated and complex to accommodate different learning paths of students in encouraging them to explore their ideas and facilitating their process of knowledge building without the teacher's direction or interruption. Third, science represented in student activities is not a fixed, dogmatic knowledge or process, but is represented in multiple ways of understanding the nature by coordinated efforts of many scientists.

In implementing such inquiry-based learning into the real science classroom, we consider the extreme amount of a teacher's effort necessary for collecting resources for student investigation, organizing activities, and, most of all, changing her views about teaching and learning science. Because there are not many teachers who have sufficient confidence in teaching content knowledge and in managing the classroom in terms of new teaching strategies with which they are not familiar, we provide an inquiry-based learning environment for those teachers and their students. In our Hurricanes '97 program, students can reach the science behind hurricanes in multiple ways as scientists use in pursuit of their inquiry and construct the knowledge about hurricanes by refining and modifying their previous knowledge whenever they experience different aspects of hurricanes. The program provides multiple resources for students' own investigations and teacher's reference such as curriculum CD, Internet web sites associated with hurricanes, and hurricane specialists and peers through our electronic message board. See Lee, Y.

J. & Songer (1998) for technology use in our program. In the next section, we will present the Hurricanes ’97 program more in depth.

## The Hurricanes ’97 Program

### Hurricanes ’97

Hurricanes ’97 is a four-week middle school science curriculum. Through a variety of activities, students come to understand hurricanes scientifically and personally in relation to their real life. There are several advantages for students to be engaged in the activities about hurricanes in our program:

- Motivation: Hurricanes can easily attract students’ attention as one of the nature’s majestic phenomena.
- Prior experience: Most students have already been exposed to hurricanes in their everyday life either by media or in person, so they can start learning hurricanes from their experiences.
- Multiple learning paths: Hurricanes can be understood at various levels, from observation-based understandings to statistical understandings, to causal understandings, so that students can develop their understandings at different levels based on activities they follow during the program. A teacher will choose activities for her students considering her and her students’ needs and resources and time available.
- Communication: Students have an opportunity to communicate with others who live both in non-hurricane regions and in hurricane regions.

Activities are arranged starting from the personal perspective in Week 1, moving to the science perspective in Week 2 and 3, and ending with the personal perspective in Week 4. This sequence not only engage students in more intellectually challenging activities as they learn more about hurricanes, but also help students relate their knowledge to real-life situations. Hurricanes ’97 is organized as follows.

Week 1: An introduction: Hurricanes and You

Students define a hurricane in their own words based on their investigations of informational resources such as Internet, multimedia (Hurricanes ’97 CD), and library books. After the first attempt to define a hurricane, students exchange their definitions with other groups inside the classroom, or, if possible, outside the classroom by using the world wide web message boards located at the Hurricanes ’97 web site (http://www.onesky.umich.edu/hurricanes97) to be critiqued. Students revise their definitions based on the critiques they receive from others and post their revised definitions to the same message board. See Lee, S. -Y. & Songer (1998) for details about the use of the message board in our program.

Week 2: Where Do Hurricanes Come From?

Students investigate the scientific cause of a hurricane in the “Exploring the Coriolis Force” activity, which will be discussed in depth later. They also measure their local weather such as temperature, air pressure, wind speed and direction so as to make sense of the range of typical measurement readings in their local weather and differences in readings between hurricanes and local weather.

Week 3: Becoming a Hurricane Scientist

This week students use data tables, charts, and graphs to track the previous tropical cyclones such as hurricanes, tropical storms, and tropical depressions. If there is a real-time tropical storm or a hurricane, students use the real one instead of previous ones. Finally they apply their knowledge to a simulated hurricane in the “Hurricane Prediction Game” on the CD to predict its position and strength and save people and properties by issuing hurricane warnings or watches to cities along the coast. Also, the prediction game can use a real-time tropical cyclone, if there is one.

### Week 4: What If a Hurricane Hits?

Students discuss about potential damages of a hurricane on human beings and possessions and learn safety procedures to protect people and properties from the natural disaster. They also compose a personal story that reflects what they have learned about hurricanes during the previous four weeks.

## “Exploring the Coriolis Force” Activity

“Exploring the Coriolis Force” is an activity in the second week, helping students learn about one of three major factors of hurricane formation: warm ocean water, Coriolis force, and upper-level wind pattern. The Coriolis force is a fundamental concept in understanding why a hurricane rotates in a certain direction depending on which hemisphere it is located. The winds inside a hurricane in the Northern hemisphere rotate counterclockwise and those in the Southern hemisphere rotate clockwise. The “Exploring Coriolis Force” includes a hands-on experiment, a minds-on experiment, and a classroom discussion.

### Part I: Hands-on experiment

The first part of the activity shows how an object moving in a straight line in a resting frame of reference can be seen in another rotating frame moving either counterclockwise or clockwise. First, students build a system as shown in Figure 1 (a). The circular cardboard 1 and rectangular cardboard 2 are attached each other at the center of the circle with a pin, so that cardboard 1 can rotate freely as a student spins it. The strip fixed on the cardboard 2 represents the track of an object moving in a straight line on the cardboard 2. A student draws a straight line along the strip from the center of the circle when the two pieces of cardboard do not move. Students will see a straight line on the cardboard 1 in this trial. While a student rotates the cardboard 1 counterclockwise relative to the cardboard 2-this is simulating the earth rotation seen above the North Pole, another student draws a straight line from the center along the strip on the cardboard 1. The line on the rotating cardboard 1 appears to be curved to the right. If a student rotates the cardboard 1 clockwise simulating earth rotation as seen above the South Pole, the line appears to be curved to the left. See Figure 1 (b).

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Insert Figure 1 here
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Part II: Minds-on experiment with the animated glossary in the Hurricanes ’97 CD-ROM

Students begin this part by reviewing the most important features of the force: The Coriolis force is a fictitious force observed only when an object is moving on the moving reference frame. If either the earth is not rotating or an object is not moving, the force cannot be detected. When students click “Coriolis Force” in the glossary in the CD-ROM, students will see the animated pictures of a plane flying downward to Chicago from the North pole. The plane moves from the Pole, leaving dots on the previous locations. The animation consists of 10 consecutive frames and plays with the rate of 5 frames/sec. see Figure 2. It is very clear for even young students to recognize the effect of the Coriolis force that a plane flying in a straight line in space will be seen as curved to the observer on earth. Students also can view the same phenomenon in the Southern Hemisphere except direction of the Coriolis force.

In the glossary, students can also view the video clip of a ball thrown by children sitting on the merry-go-around. It shows that when the merry-go-around rotates counterclockwise one cannot pass the ball to the person sitting in front if one throws the ball just straightforward. Instead, the ball goes to the person who is sitting on the right side. This video-clip also shows the actual path of the ball as seen in space, so students can compare two tracks: one is going curved as seen by children sitting on the rotating merry-go-around and the other is going straight as seen in the space which is not rotating.

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Insert Figure 2

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## Data Collection

### Subjects

23 fourth graders in an elementary school participated in the Hurricanes' 97 program for 5 weeks. The school was located in the Midwestern part of the United States where a nearby state university affects local economy, cultural diversity, and the educational level of the whole population. The participating teacher was involved in our project for a year and a half and this program was his third participation. His role in our project could be best described as a collaborator because he adopted our program considering the student needs in conjunction with his needs for innovation in his science class.

One third of the students were boys, and three of them had minority ethnic backgrounds. There were three special-ed students in the classroom who, sometimes, received different lessons in mathematics and writing. The three, however, participated in all of the activities in our program even if the activities were pretty challenging for the rest of the students. All 23 students took the pre-test, but only 21 of them took the post-test because one student moved to another state in Week 3, and the other student was absent when the post-test was taken. Typically, students were working in groups of 3 to 4.

### Field Notes

The "Exploring the Coriolis Force" activity took three periods of class time in total. Each class period lasted 45 minutes. Students did the hands-on part in their classroom in the first day and moved to the computer lab for the second minds-on part in the following day. In the third class, there was a classroom discussion among students about the Coriolis force in terms of its application to hurricanes guided by the teacher. The field notes were taken for these three days.

### Pre- test and Post-test

In the ball problem in Figure 3 (a), students were asked to draw the path of a ball thrown away from the North and South Poles. This item appeared in both pre- and post-tests. The purpose of this question was to diagnose whether students already had any sense of the Coriolis force before the actual activity, and to measure the changes in their understandings of the force after the activity. In addition, the pilot problem in Figure 3 (b) was asked during the post-test to see whether students could apply their understandings about the force to another situation. The pre-test was taken before the program started, and the post-test was taken 2 weeks after the program ended.

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Insert Figure 3 here

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### Student Interviews

8 students were selected to be interviewed- three from high, three from medium, and two from low achievers, based on classroom observations and the teacher’s recommendation. The interview was carried out after the Hurricanes ’97 program, but before the post-test was taken by all the students. In the interview, the students were asked about the two items in Figure 3 and other Coriolis force- or hurricane-related questions. Each interview lasted approximately 10 to 15 minutes and was video-taped. During the Interview some students were allowed to draw the tracks of the ball or the plane if it is necessary for them to represent their ideas.

## Data Analysis

### Coding

Students’ understandings were measured in two ways. One was classification measure, and the other was reasoning measure. To assess levels of students’ understandings about the Coriolis force, we adopted the Klausmeier’s definition of conceptual understandings at the different levels and reorganized for our purpose (Klausmeier, 1985). His original levels of conceptual understandings were concrete, identity, classificatory, and formal. We added “no conception” to his categories and combined concrete and identity as “naive”. “Intermediate” was the same as his “classificatory”, and “formal” remained the same as what he used as “formal”. The characteristic and criterion of each level of conceptual understanding is listed in Table 1.

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Insert Table 1 here

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## Classification Measure

There are two examples of the Coriolis force in the tests, the ball problem and the pilot problem. If students could successfully predict either in the ball problem or in the pilot problem, they were classified as “naive”. If students could correctly predict both problems, they were considered as having the intermediate level of understanding. If students could apply the concept to other situations in order to differentiate examples of the Coriolis force from non-examples, they had a formal level of understanding. If students had no idea about the force, their responses were considered as “no conception”.

## Reasoning Measure

If reasons for students’ answers were totally unacceptable in the scientific point of view, for example, “because big snow stops the ball” or “the air plane needs to stop at several airports for fuel”, they were classified as “no conception”. If students showed observation (experience)-based reasons such as “I experimented it” or “The ball/airplane will be curved”, they had “naive” reasons. If students could include the concept of earth rotation, comparison of the tracks of moving objects in different hemispheres, or use “Coriolis force” in their explanation, they had an “intermediate” level of understanding. If students could explain their answers quantitatively as well as qualitatively by using the following attributes of the force, they were considered to have the formal level of understanding as scientists have.

- Coriolis force is a fictitious force.

- The amount of the force affecting the path of a moving object on earth depends on latitude and the angular velocity of the earth. Therefore, the Coriolis force does not appear right above the equator and increases as latitude increases from the equator.

## Results

### The Ball Problem

The change of student responses to the ball problem between the pre-test and the post-test is apparent as shown in Table 2. Only one student drew curved tracks, which were wrong, of a moving object in the Northern and Southern Hemispheres in the pre-test. Even if most of the students knew earth is rotating, they did not know the effect of the earth rotation on a moving object before they learned about the Coriolis Force. In the post-test, 86 % of the students (N=21) drew curved tracks, and 67 % of them illustrated their prediction in the right way. This change was statistically significant: $t(.05, 20) = 5.16$, $p < .001$.

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Insert Table 2 here

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When students took the post-test, they seemed to recognize the earth's rotation affected the tracks of moving objects and showed that the tracks of the ball in two different hemispheres would not turn in the same direction. In the post-test, all but three students drew two curved tracks in the opposite way. The reasons for their answers changed from no conception (43 %) & naive (26 %) in pre-test to naive (33 %) & intermediate (43 %). This change is also statistically significant: $t(.05, 20) = 3.18$ and $p < .01$. After the Coriolis force activity their reasons became more scientifically plausible and sophisticated than before the activity. In student interview, one student said of the reason for why the track of the ball appears to be curved to the observer on earth:

> S1: Because mm...this has to do with the Coriolis force...Coriolis force is rotation...like if you are going to throw a ball on any one of the...to make it straight down...I mean it would still go straight it just wouldn't land the place where it would want to.
>
> *[intermediate level of understanding]*

He realized that the Coriolis force is a fictitious force observed by the person on a moving reference frame. Here is another reason from a student who answered the ball problem in an opposite way from the right answer:

> S2: Because the main reason is because m....well, m... no one can throw a ball straight...because unless you are in three feet away, but...if you gonna throw a ball from the North Pole to the South Pole that's like thousand feet away or more...or miles away. So,...so it's gonna curved eventually.
> I: Because...
> S2: Because...the wind and atmosphere?
> I: How did you know the track of the ball curved like that?
> S2: Well, I guessed kind of and then I know...because sometimes throw a ball to my friends one time and I stood...m...I stand...I stood on a porch and my...it was a pretty high porch and m...she was standing like on the ground. It kind of curved...and then, when she threw back, it curved in opposite direction.
>
> *[novice level of understanding]*

Why she could not correctly answer is partly because her reason is based on uncertain recollection of her previous experiences in the classroom rather than scientific understanding of the concept.

### The Pilot Problem

The purpose of the pilot problem was to see whether students could apply the Coriolis force to a different situation. As shown in Table 3, 57% of students could correctly decide the initial direction of the airplane that makes the air plane safely arrive at Chicago. 43% of the reasons indicated the intermediate level of understanding of the force while 28.5% showed naive reasons, and 28.5% either showed non scientific reasons or did not answer.

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Insert Table 3 here

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Because the pilot problem is not realistic based on students' everyday life- there is no airport at the North Pole, and, according to the typical airplane schedule, an airplane can stop by any other airports during the flight, some students used their everyday experience-based reasons, rather than science-based reasons. One example of this sort is "because it is a way you can stop for gas more if you need it." On the other hand, one interviewee showed her reasons that were firmly-grounded on the Coriolis concept:

> S4: It wouldn't go straight, so it should curve to the left or right depending on which hemisphere he is in.
> I: This is in the Northern part of the earth.
> S4: Northern part? OK. It would go like this [indicating the initial direction of the plane toward southeast (left)]
> I: Why do you think his plane has to fly that way?
> S4: Because the Northern Hemisphere is going counterclockwise, counterclockwise as I said always goes to the…wait a minute...m...it [airplane] goes to the right.

In the post-test, she was the one who explained her tracks of the moving balls in the Ball Problem: "I always remember North Pole- R [right] & South P - Left." In her case, she remembered the concept as a formula. Another student gave an Intermediate level of reason to this problem:

> S5: He wouldn't wanna go in just straight line, he would want to go a little more *[drawing the track of the airplane a little bit curved to the left from the straight line between the North Pole and Chicago]* because the earth is spinning and so he wouldn't go just straight. If he would, he would land in the ocean because of the coriolis thing. If you were in the North Pole and the earth is spinning, he would go dan, dan, dan, right here. *[Then, he drew the entire track of the plane in a way that makes the plane arrive at Chicago]*

### Stage of Conceptual Development

Out of 21 students who took both pre-test and post-test, 38% of them could identify the example that they learned in the classroom (the Ball Problem) and apply to the new problem (the Pilot Problem). According to our definition of the "intermediate" level of understanding as "consider at least two different examples of a concept equivalent," these students showed this level of understanding. 33% of students who successfully predict the result of either the ball problem or the pilot problem were classified as having the “naive” concept because they identified the concept in only one situation and did not recognize the similarity among two cases. 29% were not successful to correctly answer both problems.

### Further Application of the Coriolis Force

In student interviews, five out of eight students thought that a hurricane could not form right above the equator with almost the same reason: “because in the Northern Hemisphere, it [hurricane] turns counterclockwise and in the Southern Hemisphere it [hurricane] turns clockwise ...and it won’t have a way to turn right above the equator.” Probably, this is the best reason the students could think based on their learning experiences. Because the Coriolis force is expressed as a function of sin($\theta$ = latitude), it is zero on the equator and maximum at the pole. This reason students to explain not having a hurricane on the equator was drawn from their best of knowledge, and it was still scientifically plausible.

## Discussion

Acquisition of scientific knowledge should be understood as a stepping stone for carrying out genuine student inquiry and further investigations. The Coriolis force example discussed in this paper shows an environment in which students constructed their meaning of the Coriolis force and applied this meaning to other examples of the force. When the Hurricanes ’97 program was drafted in the summer of 1997, it was controversial whether or not the Coriolis force should be introduced as a reason for hurricane formation and a determinant for wind direction inside a hurricane. The concept of “Coriolis force” is not easy for elementary school students, even for secondary school students, who have weak concepts about force, velocity, angular velocity, and momentum to understand. The first time students encounter the concept in a normal K-12 school science curriculum is when they are in the middle school. But the demand for providing an inquiry-based learning environment in our program drove us to include the concept not in the format of just telling the concept to students, but constructing the meaning of the concept on their own through multiple activities. In the following, what we learned about our program from an elementary classroom in our effort of creating an inquiry-based learning environment will be discussed at the representation, activity, and curriculum level.

### Representation Level: Multiple Representations

In representation of Coriolis force with multimedia, we lower the level of abstraction of the concept by avoiding mathematical formula and using animated pictures. Why teaching the Coriolis force is difficult is that students might not have direct experiences with the force which affects the motion of an object on a rotating system in their everyday life. Neither still images nor detailed text-based information are helpful for students to understand the dynamics of the force. The animated pictures of the flying plane and the merry-go-around in the CD-ROM seemed to be very effective for young students to understand. This computer assistance greatly enhances students’ learning abilities to conceive the effects of the force in a macroscopic level as seen in the plane example and in a microscopic level as seen in the merry-go-around example. Multimedia has been particularly useful for explaining the dynamic nature of certain phenomena such as protein synthesis, mitosis, and meiosis in biology (Johnston & Kleinsmith, 1987) and chemical equilibrium in chemistry (Kozma et al, 1993).

### Activity Level: Combined Experiences

Not only selection of appropriate educational media, but also thoughtful integration of multimedia with student activities such as hands-on experiment would be very productive to promote student learning. Also, integration of multimedia with other learning strategies such as group discussion and good guiding questions can maximize the educational potential of learning with multimedia. “Exploring the Coriolis Force” is a combined activity of hands-on experiment, minds-on experiment, and classroom discussion. Experiencing the concept in various ways seemed to benefit students with different learning preferences. After the activities students were asked about which way was useful for them to understand the concept. The most useful experience was the CD- ROM for 50 % (n = 10) of the students and both the CD-ROM and the hands-on experiment for 45 % (n = 9) of the students, while the hands-on experiment was the most useful for only one student. Even if different kinds of learning experiences were introduced, some portion of students still think that learning from people such as teachers and other students would be the most valuable resource. One student responded in the Interview as follows.

> I: Can I ask where you get this information [about the Coriolis Force]?
> S2: I got it from...basically people.
> I: People?
> S2: Ya.
> I: Could you name some people?
> S2: my class, my team mates, and...my teacher.
> I: OK, how about the CD-ROM? There was an animation about the force.
> S2: Ya, I think it helped me, too.
> I: But it’s not helpful?
> S2: It was helpful, but it isn’t as helpful as I planned.

## Curriculum Level: Connection to Other Activities

Acquiring knowledge itself should not be the end point of learning, but the starting point for doing something more interesting, challenging, and useful to students. In Hurricanes ’97 program, once students knew phenomenological wind patterns of hurricanes in the “What is a

Hurricane?” activity, they discovered the scientific reason for the wind patterns in the “Exploring the Coriolis Force” activity. Then, they applied the concept to more sophisticated applications of the force in the “Tropical Storm Discovery” activity. In this way, students could test what they knew about the force, develop the Coriolis force concept in a deeper level by revision and modification, and apply the concept to real data about hurricanes and tropical storms. Such an internal structure of activities in a science program would be a critical component of an inquiry-based learning environment because students can construct their knowledge through multiple ways of pursuing their inquiry.

## Implications for Creating an Inquiry-based Learning Environment

In inquiry-based leaning environment, students typically spend more time making sense of each concept in more depth than in the didactic teaching. Students have a potential to learn very complex concepts at their own cognitive level if their learning experiences are designed in ways that reduce the cognitive load required to understand the concepts. Setting the appropriate level of understandings for students, multiple representations by using multimedia, and combined learning experiences would contribute to achieving this potential.

To do this, first, we need to decide the core concepts that are most important to be taught in K-12 science class and clearly establish the levels of understanding that students need to achieve at the particular grade level. Required levels of understandings would vary depending on science content and prospective students. We may expect elementary students to have a formal level of understanding if a concept is easy enough to understand. But most scientific concepts require students to have proper cognitive abilities and background knowledge. In this case, students may be asked to have an intermediate level of understanding (White, 1998). Qualitative understanding of the concept may be appropriate for younger students while quantitative understanding is relevant for older students. Definitely, through one or two activities, we cannot expect students to have a formal level of conceptual understanding, but we can expect them to have an intermediate level of understanding. If students can have an intermediate level of conceptual understanding, they can extend the concept further as they learn the concept in depth in further education. The intermediate level of understanding of a concept should be scientifically correct, but less in depth, so it would become a basis for the further development and is, in itself, sufficient enough for students' own inquiries at the time when they learn about the concept.

## Conclusion

This paper shows how elementary students developed an understanding of the complex concept of Coriolis force. The Coriolis Force is believed to be hard for young students, who conceive very primitive ideas about physical concepts such as force, angular velocity, and vectors, to learn. But, in our inquiry-based learning environment where students spent more time making sense of the scientific concept by doing a variety of activities and applying them to different, but conceptually-related situations, they were able to construct their own meanings of the concept. Our program provides the coordinated package of student activities, learning resources, and communication tools for even teachers who have limited experiences in inquiry-teaching to implement the program.

We created an Inquiry-based science learning environment by selecting a good scientific theme, considering what kinds of concepts and activities around the core theme are beneficial and functional for students' further inquiry, defining representation levels of scientific knowledge, and taking advantage of all kinds of resources which have their own strengths on student learning.

Above all, in our program we portray science about hurricanes as inquiry by simplified, but still comprehensive enough for students to explore hurricanes as scientists do. If these efforts were generated across science curricula K-12, it would be much more effective for students to learn scientific knowledge in the process of inquiry than were generated from a single science curriculum.

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Table 1

Levels of Understandings of a Scientific Concept and their Application to the Coriolis Force

| | **Description by Klausmeier** | **Criteria for the Coriolis Activity** |
|---|---|---|
| No Conception | Students have no idea or experience they can refer to. | Students do not relate the rotation of the earth to the motion of a moving object. Students may or may not know the earth rotation. |
| Naive | Students attend to something one or more times; discriminate it from other things; remember it; and then later attend to, discriminate, and recognize it as the same thing.<br>Students recognize an item as the same one previously encountered when observed in a different context. | Students explain the Coriolis force by the example that they have already experienced.<br>Students describe the motion of a moving object appeared to the observer in each hemisphere. |
| Intermediate | Students consider at least two different examples of a concept equivalent. | Students can apply the Coriolis force in the broader context (many examples). |
| Formal | Students correctly identify examples of the concept, name the concept, and indicate how examples of the concept differ from non-examples. | Students understand the Coriolis force quantitatively as well as qualitatively like a scientist.[1]<br>Students relate the concept to other attributes such as angular momentum. |

Table 2

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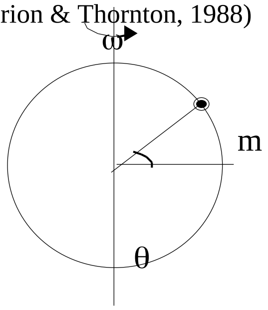
[1] The motion of the earth with respect to an inertial reference frame is dominated by the earth's rotation about its axis, the effects of the other motions (revolution about the sun, motion of the solar system with respect to the local galaxy, etc.) being small by comparison. The angular velocity vector $\omega$, which represents the earth's rotation about its axis, is directed in a northerly direction. Therefore, in the Northern Hemisphere, $\omega$ has a component $\omega_z$ directed outward along the local vertical. If a particle projected in a horizontal plane (in the local coordinate system at the surface of the earth) with **v**, then the Coriolis force becomes

$$\mathbf{F}_{\text{Coriolis}} = -2m\,\omega \times \mathbf{v}$$

Magnitude of the force: $|\mathbf{F}_{\text{Coriolis}}| = -2m\omega v \sin\theta$

Direction: to the right of the particle's motion in the Northern Hemisphere and to the left in the Southern Hemisphere. (Marion & Thornton, 1988)



Summary of the Analysis for the Ball Problem

(a) Path prediction

Northern Hemisphere (Percentage of students)

| | straight | **right** [a] | left | stray | didn't mark |
|---|---|---|---|---|---|
| Pre-test (N=23) | 88 | **0** | 4 | 4 | 4 |
| Post-test (N=21) | 14 | **57** | 29 | 0 | 0 |

Southern Hemisphere (Percentage of students)

| | straight | right | **left** [b] | stray | didn't mark |
|---|---|---|---|---|---|
| Pre-test (N=23) | 83 | 4 | **0** | 9 | 4 |
| Post-test (N=21) | 14 | 29 | **57** | 0 | 0 |

Note. [a, b] is the right answer.
The change between the pre-test and the post-test is statistically significant:
t(.05, 20) = 5.16, *** p< .001

(b) Reasons for students' answers (Percentage of students)

| Level of Reasons | Pre-test (N=23) | Post-test (N=21) |
|---|---|---|
| Formal | 0 | 0 |
| Intermediate | 9 | 43 |
| Naive | 26 | 33 |
| No conception | 43 | 14 |
| No answer | 22 | 10 |

Note. The change between the pre-test and the post-test is statistically significant:
t(.05, 20) = 3.18, ** p < .01.

Table 3

Summary of the Analysis of the Pilot Problem

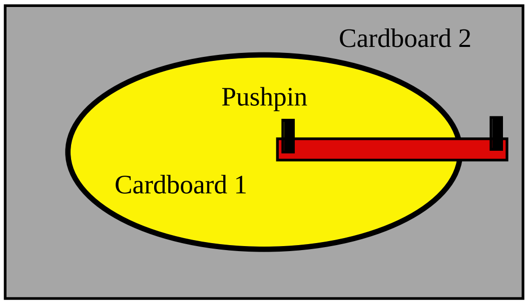
(a) Direction for the air plane

| | straight | right | **left*** | stray | didn't mark |
|---|---|---|---|---|---|
| Post-test (N=21) | 0 | 6 | **12** | 2 | 1 |

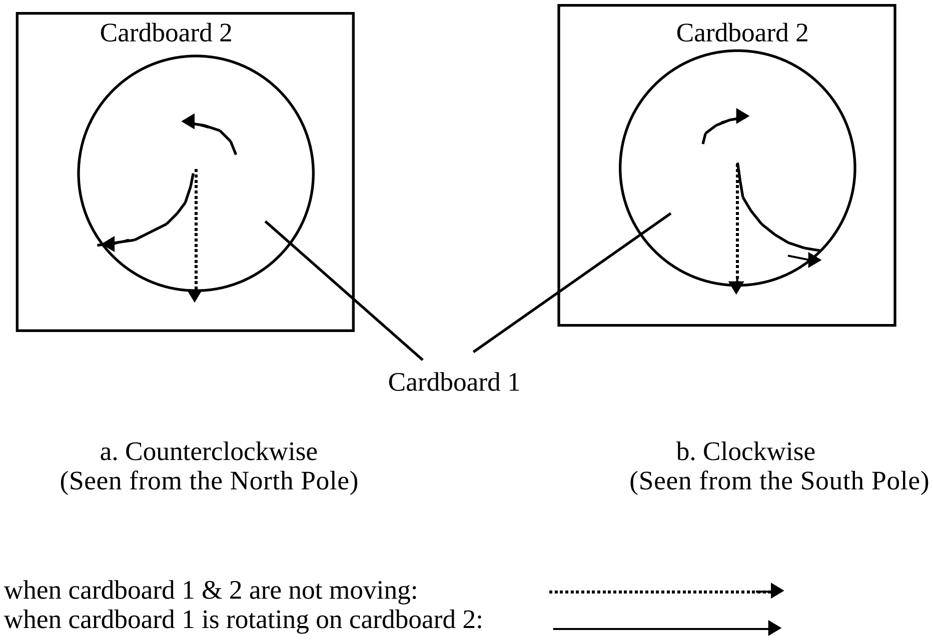
Note. * Left is the right direction for the airplane to arrive at Chicago airport. The initial direction of the plane at the North pole was coded.

(b) Reasons for students' answers (Percentage of students)

| Level of Reasons | Post-test (N = 21) |
|---|---|
| Formal | 0 |
| Intermediate | 43 |
| Naive | 29 |
| No conception | 19 |
| No answer | 9 |



(a) Setting

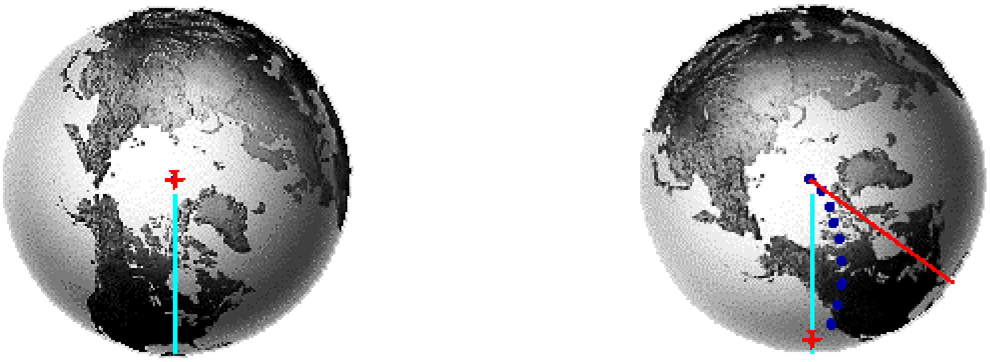


a. Counterclockwise
(Seen from the North Pole)

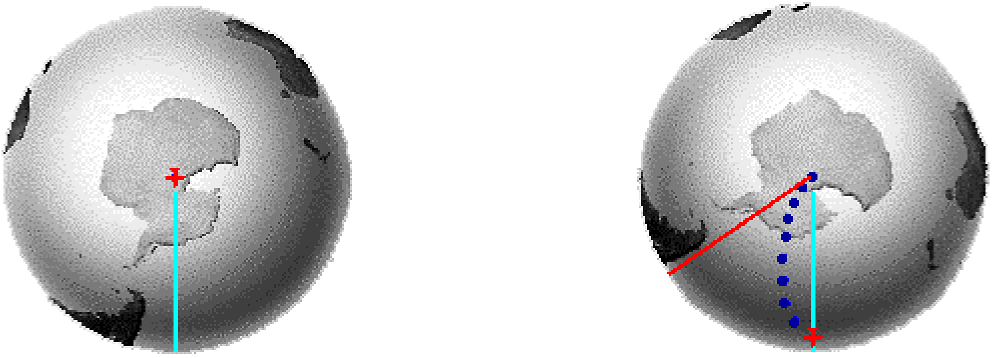
b. Clockwise
(Seen from the South Pole)

(b) Results: The tracks of moving objects on the rotating system

Figure 1. Hands-on experiment in “Exploring the Coriolis Force”



(a) In the Northern Hemisphere:
The air plane flying in a straight line in space will be curved to the right on the rotating earth.



(b) In the Southern Hemisphere:
The air plane flying in a straight line in space will be curved to the left on the rotating earth.

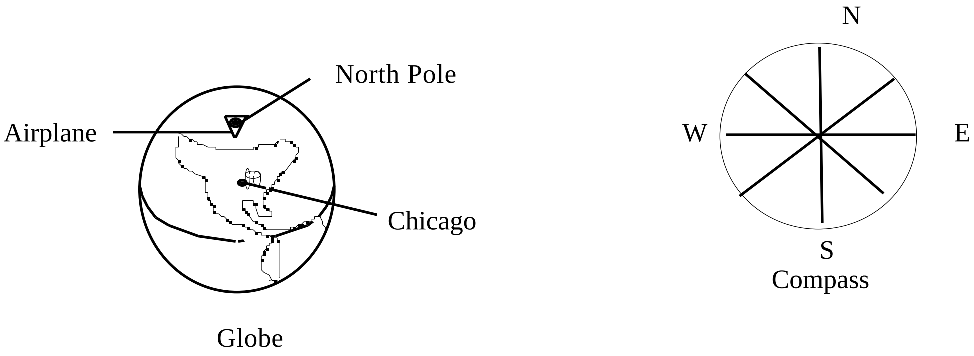
Figure 2. Effects of the Coriolis force on the motions of air planes flying from the poles

Suppose you throw a ball away from the North/South Pole on Earth. Draw the path of the ball on each circle using an arrow.

Explain your answer.

(a) The Ball Problem

There is a pilot who will fly his plane from the North pole to Chicago airport. Indicate the direction that will make his plane safely arrive at Chicago airport either on the globe or on the compass.



Explain your answer.

(b) The Plane Problem

Figure 3. Two problems associated with the Coriolis force