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ABSTRACT

This study assesses the influence of a set of activities developed based on preservice elementary science teachers' conceptions of the nature of science (NOS). It also compares the effectiveness of these activities when implemented using two approaches. The first approach was a direct explicit approach while the second featured additional reflective components. The reflective components included written and oral discussions about the elements of the nature of science throughout the courses in the second cohort. Results show that prior to instruction, most students in both cohorts believed in a single scientific method that guarantees the objectivity of scientists and scientific knowledge. All students held either an hierarchical view of the relationship between scientific theories and laws or believed that laws were well-supported, proven, or true while theories were not. Following instruction, 3 of the 35 students in the first cohort expressed more adequate views about the empirical nature of science. In comparison, half the students in the second cohort emphasized the role of evidence in setting science apart from other disciplines of inquiry. Appendices outline the activities: (1) Wind Activity Sequence; (2) Temperature Activity Sequence; (3) Water Cycle Activity Sequence; and (4) Weather Trends Activity Sequences. (Contains 20 references.) (CCM)

CHANGING ELEMENTARY TEACHERS' VIEWS OF THE NOS: EFFECTIVE STRATEGIES FOR SCIENCE METHODS COURSES

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The objective of helping students develop adequate conceptions of the nature of science (NOS) has been agreed upon by most scientists, science educators, and science education organizations during the past 85 years (Abd-El-Khalick, Bell, & Lederman, 1998). Presently, despite their varying pedagogical or curricular emphases, strong agreement exists among the major reform efforts in science education (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996) about the importance of enhancing students' conceptions of the NOS.

However, research has consistently shown that students' and teachers' views are not consistent with contemporary conceptions of the NOS (Duschl, 1990; Lederman, 1992, among others). In an attempt to mitigate this state of affairs, recent research has focused on helping science teachers develop desired understandings of the NOS (Aguirere, Haggerty, & Linder, 1990; Bloom, 1989; Brickhouse, 1989, 1990; Brickhouse & Bodner, 1992; Briscoe, 1991; Gallagher, 1991; King, 1991; Koulaidis & Ogborn, 1989). In a critical review of the attempts undertaken to improve teachers' views of the NOS, Abd-El-Khalick and Lederman (1998) concluded that those attempts were generally not successful in achieving their goal. They noted, however, that a reflective explicit approach to enhancing teachers' views was more "effective" than an implicit approach that utilized hands-on, inquiry-based science activities but lacked any explicit references to various aspects of the NOS.

The present study aimed to assess the influence of a set of activities developed by Lederman and Abd-El-Khalick (1998) on preservice elementary science teachers' conceptions of the NOS. The study also aimed to compare the "effectiveness" of the aforementioned activities when implemented using two approaches. The first was a direct explicit approach while the second included additional reflective components. The reflective components included written and oral discussions of elements of the nature of science throughout the courses in the second cohort.

The specific questions that guided this research were (a) What is the influence, if any, of using a set of specially designed activities on preservice elementary teachers' views of the NOS? (b) Does the addition of a reflective component enhance the "effectiveness," if any, of the activities used?

Before proceeding to describe the methodology undertaken in the present study, it is important to elucidate our definition of the NOS and the aspects of this multifaceted construct that were emphasized in this investigation.

The Nature of Science

Typically, the NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). These characterizations, nevertheless, remain fairly general, and philosophers of science, historians of science, and science educators are quick to disagree on a specific definition for the NOS. It is our view, however, that there is an acceptable level of generality regarding the NOS that is accessible to K-12 students and also relevant to their daily lives. Moreover, at this level of generality virtually no disagreement exists among historians, philosophers, and science educators (Lederman & Abd-El-Khalick, 1998).

In our view, the aspects of the scientific enterprise that fall under this level of generality and that are emphasized in the present study, are that scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of, and relationships between scientific theories and laws.

Method

Participants

The present study spanned two semesters. Two preservice elementary teacher cohorts participated in the study. The first cohort comprised 35 undergraduate students enrolled in an elementary science methods course during Fall term in a mid-sized Western state university. The second cohort comprised 50 students enrolled in two sections of the same course during Winter term. Twenty-five undergraduates were enrolled in the first section and 25 graduate students were enrolled in the second. Participants were mostly female (3 males in cohort 1, 5 males in cohort 2, with three graduate and one undergraduate, with the remaining 77 female). Their ages ranged between 23 and 52 with a median of 28 years. Undergraduate students were seeking a BA degree in elementary education while graduate students were working toward a Master in Teaching (MIT) degree in elementary education. The undergraduate students in the first cohort were in their fourth and final year. Both undergraduate and graduate participants in the second cohort were in the first year of their respective programs. Both groups of undergraduates had similar backgrounds in science, with most students (54) having taken between 10 and 16 credits of science. Half of the undergraduate students had taken biological sciences, while only one-third had enrolled in physical science courses. Most of the graduate students had taken between 12 and 15 credits of science, with two having previously received bachelor's degrees in engineering. These latter two students had taken more than 100 credits of science. Thus, with those two exceptions, the science backgrounds of all three groups were similar and comparable to other education students who were at similar levels in their programs.

Procedure

Data collection spanned the entire two semesters during which the study was conducted. Several data sources were used to answer the questions of interest. An open-ended questionnaire (Appendix A) in conjunction with semi-structured interviews was used to assess participants' views of the NOS prior to and at the conclusion of each course. The questionnaire (Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 1998) consisted of seven open-ended items that assessed participants' views of the tentative, empirical, creative, and subjective nature of science; the role of social and cultural contexts in science; observation versus inference; and the functions and relationships of theories and laws.

Semi-structured interviews were used to establish the validity of the questionnaire and generate in-depth profiles of participants' NOS views. Interviews were conducted with 60 randomly selected participants (20 students from each course). Half of these participants were interviewed at the beginning of each course and the other half at its conclusion. During these interviews participants were provided with their pre- or post-instruction questionnaires and asked to explain and elaborate on their responses. All interviews were audio-taped and transcribed for analysis. Additional data sources included student reaction papers, and a researcher log.

The three courses were similar in structure and aimed to prepare preservice elementary teachers to teach science. The courses were held weekly in three-hour blocks each semester, and were all taught by the same instructor. The course goals were to help preservice teachers develop (a) a repertoire of methods for teaching science, (b) favorable attitudes toward teaching science, and (c) deeper understandings of some science content area emphasized in the national *Benchmarks* (1993). The same readings, activities, and assignments were presented and undertaken in each of the investigated courses. These assignments included (a) an in-depth study of a science content area chosen by preservice teachers, (b) an interview with an elementary student to elicit his/her ideas about the science content area chosen by preservice teachers, (c) a presentation of the interview findings to peers, (d) a paper illustrating the content understandings gained by preservice teachers from their study contrasted with the corresponding understandings elucidated by the interviewed elementary student, (e) a series of three lessons designed to address misconceptions elicited during the elementary student interview, (f) weekly reflection papers on assigned readings and tasks, and (g) weekly in-class activities designed to help preservice teachers experience a variety of teaching strategies, develop content knowledge, and become more comfortable with science. The only difference between the courses offered in Fall and Winter terms was related to the NOS instruction that constituted a theme rather than an isolated topic, and the intervention in the present study.

The study featured two different interventions that were respectively implemented during Fall and Winter terms. The first intervention was implemented over the course of six instructional hours. During the first six hours in the course, the instructor (the first author) engaged students in 10 different activities that explicitly addressed the aforementioned aspects of the NOS. Detailed descriptions of these activities can be found elsewhere (Lederman & Abd-El-Khalick, 1998). Each activity was followed by a whole-class discussion that aimed to involve students in active discourse concerning the presented ideas.

Two of the activities addressed the function of and relationship between scientific theories and laws. Two other activities ("Tricky tracks" and "The hole picture") addressed the difference between observation and inference, and the empirical, creative, imaginative, and tentative nature of scientific knowledge. Four other activities ("The aging president," "That's part of life!" "Young? Old?" and "Rabbit? Duck?") targeted the theory-ladenness and the social and cultural embeddedness of science. Finally, two black box activities ("The tube" and "The cubes") were used to reinforce participants' understandings of the above NOS aspects and provide them with opportunities to apply these understandings. It is noteworthy that these activities were purposefully selected to be generic (not content-specific) given the participants' limited science content backgrounds. Following this initial NOS instruction, however, the instructor made no further attempts to address the NOS. She consciously avoided explicit references to the NOS and drawing connections between the presented aspects of the NOS and other science content/teaching methods discussed throughout the course.

The second intervention was similar to the first save one major aspect. This aspect related to the extent to which participants were given opportunities to reflect on and articulate their views of the NOS. In addition to the six-hour NOS instruction at the beginning of the course, the instructor made numerous references to the discussed aspects of the NOS throughout the course. Whether students were engaged in learning science content or pedagogy, they were often asked to reflect on how that content or those teaching strategies were related to the NOS. The instructor kept a detailed log of all such references, prompts, and reflective opportunities. These opportunities included a discussion of the *Benchmarks* definition of evolution as a scientific theory (AAAS, 1993, p. 122) and how students in the class interpreted that statement. Children's literature books were often shared with the participants and they were often asked, "What does this book have to do with science?" to prompt discussions about the NOS. In addition to these many verbal discussions, students were assigned to write two papers in reaction to specific readings and videotape presentations related to the NOS. Further description of these reaction papers and course discussions are found in the reflective component section.

Data Analysis

The second and third researchers analyzed the data. This approach was undertaken because the first researcher was the instructor of the investigated courses and consequently she might have perceived such data to be partially evaluative.

The questionnaires and corresponding interview transcripts of the 30 randomly selected participants were used to establish the validity of the open-ended NOS questionnaire. The questionnaires were thoroughly read and searched for initial patterns. The same process was repeated with the corresponding interview transcripts. The patterns that were generated from the independent analysis of the questionnaires and interviews were compared and contrasted. This analysis indicated that the questionnaires generated valid profiles of participants' NOS views as established during the individual interviews.

Next, all NOS questionnaires were analyzed to generate pre-instruction and post-instruction profiles of participants' views of the NOS in the three courses. In this analysis, each participant was treated as a separate case. Data from each questionnaire was used to generate a summary of each participant's views. This process was repeated for all the questionnaires. After this initial round of analysis, the generated summaries were searched for patterns or categories. The generated categories were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. Several rounds of category generation, confirmation, and modification were conducted to satisfactorily reduce and organize the data. Moreover, analyses of the second cohort participants' reaction papers were used to corroborate or otherwise modify the views derived from analyzing the NOS questionnaires. Additionally, reaction papers allowed the researchers to generate more in-depth profiles of participants' views. Finally, pre- and post-profiles were compared to assess changes in participants' views. These changes were compared across the investigated courses and the two interventions.

Results

The following sections describe participants' views prior to, and following the interventions. Changes in participants' views are elucidated and comparisons are made across courses to elucidate any differences that were evident between the two Winter courses that included a reflective component and the Fall course that did not. Additionally, a separate section describes the reflective component of the second intervention and elucidates its activities and discussions in relation to the changes that were evident in the second cohort participants' views.

In the following sections, a coding system is used to refer to participants. The codes "C1" and "C2" refer to participants in the first and second cohort respectively. The codes "U" and "G" refer to undergraduate and graduate participants respectively. The number following a "U" or "G" letter refers to an individual participant.

Pre-instruction NOS Views

Participants' pre-instruction views of the NOS were not different across the three courses. Consistent with previous research findings (see Lederman, 1992) participants' views harbored several misconceptions about the NOS.

The empirical and tentative NOS.

Participants in both cohorts held inaccurate ideas of the empirical and tentative nature of science. Participants tended to believe that with technological advances theories might change because we would better be able to view whatever it was we were looking at:

> As new and more powerful (more advanced) equipment becomes available theories can be retested. Our current knowledge is only as good as our current technology. C1U13

> Yes, theories can change after they are developed because of the new technology. An example would be the microscope. Several theories have changed because of high-powered microscopes. (C2U17)

> Theories do change. As technology advances we get more information, and can change the theory. (C2G23)

Students did not speak of the role of evidence as being important as how science differed in relationship to other disciplines. Rather, they spoke more of science being a study of things, while art was subjective, or a way to "prove" something:

> Art is a way to be creative. Science is a way to study things but you have to be objective. You can't be creative. (C1U33)

> Science is an attempt to find the truth. It tests theories and establishes laws. Art expresses feelings. (C1U19)

> Science is done to prove theories. Art is a way to show a picture of the world. (C2G24)

> Scientific theory is just a belief based on data currently available. Scientific law is proven fact, just like the law of gravity. (C1U7)

The view that scientific laws are "proven" and/or not liable to change indicated that participants thought that scientific knowledge is absolute.

The function of and relationship between scientific theories and laws.

All participants explicated inadequate views about the function of and relationship between scientific theories and laws. Many believed that laws are "proven" to be true while theories are not "proven:"

> A theory is a guess or a question that has not been proven or disproven by experiments. A scientific law is a theory that has been proven over and over by different scientists. (C2G9)

> Scientific theory is a best guess about how something happens or works in science. It is based on data. A scientific law has been proven repeatedly and has not changed since it was developed. (C2G10)

Many participants did not seem to realize that theories and laws were different "kinds" of scientific knowledge and that one does not become the other. They believed in a hierarchical relationship between theories and laws whereby theories become laws with the accumulation of supportive experimental evidence:

> Through the method of science a theory is formulated. Before it can become a law it is subject to the world of science to prove or disprove it. If it withstands the tests, it becomes a law. (C2G3)

> A theory is an unproven, untested, invalidated hypothesis. A scientific law would be a theory that has been validated, proven, tested, and documented to be true. (C1U33)

One student drew a diagram (see Appendix B) to illustrate the hierarchical nature of the relationship between theories and laws and stated:

> Laws started as theories and eventually became laws after repeated and proven demonstration. A law can still be disproven, but there is ample proof that it is valid. Perhaps the difference between a law and a theory is the degree of proof??? (G15)

The creative, imaginative, and subjective NOS.

The majority of participants did not demonstrate adequate understandings of the role of human inference, imagination and creativity in generating scientific claims, or the subjective (theory-laden) nature of scientific knowledge and investigation. Students thought of creativity in science more in terms of problem solving than in terms of inventing theories and explanations:

> Scientists use creativity to improve their last experiments. This is called advancement, like creating super-glue! (C1U14)

> Scientists use creativity to help them solve problems. Like to build a car that will sell better than another model because people like the design better. (C2U23)

Participants failed to recognize that scientists use their imagination and creativity throughout scientific investigations, especially when interpreting data and inventing explanatory systems to explain those data. Some participants believed that scientists use creativity only in designing experiments. These students noted that it was not acceptable or desired to use creativity or imagination in other phases of scientific investigations such as interpreting data. Such use, they continued, would compromise the objectivity of scientists:

> A good scientist must be creative to design a good experiment. That scientist must keep an open mind to what he/she is observing and not be subjective. The scientist might be imaginative in coming up with a theory, but it must be through the scientific method so they stay objective. (C2G5)

> A scientist only uses imagination in collecting data . . . But there is no creativity after data collection because the scientist has to be objective. (C2G24)

> Data needs to be collected in a very systematic way, should be repeatable, needs to be well-founded and should lack personal opinion and interpretation. Dealing with data should be objective. (C1U12)

Similarly, the majority of participants believed that science was objective as evident in the following representative quotes:

> Art tends to be more subjective. Science is objective. (C2U12)

> Scientists are very objective because they have a set of procedures they use to solve their problems. Artists are more subjective, putting themselves into their work. (C2G17)

The objectivity of scientists, the participants continued, was guaranteed by the use of "The Scientific Method." Indeed, the belief that scientists use a single scientific method or other sets of orderly and logical steps characterized the responses of almost all participants:

> Science is an academic discipline that requires the use of methods to ensure it is without bias. (C1U14)

> Science experiments are planned out ahead of time so there is no way to get the wrong results. (C2U10)

> Science deals with using a good method so we can duplicate our results. That way we know we have the right answer. It is very exacting. (C2G3)

Participants failed to recognize that the scientists' training and disciplinary backgrounds, as well as their theoretical commitments, philosophical assumptions, prejudices and preferences influence their work.

<u>Post–instruction NOS Views</u>

Participants' post-instruction views are reported separately for each cohort. The two cohorts' views are compared and contrasted in a separate section.

<u>Cohort #1 NOS views.</u>

Analyses indicated that participants' views in the first cohort were not appreciably altered as a result of the intervention. Although a few participants expressed more adequate views of some of the addressed aspects of the NOS, the majority maintained their initial views.

The empirical and tentative NOS

In post-instruction questionnaires, participants' responses still indicated difficulties in articulating how science differed from art in relation to the role of evidence (item four on the questionnaire). Only 3 out of 25 students stated that science required data while art did not

Scientists rely on data for their end results and artists do not. (C1U1)

A scientist collects data, interprets it, and reports upon it. (C1U17)

As far as tentativeness is concerned, relatively more students in the first cohort indicated that theories change. This could be taken to indicate that more of these participants adopted the view that scientific knowledge is tentative. However, in distinguishing between theories and laws, the majority still indicated that laws are "proven" and are thus *not* liable to change. As such, participants' responses were more indicative of inaccurate conceptions of the nature of scientific theories than of their commitment to a tentative view of scientific knowledge.

The function of and relationship between scientific theories and laws

As noted in the above section, students in the first cohort continued to have inaccurate ideas about theories and laws. Many students still believed that theories were unproven and laws were "proven." Others held on to a hierarchical view whereby theories would become laws with the accumulation of evidence:

> Scientific law is a theory that has been accepted and proven. Like the Law of Gravity. This theory was proven and became a law. (C1U20)

> Scientific law is a theory which has been proven time and time again. A theory is a guess or question that has not been proven or disproven by experiments. (C1U25)

> A scientific theory is somebody's idea to explain the how and the why of the world around us. A scientific law is a theory that has been proven. (C1U18)

Only one student seemed to have adopted a more accurate view of the relationship between theories and laws. Her statement that "Scientific law states what is observed and theory states the how and why" (C1U6) did not include a hierarchical reference or references to the amount of "proof" or evidence that other students thought differentiated between scientific theory and law.

The creative, imaginative, and subjective NOS

Many participants noted in their post-instruction responses that while art involved creativity and imagination, science was "factual." As evident in the following representative quotes, these students continued to harbor inaccurate understandings of the creative nature of the scientific endeavor:

> Science must be precise to get the best results. Art has more creativity. (C1U33)

> Science is based on facts that the scientists hope to prove. Art is more interested in feelings and emotion. (C1U2)

Only one student expressed more adequate views of this aspect of science. Indeed, she noted that scientists create laws and theories:

> Science and art are similar in that scientists and artists both creatively interpret something within the medium they are given. For example, in science, the medium is the entirety of scientific law. The scientist is creative in visualizing an interpretation of how all scientific laws go together. In so doing, the scientist may create scientific theory. (C1U12)

Moreover, the responses of a majority of students in the first cohort indicated a still-present belief in the existence of a single scientific method:

> In art the creative, subjective approach is valued. In science the objective approach is more important, and you must document your work through the scientific method. (C1U10)

As evident in the above quote, some participants held on to their view of science as an "objective" enterprise. However, significantly more of them noted that scientists' backgrounds, theoretical commitments, and personal views influence the way they interpret data:

> Scientists probably interpret the experiments and data differently, or they may have their own pre-determined theories that causes them to view the data in other ways. (C1U7)
>
> Data and experiments are interpreted differently for each scientist depending on their own theories. Biases are supposed to be left out, but do at times appear in findings. (C1U32)
>
> It all comes down to how each scientist takes in and interprets the experiments and data. They take the data and within their minds they see different pictures which lead to different interpretations of what is happening. (C1U27)

It is noteworthy, however, that a few participants attributed negative connotations to this theory-ladenness of science. They viewed the "subjectivity" of scientists less as an aspect inherent to scientific investigation—an aspect that scientists actively attempt to ameliorate—and more as an intentional search for pre-conceived results for the purpose of securing research funds:

> I think it is just a way for scientists to get more funds to find out something that may never be proven. It sounds more like they want their opinions believed than anything else. (C1U5)
>
> Each one has come up with their own hypothesis even though they are looking at the same data because each is trying to come up with the findings they are seeking. (C1U35)
>
> When a scientist has an opinion about something they are not going to change their outlook probably because that is how their program is funded and they want to get the expected answers. (C1U31)

<u>Cohort #2 NOS views.</u>

Relatively more participants in the second cohort expressed more adequate post-instruction views. The changes in participants' views due to the reflection-based intervention were particularly pronounced with respect to four aspects, (a) the empirical NOS, (b) the explanatory nature of scientific theories and their role in guiding future research, (c) the difference between scientific theories and laws, and (d) the role that imagination, creativity, and personal and social attributes play in the generation of scientific claims. Moreover, the larger majority of participants did not make any references to indicate that they believed in the existence of a single scientific method.

The empirical NOS and the nature of scientific theories

Most students in both the undergraduate and graduate sections of the second cohort agreed that empirical evidence sets science apart from other disciplines such as the arts as evident in the following representative quotes:

> Science includes observation, study, and experimentation of the world. Scientists then formulate theories and laws about what is observed. (C2U4)

> Scientists collect data to support their interpretation of the world. Artists just show their interpretation of the world. (C2G14)

The post-instruction responses of participants in the second cohort also indicated more adequate views of the nature of scientific theories. The majority of these participants now noted that theories "are powerful ways to explain natural phenomena" (C2U22). Moreover, the responses of many participants indicated an appreciation for the role of scientific theories as guiding framework for future research efforts:

> Theory can provide a way to guide thinking. Theory sparks creative analysis and can open the door to further inquiry, discussion, questioning, and testing of a theory to see whether it is the best explanation for what is observed. (C2G11)

The function of and relationship between scientific theories and laws

Only 4 out of 50 participants in the second cohort retained a hierarchical view of the relationship between scientific theories and laws:

> Theories change after new scientific evidence makes the theory into a law by continuous proof of the theory (C2U24).

> Yes, theories sometimes do change. It either changes into a law, or it is disproven and is no longer a theory (C2G12).

Four other participants, two graduates and two undergraduates, retained the erroneous views that theories and laws were difference because laws were accepted as "truth," whereas theories lacked verification:

> Theories are still being doubted, or have too many loopholes for absolute acceptance. Scientific laws are accepted as truth. (C2U20)

> Scientific laws have been proven time and time again since the recorded history of humankind. They are ALWAYS true within the given sphere. They will remain true unless nature changes. (C2G13)

However, many participants adopted the more adequate view that scientific theories and laws were different kinds of scientific knowledge. These participants noted that while a scientific theory is an inferred explanation for observed phenomenon, a scientific law states, identifies, or describes relationships among observed phenomena:

> Scientific theory is the inferred explanation for observable phenomena. Scientists infer explanations by observing. Scientific law is the statement of what you observe happening (C2U8).

> A scientific law <u>describes</u> something that happens in nature. A theory is an attempt by scientists to <u>explain</u> why nature is the way it is (C2G18)

The subjective and creative NOS

Students in both the undergraduate and graduate sections articulated better understandings of the role of creativity and subjectivity in science. Over half of the students in the second cohort believed that science, like art, required creativity and imagination, and both were in many respects subjective:

> Both science and art are subject to interpretation. Differing opinions allow either to approach new methods or ideas with creativity (C2U19).

> Both science and art are created by humans' minds. Both reach their fullest expression only when the scientist or artist shares his/her creation with other human beings. However, science is based on evidence, whereas art is not (C2G11).

Fifty percent of the second cohort students no longer believed that creativity was only used in the initial stages of scientific inquiry, but that it was an integral part to all stages of scientific investigation. Additionally, many students used the term creativity in the sense of inventing theories and explanations rather than problem solving or resourcefulness:

> You need to design an experiment which requires creativity and imagination and it takes imagination and interpretation to create a hypothesis and theory. (C2U3)

> Scientists use their imaginations in creating theories. Especially when experimenting and investigating there are so many different ways to look at science. Scientists use the knowledge gained from their experiments and observations, but their creativity and imagination are also important in coming up with a conclusion or in developing a theory. (C2U11)

Nonetheless, the view that "creativity" in science was related to solving society's problems such as curing diseases or reducing pollution, rather than the invention of explanations, was expressed by approximately one-fourth of the students in the second cohort in their post-instruction responses:

> Scientists use their creativity and imagination to find cures for diseases like cancer. (C2U12)

> Scientists manipulate variables to see if results change. This creativity has led to the discovery of vaccinations for disease. (C2G7)

Three-fourths of participants in each section of the second cohort demonstrated adequate views of the subjective (theory-laden) NOS. For instance, they recognized that scientists' prior knowledge, personal backgrounds and viewpoints influence the ways in which they interpret empirical evidence:

> Scientists are human. They learn and think differently, just like all people do. They interpret the same data sets differently because of the way they learn and think, and because of their prior knowledge. (C2U24)

> The human element in analyzing and interpreting data leaves much room for varying views. This is the creativity of science showing itself. Individuals will have different natures, mental processes, and backgrounds. The interpretation of data is subject to the human element (C2G23).

Only 3 in each section of 25 students still held fast to the notion that scientists purposively interpret data differently because they seek to support their own theories and secure funding:

> Scientists are interpreting things different to prove what they believe. They may ignore certain facts and pay attention to only the things that support their own ideas (C2U10).

> Scientists interpret data to steer towards proving their own hypotheses (C2G13).

Summary of Results

Prior to instruction, most students in both cohorts believed in a single scientific method that guarantees the "objectivity" of scientists and scientific knowledge. All students held either a hierarchical view of the relationship between scientific theories and laws, or believed that laws were well-supported, "proven," or "true" while theories were not. Moreover, participants held inadequate views regarding the role of human inference, imagination, and creativity in generating scientific claims.

Following instruction, three of 35 students in the first cohort expressed more adequate views about the empirical NOS. In comparison, half of the students in the second cohort emphasized the role of evidence in setting science apart from other disciplines of inquiry. Moreover, while many of the first cohort participants held fast to the view that there was a single scientific method through which objectivity was maintained and appropriate conclusions drawn, no participants in the second cohort made similar references. Also, more participants in the second cohort demonstrated better understandings of the explanatory function of scientific theories and their role in guiding research efforts.

Regarding the relationship between scientific theories and laws, only one student in the first cohort abandoned the hierarchical or "laws-as-truths" viewpoint. By contrast, only four students in the second cohort retained the hierarchical view. Nine others expressed more accurate conceptions of the difference between theories and laws. They noted that theories are inferred explanations for natural phenomena while laws were descriptions of observable relationships among phenomena.

Probably the greatest improvement in the views of participants in both cohorts was related to the role of human attributes such as creativity and subjectivity in science. In the first cohort some students noted that scientists interpreted evidence based on their own backgrounds. Substantially more students from the second cohort, however, expressed more accurate post-instruction views in this regard. Half of these latter participants believed that creativity was involved in all stages of scientific investigations, and three-fourths recognized that scientists' background played a role in interpreting data and reaching conclusions.

While participants' views of certain aspects of the NOS improved, particularly for participants in the reflective group, there is still much to be desired. Nonetheless, the results of the present investigation seem to indicate that the addition of a reflective component to explicit NOS instruction resulted in *more* students adopting adequate views of the NOS. We now turn to examine in some length the reflective component of the second intervention.

The Reflective Component in the Second Intervention

Following the initial six-hour NOS instruction and throughout the second cohort's classes, students were asked to reflect, both orally and in writing, upon various aspects of the NOS as they arose during activities or as they related to course readings. The NOS aspects that were common throughout the reflective component of the second intervention were identical to those adopted and emphasized in the present study.

Classroom Discussions

Students were often asked to relate the NOS aspects discussed at the outset of the intervention to other topics discussed in the course. For instance, at about midpoint in the semester, participants were asked how whether NOS was related to the assessment of elementary students' science content knowledge. The ensuing discussion in the graduate section of the course highlighted the distinction between observation and inference as evident in the following excerpt:

> Student 1: Assessment is only a picture of what students might know, not a given of what they actually do know. It is like science. You are looking at pieces of evidence, trying to draw conclusions and then infer what the evidence means about what the students know about a given concept. Just like science your conclusions are tentative because with new evidence your interpretations may change about what the student knows.
>
> Instructor: That is an interesting idea. It does relate to our discussions on the nature of science. Can you say more?
>
> Student 2: Yeah. It is like the "tubes" activity (one of the activities presented in the first two weeks of class). With a lot of variety of assessments you can get a better picture of what the student knows than with only one method of assessment. With the "tubes" activity, if you pull only one string you will have less of an idea of what is inside the tube than if you pull all of the strings and see what happens.

In a related discussion, the reading for the week addressed the assessment of process skills. The instructor raised the following questions, "Do you think there is a scientific method that includes all of those process skills in a particular order? Can we use this scientific method to assess students' mastery of process skills?" The discussion that followed started students thinking about the distinction between the finished products of science as they appear in professional journals and the actual work that scientists engage in their day-to-day activities:

Students: that is how all the journal articles are written. Yes, there is definitely a scientific method.

Instructor: Is the "method" actually step-by-step, just as published? When you "do science" do you always ask a question, then observe, then hypothesize, then design your study, then draw your conclusions, etc.?

Student 1: No, not really. It is more mixed up in order when you do it. When you write it up you kind of have to "figure out" a logical way to present what you did and then you can probably get to publish it.

Student 2: Probably you do observations and all those things, but they are in different orders. Then when you write it up is when you put it in the order the magazine [journal] wants.

Another discussion that focused on the notion of unifying themes from *Benchmarks for Science Literacy* (AAAS, 1993). In the undergraduate class, the instructor asked whether this discussion was related in any way to earlier NOS discussions. Students referred to the "Tubes activity" in the attempt to explain how and why "Models" are a unifying theme in science:

Student 1: It is like the tubes activity.

Instructor: How so?

Student 1: You are seeing the evidence when you pulled on the strings of the tube and the evidence showed you how you could build your tube to match the real thing. You don't really know what the real thing is, but can approximate it through the model. If the model works like the real thing, it is a good model.

But you still don't know if it is like the real thing. Still, the model can help explain what you are studying.

The above discussions might help to illustrate the importance of explicit prompts to get students to think about and reflect on different issues related to the NOS. Without such prompts, these discussions were not likely to have taken place. Toward the beginning of the courses, these discussions were almost exclusively dependent on explicit prompts from the instructor. It got students involved in discourse about the NOS. Such involvement, we believe, was crucial in helping students clarify their ideas about the NOS for themselves in the first place, and for other in the second place. However, as the term progressed, it was interesting to note that the students began to recognize on their own what elements of the NOS were relevant to various discussions. At this stage, the instructor's role shifted from prompting discussion about the NOS to facilitating the discussion, providing focus, and helping participants to come to some sort of closure.

For instance, at about the midpoint of each class, the children's book *Earthmobiles as Explained by Professor Xargle* (Willis, 1991) was read to the class. This book discusses transportation on Earth from the viewpoint of aliens. The question was raised "Why would I read this book to you? What does this book have to do with science?" The graduate students noted that the book was talking about the NOS. The instructor capitalized on this opportunity, and as evident in the following excerpt, attempted to focus participants thinking on the distinction between observation and inference:

Student 1: It talks about different viewpoints.

Student 2: Yes, it is like drawing conclusions based on your own viewpoint.

Student 3: It is good for sharing how things can be described and interpreted from different viewpoints.

Instructor: To me it is like science because the aliens are taking the evidence of what they observe and interpreting through their own lens. They are drawing conclusions and presenting them based on their prior knowledge and their interpretations from that evidence and knowledge. They don't know for certain if their ideas/interpretations are correct, but they are reasonably sure that their conclusions, based on their observations, make sense.

Student 4:This is another nature of science thing again.

Written Reflections

Students in both classes of the second cohort were required to respond in writing to two reflective prompts that related directly to the NOS, and one that allowed them to reflect on their experiences in the course as a whole. The first paper was related to the prologue of Penrose's (1994) *Shadows of the Mind: A Search for the Missing Science of Consciousness.* Specifically, students were asked:

> How do you see this article does/does not fit with our discussions of the nature of science? Include the elements of tentativeness, creativity, observation versus inference, subjectivity, relationships of theory and law, and social and cultural context in your response.

Student responses to this prompt focused on the social, subjective, and tentative NOS, and the distinction between observation and inference:

> Jessica and her father's theories about the outside world could never be more than tentative because they can never be sure whether they made the right inferences from their observations of the shadows. This is the case in science today. Since we cannot directly see the atom or black holes, our inferences about these concepts are tentative even though they are as reasonable as possible from the evidence. (C2G13).

> Jessica's father said it would be difficult to persuade cave-confined people that their theory of the earth going around the sun is accurate because:
> - Their possible experience and mindsets are so limited as results of their backgrounds in the cave.
> - Their observations could be interpreted in different ways. (C2U8)

> I thought the boulder sealing the people in the cave was a nice metaphor for how much we can see of astronomy from our planet. We can't really see much, so we have to draw tentative conclusions from what we can observe. (C2U23)

> One of the aspects of the nature of science that this story illustrates is subjectivity. We interpret things based on what we know. Because if we were born in a cave we would have to infer what was outside the cave from observations, we might not really know what is there, though it would make sense to us. Much of our scientific knowledge today seems to me to come from observing the "shadows on the wall" and maybe what we think we know is really way off. (C2U19)

> One student chose to illustrate her ideas through a concept map (See Appendix C).

For the second reflection paper, the students watched Bill Nye the Science Guy "Pseudoscience" episode and responded to the following prompt:

> How do you see what Bill Nye shared in the "Pseudoscience" episode fitting with our class discussions of the nature of science? Again, include elements of tentativeness, creativity, observation vs. inference, subjectivity, relationships of theory and law, and social and cultural context in your response.

Again, students focused on the tentative and empirical nature of scientific knowledge and the roles of observation versus inference in the generation of scientific knowledge:

> The episode showed that new evidence can change our view about what we know about science. Bill Nye focused on observation vs. inference, because he pointed out how without direct observation inferences could really be wrong, like with thinking crop circles are created by UFOs. (C2U18)

> The show really discussed the difference between science and pseudoscience. Real science can be tested. Pseudoscience is not testable. (C2G5)

> The thing that struck me is that even when you observe something that doesn't mean you will make a good inference. Like when Bill Nye said he was a ghost, you knew he wasn't even though what was observed made it look like he was a ghost. (C2U25)

In the third reflection paper, students were asked to prepare a "Top Three List" of the most important things they believed they learned in their methods course. Four of the graduate students mentioned the NOS as one of the important things they learned about. None of the undergraduates mentioned NOS. It is possible that the graduate students, who were more reflective in their discussions and written responses, gained a better understanding of the importance of knowing about science itself when becoming teachers:

> My favorite part was learning about science—like the string in the tube, and the cube with one side down. These types of activities are powerful examples of working on scientific ideas without being able to observe actual parts, like atoms. (C2G11)
>
> I learned that creativity is just as important in science as it is in the arts. Scientists must create problems to study, ways to study them, and ways to synthesize the information they learned. The "Prologue" article showed how creative Jessica and her dad had to be when they discussed the cave question.
>
> I learned that in order to be able to effectively TEACH science, I have to have a clear understanding of what IS science. (C2G17)

Implications

The results of the present study are consistent with research on student misconceptions and serve to show the tenacity with which students hold on to their own views. After all, participants' views about the NOS have developed over years of elementary and secondary education. It is unlikely that such views can be undone as a result of six hours of instructional activities even if such activities explicitly address specific aspects of the NOS. It is also the case that the instructor of the course was new at using the activities in the course, and could have become better at presenting the activities in the second semester to the second cohort. Nonetheless, the results of the present study serve to substantiate the view that an explicit approach to teaching students about the NOS, coupled with reflective elements spanning the entire science methods course is more effective than simple direct instruction in an isolated unit.

For participants in the first cohort, six hours of instructional activities designed to illustrate elements of the NOS were only minimally effective in improving their views. Nonetheless, the addition to this six-hour instructional component of a reflective component centered on the theme of NOS throughout the investigated science methods course resulted in changing the views of substantially more participants in the second cohort. Yet, there is still much to be desired. At best, only three-fourths of the second cohort participants held acceptable views of the role of subjectivity and creativity in science, and one half held more acceptable views of the relationship between scientific theories and laws. Many other targeted aspects of the NOS showed no improvement.

So, it can be asked whether the project was successful given that many students in the second cohort still held less than adequate views. The answer would be that many participants made impressive changes in their views of and thinking about the NOS, and that given more time, and more dedicated direct and reflective activities, others could be helped to develop desirable views. However, investing more time in teaching about the NOS in an elementary science methods course may not be feasible. This is especially so given that most elementary preparation programs include only one science methods course in which a plethora of other science and science teaching topics must be covered.

Nonetheless, another route can be taken within the timeframe of an elementary science methods course. Participants in the present study were not made aware of the inadequacy of their ideas at the outset of the course. In other words, these participants did not experience any cognitive dissonance regarding their NOS views and, thus, might have had no incentive or desire to change their ideas. Making students aware of their misconceptions prior to teaching them about the NOS might facilitate changing their ideas toward more current conceptions. In other words, explicit and reflective instruction about the NOS integrated within a complete conceptual change approach might serve to better enhance student views. Indeed, such an approach will be the focus of our next research effort.

WEATHER ACTIVITY SEQUENCES FOR CONCEPTUAL ACTIVITY

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Guiding children's conceptual development can often be a difficult process. Children are quick to figure out what the teacher wants as the "right answer," without understanding the underlying concepts or why that is an acceptable answer. This chapter presents a paradigm that early childhood educators can use to develop activity sequences to teach science process skills and related mathematics skills, as well as help children answer why. This paradigm draws upon the current knowledge and beliefs in science and early childhood education, and it allows teachers to apply the activity sequences to various contents or thematic topics. The philosophical basis for this paradigm is constructivism.

Constructivism

Constructivist practice takes many forms in the classroom, but at the heart of the forms of constructivism lies the notion that individual human minds build understanding. Williams and Kamii (1986) define constructivism as the formation of knowledge through acting on an object or the environment. Children are particularly adept at building meaning in their world; sometimes the meaning is agreeable and sometimes the meaning is not agreeable to the adult communities surrounding the children. Preschool, kindergarten, and most primary grade children are prelogical in their thinking. Young children sometimes explain things using a combination of their intuitive thinking and misapplied information. Regardless of the meaning that children form about a subject, concept, or process, the understanding that the children create is real to their experiential world.

Piaget and Vygotsky were early psychologists who helped shape current constructivist thought. Piaget defined age dependent stages of ability from thinking in a sensory motor mode through the ability to think abstractly. Movement through these stages is not automatic. Young children need many experiences so that they can create meaning and further develop their thinking abilities. Thus, it is very important that young children be exposed to an enriched environment that challenges their current thinking (Staver, 1986). Vygotsky was more concerned with social construction of knowledge. Children must learn to share, communicate, and thus work together. The Vygotskian tradition led to social constructivism that incorporates the same ideas as Piaget's individual constructivism and then adds the interaction of children. Children, plural, are the operational imperative in social constructivism. Children interact, and then children create meaning. The teacher's role is to determine the meaning the children have created to explain various concepts, processes, or skills.

Teachers whose teaching is consistent with constructivist ideas encourage children to think aloud, and give verbal or pictorial descriptions of their current thoughts. After constructivist teachers discern the children's meaning, the teachers deliberately challenge the children's thinking. Teachers direct questions to the children in a fashion that causes the children to rethink, discuss, and negotiate new meaning(s) (Kasten & Clarke, 1991). Another tactic teachers might choose would be to provide discrepant events that the children encounter as a group, and view the same phenomenon.

Constructivism emphasizes the importance and interrelatedness of concepts, skills, and attitudes in children's learning and development. Katz and Chard (1989) identify these same aspects as knowledge, skills, and dispositions. These early childhood educators also emphasize the development and enhancement of the whole child in order to promote learning and conceptual development. In teaching the young child, sensory input and movement is a critical aspect of learning, as these have been the major modes of learning for the first two years of life. Language and interaction with other perspectives also move into primary modes as children become three and four years of age. During the early childhood years, children begin to understand that written symbols are used to represent objects and ideas. Children expand their thinking and modify their logic on (a) sensory input, (b) interaction with manipulatives and thoughts about their actions, and (c) their experiences and encounters with different perspectives. Young children begin to see relationships among concepts only if they are able to interact and think about objects and things that they can manipulate (Clements & Battista, 1990; Williams & Kamii, 1986). Through interaction with others, experiences over time, and learning more about their world, children begin to move into logical thinking.

Building on Interests and Life Experiences

Teachers whose teaching is consistent with constructivist ideas are aware of the importance of building on and making connections to the child's knowledge and experiences, or scaffolding. By knowing the range of new experiences and knowledge that each child can grasp and understand, the teacher can assist the child to make connections (Berk & Winsler, 1995). Each child is unique in her or his abilities, experiences, and perspectives of the world. The effective teacher understands each child, and facilitates his or her development by providing experiences that broaden and alter the conceptual understandings.

The constructivist educator must continually assess the children's intellectual development, select tasks and experiences which are appropriate for the children, analyze children's responses in terms of developmental criteria and understanding (along with content), and promote cognitive development through interaction with materials, experiences, investigations, and other children. The teacher presents experiences, learning activities, and investigations that are relevant to the developmental stage and interests of the children, thereby nurturing children's natural curiosity. Raw data and primary sources, along with manipulative, interactive, and physical materials are used for learning activities with the children. Child autonomy and initiative are encouraged and accepted.

5 Es Paradigm

We have built on past research and work in the field of science education (Science

Curriculum Improvement Study, 1976; Thier et al., 1986; Trowbridge & Bybee, 1996) and developed a paradigm that can be used to promote conceptual understandings and "scientific literacy." We have modified Trowbridge and Bybee's (1996) model into both a planning (unit planning) and an instructional (learning activity sequence) paradigm. The presented paradigm is based on both individual and social constructivist views of learning. A constructivist paradigm, like this one, is inconsistent with many examples in the literature which present completed, detailed, lesson plans. A truly constructivist model must be dynamic and fluid, since it is dependent on the constructs children form during interactions with materials, environment, and peers.

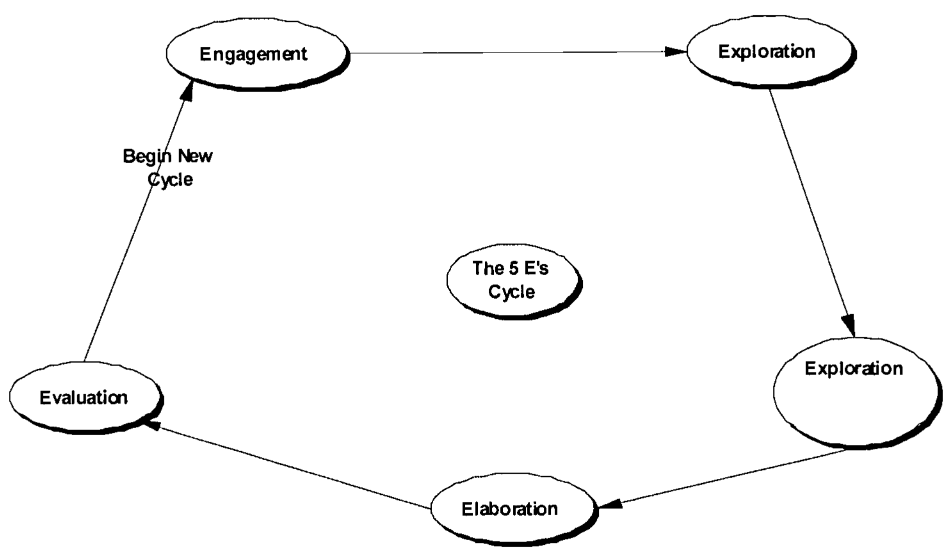
The five phases of the presented paradigm are: engagement, exploration, explication, elaboration, and evaluation (5 Es) (See Figure 1). The first phase is that of *engagement.* This initiates the learning process when interest and curiosity in the topic are generated. This phase makes connections to the past and future activities. Questions are raised about the topic and activities. These initial activities should be concrete and engaging.

The second phase is *exploration.* Exploration provides experiences that include the concepts, processes, and skills important to the topic. The topic is explored through investigations, manipulations and open-ended problem solving. Children are allowed some freedom to explore and manipulate problems presented by the teacher. This phase emphasizes active, open-ended investigations by the children, not demonstrations by the teacher.

The third phase, that of *explication,* is when vocabulary, terminology, labels, definitions, and explanations are initially brought into this cycle. Children focus on specific experiences, discuss them, and are formally introduced to concepts and labels. Discussion of the topic includes justifications and clarifications of the varying perspectives and findings that arose during the exploration phase. Children are the main contributors to the discussion.

The fourth phase, *elaboration,* includes active use of the newly learned concepts, skills, and vocabulary and applying the knowledge to new situations or extending it to other, appropriate

Figure 1. The 5 Es cycle.



situations. Interrelated experiences that extend the children's understandings and applications of concepts, processes, and skills are presented. New and different experiences develop deeper and broader understandings. Elaboration includes both application of knowledge, skills, concepts, and vocabulary, along with extension, transfer, and generalization of these knowledge and skills.

The final phase, *evaluation,* focuses on assessment. Authentic activities are used to assess the children's understandings and abilities. Children are also encouraged to assess their own progress. The extent to which the topic has been learned and new directions for further investigation are determined. General attitudes and behaviors towards working with others and investigating problems are also assessed. Figure 2 provides guidelines for assessing children's general science skills and attitudes.

Figure 2. Criteria for assessing children's performance (from National Research Council, 1996).

Performance Indicator	Evidence/Criteria
Following directions	Child follows the directions
Measuring and recording data	Measurements are reasonably accurate and include correct units.
Planning	Child organizes the work appropriately.
Elegance of approach	Child invents a sophisticated way of collecting, recording, or reporting observations
Evidence of reflection	Child comments on observations in ways that indicate the he/she is attempting to find patterns and causal relationships.
Quality of observations	Observations are appropriate to the task, accurate, and have some basis in experience or scientific understanding
Behavior in the face of adversity	The child seeks help and does not panic if sand, water, or other materials are spilled, but proceeds to clean up, get replacements, and continue the task.

This 5 Es paradigm emphasizes physical interaction with materials and interpersonal

interactions with teacher and peers. The 5 Es also includes vocabulary and language development, which enhances young children's conceptual advancement. The basic science processes of observation, classification, communication, and measurement, are stressed throughout the paradigm. The authors view the 5 Es paradigm as a guide, for teacher planning and implementation to enhance conceptual development through appropriate learning experiences for children.

Science process skills provide a basis in the logical disciplines for children to understand their world and the natural phenomena in it (National Research Council, 1996). For young children, emphases on the basic process skills of observation, classification, communication, and measurement are of critical importance. These processes are essential for children to describe and think about objects and events, to communicate with one another, and to explain and understand different perspectives. Expanding children's communication and language skills significantly augments their thinking and conceptual development (National Council of Teachers of Mathematics, 1986; Perlmutter, Bloom, & Burrell, 1993). Providing meaningful experiences with concept and language enhancement, also allows children to connect vocabulary terms with activities, processes, and attitudes (Flick, 1993; Kilmer & Hofman, 1995).

Therefore, in setting up and establishing the classroom environment and learning activity sequences, there are several issues to be considered:

1. Children learn through hands-on, minds-on activity.

2. Children need to be able to make choices.
3. Children focus and attend best if the learning is related to their interests.
4. Children learn in an integrated fashion. The curriculum areas are not separated in life or in the minds of young children.
5. Children need interaction with others to confront differing ideas and to realize that there are other opinions and perspectives.
6. Children need interaction with others to determine common understandings and transmission of culture.
7. Children need broad and extended bases of experiences.

Developing Learning Activity Sequences

The 5 Es provide a template for planning learning activity sequences within a unit of study. The emphasis is on children actively learning and the teacher facilitating. In an activity sequence, the first phase, engagement, is used to focus children's interest and attention on the topic. In the exploration phase, children actively explore the topic and manipulate materials relating to the topic. In the explication phase, the children learn about the concepts and a formal vocabulary is provided by the teacher and attached to these concepts. During elaboration, the children apply and extend the newly developed concepts. In the final phase of evaluation, children reflect on the concept and vocabulary and their understandings are assessed by the teacher. The definition of the five phases reflects this transfiguration as follows.

Engagement

This phase initiates the learning task. This phase should make connections between past and present learning experiences, and anticipated activities and focus children's thinking on learning outcomes. The children should become mentally engaged in the concepts, processes, or skills to be explored. This portion of the lesson plan focuses on the learner and learning. Thus, focusing on what the child is experiencing and learning is imperative for conceptual development.

Exploration

This phase provides children with a common base of experiences within which they identify and develop current concepts, processes, and skills. During this phase, children actively explore their environment and/or manipulate materials. The children also discuss the different extents of their findings within small groups.

The teacher inquires about children's understandings of concepts in order to ascertain in which direction and on which levels to proceed with learning activities. The teacher probes into children's levels of reasoning, asking for justification and then exposes the children to differing points of view through experiences, tasks, learning activities, and investigations. Children are encouraged to record their data in notes, on charts, or in picture form. The teacher engages the children in experiences that might engender contradictions to their initial responses and then encourages discussion.

Explication

This phase of the sequence focuses children's attention on a particular aspect of their engagement and exploration experiences and provides opportunities for them to verbalize their conceptual understanding, or demonstrate their skills.

This phase also provides opportunities for teachers to introduce vocabulary, formal labels, or definitions for the concepts, processes, or skills explored in the previous phase. The teacher asks questions and translates children's words to science terms or formal labels. The teacher may encourage children to talk with one another and develop further explanations. (This is not an appropriate place or paradigm for lectures.)

During discussion, the teacher introduces content vocabulary and specialized terms. At this point, cognitive and science terminology such as "observe" and "classify" are used when framing additional tasks and investigations. The teacher encourages children to engage in dialogue with one another. The teacher also encourages critical thinking by asking thoughtful, open-ended questions, and encouraging children to ask questions of each other. Sufficient wait time is allowed after posing questions to allow for thoughtful answers, and to provide time for students to construct relationships and create metaphors.

Elaboration

Children's responses are used to drive lessons, shift instructional strategies, and alter content. Subsequently, the teacher sets up experiences, tasks, and activities that require the children to apply and transfer this newly grasped understanding. The children work predominately in small, heterogeneous groups, so that they encounter other opinions and points of view. The experiences and tasks are related to the children's lives, and are meaningful and of interest to them.

This phase challenges and extends children's conceptual understanding and allows further opportunity for children to apply concepts, processes, or skills to a novel application. Through new experiences, the children develop deeper and broader understanding, gain more information, and strengthen skills.

<u>Evaluation</u>

Lastly, the teacher assesses children's understandings through meaningful tasks (Brooks & Brooks, 1994). Assessment is intertwined with instruction, and includes assessment of children's: problem-solving, record-keeping, work with materials and peers, and analyses of thinking processes. Assessment results also provide information useful for further planning (Hein & Price, 1994).

This phase of the sequence encourages children to assess their understandings and abilities. The teacher evaluates concept, skill, and process development by assessing what the child has understood and accomplished. This will guide further explorations to meet educational objectives or curricular goals. It is important to note, that if some children have not adjusted or revised their thinking, this concept may be beyond their "zone of proximal development." Teachers need to allow children's "logical" thinking and responses, even if they are incorrect. Later investigations, interactions, experiences, and developmental learnings may alter the thinking of these children. To coerce them into mouthing the generally accepted reality may force their true beliefs underground where they are not available to transformations or modifications through explorations.

When implementing the 5 Es, it is helpful to keep in mind the role of the teacher and the role of the children. For example, do not force a "correct" response. If children are "told" an answer or explanation, they mimic this in their responses without modifying or adapting their thinking (schemas). We have found that separating what the child is to do from what the teacher is to do ensures that the child is involved in active experiencing. Other clarifications are listed in Figure 3. One way to assess the overall activity sequence is to develop a checklist that includes the following points:

- Is the topic interesting to children?
- Is the topic interesting to me (the teacher)?
- Is the activity sound in terms of curriculum and content?
- Are there adequate resources for this activity sequence?
- Will the activity sequence engage children at different levels of abilities?
- Are there strong cross-curricular connections?
- Are there sufficient opportunities for children's input to guide or determine direction?

- Is there an emphasis on oral and written language development and communication?

The 5 Es learning activity sequence planning template facilitates conceptual development through interactions with materials, teachers, and peers. (Note: If you are unable to determine an activity for a concept, some possible resources are: another teacher (middle and secondary teachers are also useful as content consultants), activity books in the library, a National Science Teachers Association journal, Science and Children, other journals for teachers of young children, and ERIC documents.) When working with young children, most learning activity sequences should be exploratory in nature.

To illustrate application of the learning activity sequences, we have developed a unit on weather. The aspects of weather that we have chosen for the children to explore are wind, temperature, the water cycle, and weather trends. Within each of these major categories, we identified several topics (utilizing national science and mathematics standards, and state science and mathematics standards) as important for children to understand. The aspects of weather we have chosen for the children to explore are wind, temperature, water cycle and weather trends. Within each of these topics, we identified several subtopics (utilizing national science and mathematics standards and state science and mathematics standards) as important for children to understand. The first topic is wind with subtopics of directionality, moving things, and speed. The second topic is types of weather with subtopics of sunny, rainy, cloudy, thunderstorm, hurricane, foggy, and tornado. The third topic is temperature which includes feeling on skin, cold, warm, chilly, thermometer, degrees, and "reading" thermometers. The last topic is the water cycle, which

Figure 3. Implementing the 5 Es learning activity sequence

Engagement create interest in topic raise questions	**Engagement** show interest in topic ask questions
Exploration encourage children to work together observe and listen to children asks questions to redirect children	**Exploration** think freely about topic suspend judgment and try alternatives record observations and ideas discuss ideas and experiences
Explication have children explain in own words have children define in own words ask for justification from children use children's previous experiences and understandings to explain concepts provide definitions, explanations, clarifications, and formal labels	**Explication** explain possible solutions to others use observations and data in explanations listen critically to others' ideas
Elaboration encourage children to apply and extend learnings to new situations remind children of alternatives expect children to use formal labels remind children of existing data and evidence ask "What do you think?" "Why" ask questions to redirect children	**Elaboration** apply new learning in new but similar situations use newly learned terminology ask questions, propose solutions, design investigations make reasonable conclusions from evidence record observations and explanations with peers
Evaluation observe and record as children apply new learnings look for evidence that children have changed encourage children to work together on their thinking guide children to also assess own learning ask open-ended questions to assess childrens' reasoning	**Evaluation** evaluate own progress and learning demonstrate reasonable understanding of new learnings discuss investigations and conclusions apply observations and evidence to answer open-ended questions

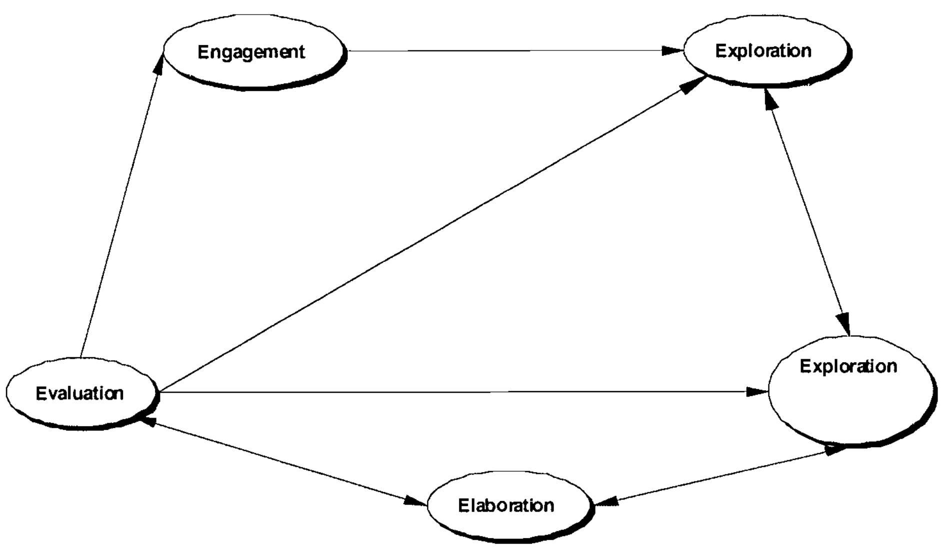
includes evaporation, clouds, humidity, condensation, dew, fog, frost, and precipitation types.

The four learning activity sequences on the following pages illustrate how the teacher could use the 5 Es to plan and teach particular concepts for a unit on weather. The following activity sequences are presented: Wind Activity Sequence which includes blowing winds, wind directions, and speedy winds; Temperature Activity Sequence which includes feeling hot and cold, and measuring air temperature; Water Cycle Activity Sequences which includes condensation and water cycle; and Weather Trends Activity Sequence including foggy days. These sequences can be found in Appendices A – D.

Because the phases are extremely flexible, the 5 Es paradigm is particularly good *for* affecting adaptations for various ability levels. During exploration, activities can be individualized easily to suit special needs. In addition, during the phase of elaboration, extension activities for individual abilities are easily developed. Another possibility that utilizes the inherent flexibility of the 5 Es paradigm is the ability to cycle from explication back to exploration when a child is not yet ready to apply the concept in the elaboration phase. Many children will remain in the exploration phase for an extended period. Figure 4 illustrates how a teacher may recycle among the phases in order to meet the needs and abilities of the children. This can only be determined through observations of children's abilities and thinking processes.

Remember, this is a cyclical learning and instructional strategy. Teachers may choose to cycle between two or three phases before continuing. Some children may not progress beyond the exploration phase in understanding certain concepts based on their experiences and developmental level. The 5 Es is not a linear paradigm. The teacher can remain in one phase or can cycle between two or three phases. If' in the evaluation phase, the child or teacher sees a need for further development or application, they can easily recycle back to the phase that can be utilized to meet this perceived need. Sometimes a teacher cycles between exploration and explication, or among explication, elaboration, and evaluation, using different activity sequences each cycle. This flexibility allows the teacher to meet the individual child's needs and to develop specially tailored activity sequences.

Figure 4. Cycling within the 5 Es.



<u>Conclusion</u>

Educators need to remember that children share many behaviors with scientists as they are exploring and learning about their world. Through their experiences, they are developing concepts, skills, processes, and positive dispositions toward learning about their world. This 5 Es paradigm for planning units of study and instruction of learning activity sequences will assist teachers to guide children in discovering and correcting their naive theories. Through implementation of the 5 Es cycle-engagement, exploration, explication, elaboration, and evaluation-teachers can augment children's intellectual development based on understanding the underlying concepts and relationships among materials, the environment, and society. This paradigm takes into account the nature of the young child as a learner, the philosophy of constructivism building on both science education and early childhood education), and the cyclical and spiral learning that occurs through learning activity sequences. When implementing the 5 Es paradigm, teachers will find that it is continuously evolving. Each phase is dependent on the one in front of it. Often, teachers will continuously recycle through the beginning phases, as the children need more experiences and explorations before they are ready to move on. The flexibility of this paradigm makes it unsuitable for the typical linear unit or lesson plan that can simply be copied for use in class. The 5 Es paradigm is learner centered and depends upon the learner and topics being addressed, as to how it may evolve for a particular group of children.

Throughout this paper, the use of experiential happenings has been emphasized in the planning and implementation of instructional learning activity sequences. Hands-on, minds-on learning is needed for conceptual development. Because of the open nature of these experiences and investigations for young children, the ability of children to develop the concepts and skills to the degree they are capable of, is unlimited.

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Appendix A

Wind Activity Sequence

Blowing Winds

What the children do

Engagement

Watch a fan that is blowing streamers.

Exploration

Watch the fan blow the streamers at slow, medium, and fast speeds.

Hold streamers on different sides of the fan (at a distance). Determine which streamers blow, and in which direction. Draw pictures of the fan, wind, and streamers.

Explication

Children explain the direction and the speed the streamers are blowing based on the direction and speed the wind from the fan is blowing.

Elaboration

Examine the wind blowing objects outdoors (streamers, leaves, grasses, dust,

Evaluation

Children move like an object being blown by the wind.

What the teacher does

Engagement

Set up a fan to blow streamers tied to the grill indoors.

Exploration

Have the children *watch* the fan blow the streamers at slow, medium, and fast speeds. Have children hold streamers on different sides of the fan (at a distance).

Ask: which streamers blow, and in which direction? Which direction is the wind blowing? Which direction are the streamers blowing? Have the children draw pictures of the fan, wind, and streamers.

Explication

Have the children explain the direction and the speed the streamers are blowing and how they relate to the direction and speed the wind from the fan is blowing.

Elaboration

Take the children outdoors to examine the wind blowing objects (streamers, leaves, grasses, dust, etc.).

Ask: which direction is the wind blowing? How do you know the wind is blowing in that direction? What other objects are blowing in the wind? Are they blowing in the same direction?

Evaluation

Have the fan blowing without the streamers. Ask the children to stand in the wind and to use their arms as if they were limbs on a tree. They should be able to show the direction and type of movement that tree limbs would make when blowing in the wind. The teacher may move the direction the wind is blowing to corroborate directionality and may change the speed of the "wind" to see if children make their arm wave more in stronger "wind."

Wind Directions

What the children do

Engagement

Children take compasses and go outside with them. They experiment with the compasses.

Exploration

Children point their compass north and set it on the ground in front of them.

Children *turn* to face the wind so that it blows straight into their face. They will notice the direction that they are facing (they will read the compass).

Explication

Children explain the direction the wind is blowing based on the direction they are facing and their reading of the compass.

Elaboration

Repeat the investigation and determine the direction the wind blows for several days. In pairs, the children can list or chart the days and wind direction for the week.

Evaluation

Draw the direction of the wind.

What the teacher does

Engagement

Explain to children that compasses help us to determine direction. Explain how the compass works and N, S, E, W. Have enough compasses for each child or pair of children. Take the children outside on a windy day.

Exploration

Help the children line up their compasses with North and set them on the ground. Have the children turn their faces into the wind.

Ask: Which direction is the wind blowing from? Which direction (compass letter) is the wind blowing from? What else is the wind blowing that helps you determine where is it blowing from (trees, etc.)?

Explication

Have the children explain the direction the wind is blowing from and how they determined the direction.

Elaboration

Take the children outdoors to determine the direction the wind blows for several days. List or chart the days and wind direction for the week.

Evaluation

Have the children draw the direction of the wind. One sample can be used each day for class weather charts. Other papers can go in a book that the children are making about weather.

<u>Speedy Winds</u>

What the children do

Engagement

Children look at anemometers (official or homemade). They experiment with the anemometers by blowing against the front and back of the cups.

Exploration

Children take the anemometers outside and determine if the wind makes the anemometers move.

Explication

Children describe how fast the wind is blowing. At slow speeds, the children can count the number of turns the anemometer makes in a minute.

Elaboration

Children further investigate the wind speed by observing how the wind is affecting blades of grass, leaves, and branches of trees.

Evaluation

Illustrate the effects of wind on blades of grass, leaves, and branches of trees at the different wind speeds.

What the teacher does

Engagement

Provide several anemometers (purchased or homemade) for the children to look at and experiment with by blowing against the front and back of the cups.

Exploration

Have the children take the anemometers outside and determine if the wind makes the anemometers move.

Explication

Ask the children to describe how fast the wind is blowing. Can they count the number of turns the anemometer makes in a minute? Can the children blow as fast as the wind is blowing? Is the anemometer turning fast, medium or slow? How can they tell? Tell the children that they are using an anemometer, and that this is a tool that measures wind speed. Have the children describe how it works.

Elaboration

Take the children outside with the anemometers on still days, on slightly windy days, and on very windy days. Have the children explain how fast the wind speed is on each of these days. How does the anemometer react?

Have the children further investigate the wind speed each day by observing how the wind is affecting blades of grass, leaves, and branches of trees. Have the children examine the wind speed using the Native American tradition:

No wind = no leaves or branches moving

Slight wind = leaves and grass blades gently waving in the wind

Medium wind = small branches and bushes gently bending in the wind

Strong wind = medium branches bending in the wind and grass blades bent over in the wind

Evaluation

Have the children illustrate the effects of wind on blades of grass, leaves, and tree branches at the different wind speeds.

Appendix B

Temperature Activity Sequences

Feeling Hot and Cold

What the children do

Engagement

Using warm, room temperature, and cold liquids, children order the liquids by warmest to coldest (serial classification).

Exploration

Children use thermometers. Children note where the red line on the thermometer is for room temperature.

Children record if the red line inside the thermometer is higher or lower as they place it in different containers.

Children observe the red lines in thermometers to see if their earlier serial classification by touch show that the height of the red line changes accordingly if temperature is cold or warm.

Explication

Children explain what the red line indicates about warmth or coldness of the liquid. Teacher explains that the instrument they are using is a thermometer.

Children explain what the thermometer measures.

Elaboration

Children can measure the temperature of other objects, liquids, and gases. Children select the objects to take the temperature of and then draw a red line on the paper that matches the red line on the thermometer. Children then serial order the temperatures of solids, liquids, and gases in the room.

Evaluation

Children "measure" the temperature of novel objects such as an ice cube,. and a container of orange juice that has just been removed from the refrigerator. Children serial classify the order of the temperature of the objects from hottest to coldest.

What the teacher does

Engagement

Provide a minimum of three containers of water for each pair of children (one cold container, one warm or room temperature container, and one hot (not too hot) container of water).

Ask: Which liquid is coldest? Hottest? What sense are you using to decide how hot or cold the water is? Tell children to arrange containers from hot to cold.

Exploration

Provide each pair of children thermometers. (Make sure to use large, safe, and easy to read thermometers.) Have children note where the red line on the thermometer is for room temperature.

Have the children set thermometers in the liquids. Children record if the red line inside the thermometer is higher or lower as they place it in each container.

Children observe the red lines in thermometers to see if their earlier serial classification by touch show that the height of the red line changes accordingly if temperature is cold or warm.

Explication

Ask: How long is the red line when the liquid was cold? How long is the red line when the liquid is warm? Do you think the length of the red line stays the same all the time? Explain that the instrument they are using is a thermometer. Have the children explain what the thermometer measures.

Elaboration

Make sure that other solids, liquids, and gases are available so that children can take the temperature.

Have children draw a red line on the paper that matches the red line on the thermometer. Ask the "explain" questions again.

Have children serial order the temperatures of solids, liquids, and gases in the room.

Evaluation

Select novel objects that the children haven't yet measured the temperature of and that they have not previously serially classified according to temperature. Have children indicate serial order based on touch and then by adding the technology of a thermometer.

<u>Measuring Air Temperature</u>

What the children do

Engagement

Children explain how they know if it is hot or cold outside.

Exploration

Children experience thermometers and measure the temperature of their hands and of the air.

Children measure the temperature outside the classroom and compare to earlier temperatures.

Explication

Children tell what hot, warm, and cold feels like. Children tell what hot, warm and cold looks like on the thermometer.

Elaboration

Children keep a chart of daily room temperature and outdoor temperature.

Children graph the weekly and monthly indoor and outdoor temperature.

Eventually children can graph the temperature for the seasons during the school year.

Evaluation

Towards the end of the school year, children tell the temperature patterns of the seasons.

What the teacher does

Engagement

Distribute thermometers to children. Tell children that they get to use these tools today.

Exploration

Show children where to hold the thermometer, and how to read the red line. Have children hold the bulb between their hands and observe what happens to the red line. Have children hold the bulb in the air to determine room temperature. Take the children outdoors. Have children hold the bulb in the air to read the outside temperature. Have children (if able) write the inside and outside temperature on a previously prepared chart.

Explication

Ask, "Is the temperature the same or different inside and outside?" Tell the children that these tools are called "thermometers." This tool is used to measure temperature, or how hot or cold something is. (Write thermometer on board.)

Elaboration

Continue taking indoor and outdoor temperatures daily

Ask: which season is coldest outside? Hottest outside? What kind of weather is outside when it *is* hottest? Coldest?

Evaluation

Have children draw a picture of a cold, warm, and hot day outside.

Appendix C

Water Cycle Activity Sequences

Condensation

What the children do

Engagement

Early in the morning at the start of school, children examine the wet grass.

Children examine the exterior wetness of their snack or lunch time cold drinks.

Exploration

Children investigate several containers with warm liquids, room temperature liquids, and cold liquids. Both clear and colored liquids are provided both warm and cold. Children write or draw their observations using the five senses. If children are unable to write or draw, a list of the children's spoken words can be created. (Children can taste the water on the outside of the container and the contents to determine if it is the same liquid that is inside the container.)

Explanation

Children explain how the water, condensation, was formed on the container.

Children will learn vocabulary of "condensation," "dew," etc.

Elaboration

Children decide how they might further investigate condensation. They conduct many other investigations and record (with teacher assistance) their findings.

Evaluation

Children determine what they learned. Children will present their findings, or brainstorm what they learned, and the teacher writes it down. Children draw pictures of condensation. If some children's conceptions remain naive, allow them further experience with condensation across the school year.

Say, "Touch the grass, and tell me, what do you feel?" Later in the morning, the teacher directs students to observe again, and asks, "What do you feel on the outside of your drink box?"

Exploration

Provide a variety of warm and cold liquids in clear glass and plastic containers (water, cola, milk, tomato juice, etc.) Make sure the drinks are visible and the products (e.g., cold, milk, etc.) are known. One container of each liquid will be at room temperature while the other will contain very cold liquid. Both clear and colored liquids are required, so children can further explore if they assume that the container leaks. Then ask, "What do you feel on the outside of the container?"

Encourage the containers to be touched and compared. Ensure that all five senses are used. Encourage written, drawn, and spoken responses. (Young children may not be able to record their observations, but the teacher may break the investigation into steps, and the children can voice their observations at each step and the teacher can record these.)

Ask guiding questions such as, What does the outside of the container feel like? Which containers are wet? Are only the cold containers wet on the outside? Are the warm/room temperature containers also wet on the outside? What does the liquid taste like? Is it the same liquid that is in the container? (This helps dispel the notion that the container is leaking.) Accept all answers and ask further questions to help clarify observations. Children's answers should be collected in some format.

Explication

Ask questions such as, What is on the outside of the container? What temperatures allowed the water to form on the outside of the container? Where did the water come from? What does it mean when we say there is water is in the air? Ask the children to explain their thinking, and provide children with the appropriate vocabulary and labels for the concept being explored (e.g., dew, condensation, and humidity).

Elaboration

Assist children in deciding how they might want to further investigate condensation. Perhaps the children want to see if cold solids also cause condensation (e.g., flour, and cold rocks). Perhaps other liquids should be investigated. Perhaps children want to determine if light or darkness affects condensation. These investigations are then set up. Have the children observe and record their findings, and compare these findings to those during the exploration phase.

Evaluation

Have the children determine what they learned. Perhaps the children will present their findings, or brainstorm what they learned and the teacher writes it down. If some children's conceptions remain naive, then allow them further experience with condensation across the school year.

<u>Water Cycle</u>

Water Cycle Chorus:

Rain falling down,
Back to the ground,
Streams going by,
Back to the sky,
Water cycle, water cycle, water cycle.

What the children do

Exploration

Children begin making motions to fit the words. Children draw pictures of a circle, cycle. Children draw a stream, clouds, and rain. Children draw a circle that attaches these things together.

Explication

Children show motions or draw pictures to illustrate a cycle. Children tell in their own words, what a cycle is.

Elaboration

Children tell stories about being caught in a rainstorm, or how humid it is today. Children tell stories about steam rising from pots of boiling water, or fog on the lakes and rivers in the morning.

Evaluation

Children tell or draw a water cycle story.

Engagement

The chorus of the song, "Water Cycle" is playing. Children are listening and learning the words.

What the teacher does

Engagement

Play the chorus of the song "Water Cycle" repeatedly. Teach the children the words to the chorus.

Exploration

Encourage the children to create movements to match the words of the song. Supply paper and crayons so that the children can draw a cycle or a circle. Ask the children about water in the air, from the previous activities on condensation. Ask what a lot of water looks like and feels like. Ask about rain, what is rain, how does rain happen.

Explication

Ask, "What is a cycle? Rain falls down to...? The streams and creeks run to ...?
The water goes to...?" Ask a circle to be drawn so that these items are
attached.

Elaboration

Show a teakettle boiling, with steam coming out of the spout. The teacher holds a cookie sheet over the steam. The teacher asks for observations about water in the sky, about water condensing on the cookie sheet, about water falling off the cookie sheet.

Evaluation

Have the children create a drawing to illustrate the miniature water cycle created by the teakettle.

Appendix D

Weather Trends Activity Sequences

Foggy Days

What the children do

Engagement

Children stand in the fog and observe with all their senses.

Exploration

Children write or draw their observations. Other days children look at clouds in the sky and observe.

Explication

Children speculate what fog is made up of, how it formed, and why it is on the ground instead of up in the sky.

Elaboration

Children share information about driving through fog, fog on the mountains, over the rivers, and over the lakes. Children share information about airplane trips that they have taken through the clouds.

Evaluation

Children draw or explain similarities and differences between fog and clouds.

What the teacher does

Engagement

Have the children stand in the fog and make observations. Go inside and record the observations for the children.

Exploration

Have the children write or draw their observations.

Explication

Tell children that fog is a cloud on the ground instead of up in the sky. Ask children what fog is made up of, how it formed, and why it is on the ground instead of up in the sky.

Elaboration

Have children share information about driving through fog, fog on a mountains, fog over rivers, and fog over lakes. Have children share information about airplane trips that they have taken through the clouds.

Evaluation

Have children explain similarities and differences between fog and clouds.

Daily Weather

What the children do

Engagement

Each day the children go outside or look out of the widow and draw the weather.

Exploration

Children measure the temperature outdoors each day at the same time. They graph the temperature, and draw a picture of the weather.

Explication

Children describe the weather each day. Children explain the water cycle and what is happening outside that relates to the water cycle.

Elaboration

Children examine weather patterns by looking at the temperature and precipitation charts that they have made. Children will describe weather patterns by the seasons.

Evaluation

Children name and draw the type of weather and temperature on several school days.

What the teacher does

Engagement

Each day, have the children go outside or look out of the window and draw a picture of the weather.

Exploration

Have the children measure the temperature outdoors each day at the same time.

Have the children graph the temperature and draw a picture of the weather.

Explication

Have the children explain the weather each day. Children explain the water cycle and what is happening outside that relates to the water cycle. Ask: What part of the water cycle are you seeing when the water is falling from the clouds? What do we call water falling from the clouds? What do we call frozen water that falls from the clouds? What part of the water cycle is happening on a clear day?

Elaboration

Have the children examine weather patterns by looking at the temperature and precipitation charts that they have made. Have the children describe weather patterns by the seasons. Draw the season lines on the charts or the children can state where they believe the season lines should go. (Repeat this lesson throughout the year.)

Evaluation

Have the children name and draw the type of weather and temperature on several school days. One sample can be used for class charts. Other papers can go into a book that the children make about the weather.

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