Introduction

Research Project Objectives

The objectives for this research project consist of two interrelated strands. As a subcontract to an NSF materials development grant of the Lawrence Hall of Science (LHS), this project has practical objectives concerning classroom implementation and student evaluation of a subset of materials developed by the LHS development team as part of their ***Seeds of Science • Roots of Reading*** series. The second strand consists of research objectives involving in-depth descriptions of literacy/science tasks in an early elementary classroom and the role of multiliteracy in the development of scientific knowledge during inquiry science/literacy learning.

The objectives of the practical component are to: provide the development team with detailed analyses of the implementation of the "Shoreline Science" science/literacy unit in this classroom; discuss the role of the instructor and provide information for writing an improved teacher's guide; recommend unit modifications; and make recommendations for improved student evaluation. The objectives of the research component are to: make an in-depth qualitative description of the multiliteracy tasks and products; describe the way scientific knowledge develops; and describe the role of literacy and multiliteracy in this development of scientific knowledge, all in the specific classroom under study.

Summary of Main Findings

The current research project consisted of an in-depth qualitative investigation of a second grade classroom experiencing an inquiry-based science/literacy unit developed by the Lawrence Hall of Science. The unit was derived from an earlier unit in the Great Explorations in Math and Science (GEMS) program, entitled ***On Sandy Shores***. The new unit is entitled ***Shoreline Science*** and, as the first of a number of planned units in the ***Seeds of Science • Roots of Reading*** series, it sought to adapt and transform the older GEMS unit to fully integrate literacy learning, to deepen and extend the science content, and to apply current, research-based pedagogical knowledge in both literacy and science to its curricular design. It was designed to develop scientific knowledge of the sandy shore ecosystem for elementary school (2nd to 3rd grade) children, to convey standards-based life science content, within an interdisciplinary framework that equally emphasized literacy learning and science inquiry. The program defined itself as one that would "encourage the acquisition of both science and language, especially among English language learners." At a very basic level, the current research project aimed at providing an in-depth description of the multiliteracy tasks and products in this unit. The following is a summary of the description of the tasks and products that were analyzed.

Description of Inquiry Tasks (Video Data)

Six tasks were videotaped and analyzed as part of this research project. The six tasks were: Development of Scientific Thinking – Categorization; Development of Scientific Description – Knowledge of Tools of Measurement; Development of Scientific Thinking – Understanding Process through Shared Reading; Summarization of a Scientific Process through Picture Drawing; Summarization of a Scientific Process through Narrative Writing; and The Development of Scientific Vocabulary.

Development of Scientific Thinking – Categorization

This task consisted of the classroom activity of "Beach Bucket Scavenger Hunt." The task was conducted by small groups of students exploring simulated beaches, finding objects in the sand and then categorizing them. Overall it was found that this task involved a movement from a holistic concept of sand to a differentiated understanding of the components of sand and their sources. The task of categorization involved a four-stage learning cycle. The initial stage involved a process of just looking, picking up and noticing individual objects. This stage allowed some initial differentiation in the observed phenomenon. The second and third stages involved the creation of rudimentary groupings and then the questioning and modification of these groupings and definitions of objects. The third stage was found to be particularly important in that oral discussion, argumentation and verbal reflection allowed the modification and evaluation of the groups that had been formed. The last stage was characterized by the use literacy, visual representation and scientific terminology. It was at this stage that the decision about the category of an object, its scientific name, its clear definition and its group membership was finally decided. This decision was mainly made in reliance on an authority.

Development of Scientific Description – Knowledge of Tools of Measurement

This task consisted of the classroom task of "Science Inquiry of Sand". The aim of this task was to develop the concepts of measurement and observation based inference as part of the epistemology of science. The activity consisted of observing sand using magnifying glasses and microscopes, considering the different types of sand and inferring the components of the sand. This process of utilizing tools to observe sand involved a transformation of the way observation was conducted. Instead of an open process of just noticing, the method of scientific description involved a directed observation process based on enhanced visual abilities through the usage of tools. The task of developing scientific description as part of the process of scientific thinking involved the movement from open noticing to directed noticing and then the usage of the information obtained for the organization of knowledge in world knowledge schema, scientific patterns of comparison and scientific argumentation. The process of directed tool-based observation was found to be pivotal in that this was the evidence that was then used in the organizational scientific tasks. Once a process of conceptual organization occurred, this conceptual information was redirected back to the tool-based noticing process, resulting in further empirical observations and conceptual categorizations and distinctions.

Development of Scientific Thinking – Understanding Process through Shared Reading

This task consisted of the classroom activity of a shared reading of a specially prepared reader entitled "Sandy's Journey to the Sea" and the associated production of a summary chart based on the reader. The aim of these activities was the development of the understanding of how sand is formed. The method employed to develop this understanding consisted of the literacy activity of shared classroom reading and teacher-led visual representation of this process. The task of understanding a process involved a four stage learning cycle. The initial stage involved generating some basic knowledge about the specific process being learned and providing a more general template of what a scientific process is. The second stage consisted of activities directed at enhancing and developing the reading and learning process. These activities form an introduction into the reading itself and the meanings that will be encountered. The third stage consisted of a shared reading activity in which the text was read together and local meaning was discussed. The final stage consisted of summarizing the meanings found in the shared reading. This process of summarization was conducted through verbal interaction, pictorial representation and written note taking.

Summarization of a Scientific Process through Picture Drawing

This task consisted of the classroom activity of producing a pictorial account of a rock's journey to the sea and was designed to summarize the process of beach formation. This task followed the shared reading of the reader "Sandy's Journey to the Sea." The task of summarization through picture drawing involved a three-stage process. The initial stage consisted of the creation of a partial representation of the process. This partial representation focused on a detail or provided a schematic contour. In the second stage, a verbal interaction directed an understanding that additional features needed to be represented in the pictures in order to capture the process. This led to the completion of the pictorial representation. In this final stage, the global aspects of the process were addressed and solutions posed as to how to pictorially represent this.

Summarization of a Scientific Process through Narrative Writing

This task consisted of the classroom activity of producing a narrative account of a rock's journey to the sea. This narrative writing task followed the pictorial summary of the same process. The pictorial representations in the form of postcards and the original readers from the shared reading were present during the narrative writing process. The task of the summarization of scientific process through narrative writing was characterized by the process of cross modal integration. The stages of written text discussion and drawn picture discussion provided knowledge that was utilized in the text production process of written text. However, the final text written consisted of a limited narrative mainly based on a pictorial analysis.

The Development of Scientific Vocabulary

This task consisted of the learning of the concepts of weathering and erosion. The activity consisted of a classroom discussion of the meaning of the scientific concepts and an acted out demonstration of the weathering and erosion process. The process of learning a scientific vocabulary involved three different stages of description. These three stages worked together to provide a multi-representational description of the word meaning. The scientific term was described through a verbal description of the process being described. This verbal description involved the use of students' prior knowledge and a global text organizer such as a narrative or cause and result pattern. The scientific term was also described through the physical acting out of the process being described. This physical process was combined with a process of noticing. In the word definition stage, the scientific term was shown to group together different observations and phenomena under a common heading. Within this context, the explicit definition of the term was provided. These three ways of developing a scientific vocabulary worked together with quick shifts among the three stages.

Description of Multiliteracy Products (Multiliteracy Data)

Twelve multiliteracy products were analyzed as part of this research project. The twelve products were: The Beach Folder Picture; The Colored Map; Photograph Description; Beach Bucket Scavenger Hunt and Categorization; My Favorite Rock and Shell Description; Chapter Beach Books; Directed Observation – Sand on Stage and the Unknown Sand; My Sand Summary; Making Inferences; The Postcard Story; Beach Animal and Plant Report; and Oil on the Beach – Observation and Prediction Worksheet.

Beach Folder Pictures

This multiliteracy product was the result of one of the first activities conducted by the students. This activity consisted of producing a drawing of a beach. This drawing was used as a cover for a folder that was designed to include vocabulary items and scientific concepts. The beach folder picture was an early visual representation task that was designed as a way of activating knowledge relating to the beach. This was an open task that essentially asked for a static representation of a beach. At this early stage in the educational process of the science/literacy unit, the students had undifferentiated understandings of the beach and its contents. These understandings were experiential and consisted of presenting three areas (beach, sea and sky) with expected objects such as sea, sun, sky and clouds. The visual representations were mainly descriptive, schematic with a low density of information. The pictures were not detailed and tended to present static depictions of expected objects. The genres used were descriptive or narrative pictures.

The Colored Map

This multiliteracy product was the result of an early classroom activity designed to make students understand that most of the world is covered with water. This had been a point of discussion in an early class, and the teacher decided to introduce a visual representation as the best way of overcoming any misconceptions in relation to this geographical knowledge. The map coloring activity was conducted on a photocopied map of the Continental United States. In its original form the map was a black and white page with the land mass presented with an outer line contour. The land mass presented consisted only of North America, Canada was not represented. Visually, the map showed North America and Mexico as an island. The central aspect of this activity for the student was the coloring in of three aspects of the map – the water in blue, the land in brown and the shoreline in red. This activity involved using a key, coloring and symbolically marking using the key and understanding a basic inference based on a visual analysis. The task produced a schematic visual representation with limited informational content. The inferential component of this activity was flawed involving a contradiction between the visual representation and the authorized statement of summary. This activity involved reading and following an instructional worksheet with color-coding instructions. The genre was a schematic visual representation.

Photograph Description

This multiliteracy product was the result of an early knowledge activation activity. The central aim of this activity was to generate discussion about beaches and to activate the students' knowledge of beaches. The activity was multimodal and consisted of the description of a beach presented in a photograph. The activity was organized as a worksheet in which the photograph was at the bottom of the page and space for the written description was left at the top of the page. The written description was initiated by placing a sentence and a half at the beginning of the paragraph. The beginning sentences were "Here is a photo. I can tell that a beach is there because." The activity had a component of developing an understanding of the role of visual analysis in supporting a claim. The analysis of the descriptive paragraphs supported previous analyses about the experiential nature of knowledge of the shoreline at this early stage in the unit. The students demonstrated an undifferentiated understanding of the sea and beach. In producing the paragraphs the students used three sources of information, the visual analysis, background knowledge and stock statements from the teacher's discourse. However, they relied on background knowledge and the teacher's statements. They showed a limited understanding of the role of visual analysis and information in supporting a claim or a description. Although the design of the activity asked for a written description, the students presented lists of written objects without connecting them. The genre of this activity consisted of a list of objects functioning as a description of a photograph contents.

Beach Bucket Scavenger Hunt and Categorization

Three multiliteracy products were produced during this activity. The three products were: a beach bucket findings list, an evidence categorization activity and an alive/never alive categorization activity. All three multiliteracy products were the result of the activity of beach bucket scavenger hunt, a simulated exploration of beach contents. The aims of this activity were: the development of an observational understanding of the beach contents, the development of an understanding of systematic observation, the development of categorization skills and the development of inferential processing. The data demonstrated a widening of the knowledge the students had relating to the contents of the beach. The beach exploration list included a much wider set of objects than those recorded in the earlier knowledge activation activities. In the categorization tasks, this wider list was reorganized into a series of categories based on inferential information. In both of the categorization activities, students demonstrated the ability to use inferential information in the assignment of objects to the different categories. The exploration and categorization activities involved the generation of item lists. There was a progression in the graphic format among the three activities. The first used a simple line format, the second utilized the graphic organization of four separate areas arranged on a page and the third utilized a Venn diagram with two interconnected circles and an overlapping area. Students easily negotiated the first two formats but had difficulty with the overlapping area of the Venn diagram. These activities demonstrated a development in scientific knowledge, procedure and thinking. The knowledge of the beach had more differentiation than in the early knowledge activation activities. Students learnt and practiced methods of data observation and data recording using word lists and graphic organization. In order to generate the lists according to categories, an inferential process was involved, and, for the Venn diagram, an additional problem solving component in relation to the overlapping area was included. Students were involved in the reorganization of the same data for two different categorization exercises. Although there were difficulties for some students in relation to the graphic organization of the Venn diagram, the current set of activities demonstrated a rudimentary development in scientific knowledge and thinking. The genres of this activity consisted of a list of found objects, a graphic organization of word list and a Venn diagram.

My Favorite Rock and Shell Description

Two connected multiliteracy products were the result of this activity. The activity consisted of providing both a written and a pictorial description of a shell and a rock. This activity had several related aims: to direct the students to conduct a detailed observation of objects found at the beach, to provide the experience of recording an observation and to enhance the students' epistemological understanding of the argument structure of a claim supported by specific evidence. This activity was conducted in several stages consisting of: choosing a shell and rock, criteria based observation of a shell and rock and the written description (in two drafts) and visual representation of the shell and rock. For the written description of the shell, the students were provided with a worksheet with lines that had the following sentence at the beginning of the page "This shell from the beach is my favorite for many reasons." For the description of the rock the students were given a handout with the following sentence at the beginning of the page "This rock from the beach is my favorite beach rock because." The written paragraphs and majority of the rock pictures were rich with content and demonstrate that the directed observation was successfully conducted. The paragraphs of both the shell and rock were coherent and organized around the categories of information used for the object observation. The students produced well-organized, detailed written descriptions. The epistemological aim of enhancing the students' understanding of argument structure did not seem to have been achieved in this activity. The genres of this activity consisted of descriptive paragraphs and descriptive pictures.

Chapter Beach Books

This multiliteracy product was the result of the activity of writing a beach book consisting of four chapters relating to different aspects of the beach. In its design this activity had the aim of summarizing previous learnt material and experiences relating to the beach and a component of individual research in which the children were supposed to read and summarize their own knowledge of different beach creatures. In order to facilitate the book writing process, each student was provided with a schematic outline of the book and its chapter headings, a page with a summary of key concepts that have been learnt and sources to conduct individual research. These materials, in conjunction with brainstorming and outlining activities, were intended to provide a scaffolded book writing and knowledge summarization activity. The limited ability of the students to write informational paragraphs seemed to limit the writing of the specific chapters of the book. No student wrote all four chapters with most students writing only two chapters. The content of the chapters did reflect some of the key ideas developed in the unit. But the writing of the chapters seems to have relied heavily upon the summary of key ideas provided on a handout. These were expressed in brief paragraphs consisting of collections of individual sentences rather than organized informational paragraphs. The content of the chapters and the process of note taking and chapter outlining did show an understanding of differentiated chapter content. The use of symbolic notation was an interesting development, showing a movement towards the type of notation that is often used within descriptions of scientific processes. Overall, this activity did not result in the students clearly conceptualizing their understandings of the work conducted within the unit. The genre of this activity consisted of informational paragraphs organized under four chapter headings.

Directed Observation – Sand on Stage and the Unknown Sand

This multiliteracy product was the result of the literacy activities of Sand on Stage and the Unknown Sand worksheet. Both of these multiliteracy products functioned as a method of both recording and directing the process of scientific description of sand and the role of tools of measurement in this process. Both of these multiliteracy activities consisted of worksheets with a series of questions and activities that needed to be addressed. The aim of these activities was to develop the students' understanding of measurement, directed observation and the multiliteracy representation of observational findings. This directed, tool based observation and the use of the worksheet extended the students' understanding of the components of sand and the way scientific observation is conducted. The recording of detailed and rich observations of the sand demonstrated the students' understanding that science involves the attempt to represent what is observed and not just schematic responses based on prior knowledge. The students' responses to the worksheets demonstrated an ability to use the tools provided to them and to work in a systematic and guided format. The specific knowledge acquired during this observational process consisted of a more in-depth and detailed understanding of the qualities of sand, the connection between the sands observed and rocks, and some understanding of the potential sources of this sand. In recording their observations, the students used both written and visual forms of representation. The genre used in this activity consisted of a directed observation worksheet.

My Sand Summary

This multiliteracy product was the result of an observation activity involving a microscope. This activity was a continuation and intensification of the activities described in the analysis of The Unknown Sand and Sand on Stage. The activity of My Sand Summary consisted of the observation of a small sand sample under a microscope and in two drafts writing of a descriptive paragraph summarizing the observation. The aim of this activity was to widen the students' experience with different scientific tools and to provide additional experience of using literacy to record observations made. The students wrote coherent organized paragraphs. This activity extended previous observational tool-based activities conducted by the students. In the descriptive paragraphs the students discussed the grains of sand and represented the sand in a diversified manner, differentiating among differences in color, size, shape and source. The use of the microscope was seen to change the representation of the sand grains. The specific knowledge gained by the students addressed the composition of the sand and the individual characteristics of the sand grains. The genre used in this activity consisted of a descriptive paragraph.

Making Inferences

This multiliteracy product consisted of two worksheets that required students to make inferences and then explicitly state the evidence that was used to make these particular inferences. This activity had the epistemological aim of making the structure of a scientific argument explicit. The argument structure that this activity addressed was the evidence-based inference. The two worksheets had a similar, three-part structure. Both worksheets consisted of the presentation of some initial information under the heading "What I know" or "You know"; the call for an inference under the heading "My inference is" or "Inference"; and a final section with the request to explicitly state the nature of the evidence used to support the inference that had been made. The analysis of this activity revealed that the students did produce inferences. These inferences were extensions of activated schematic background knowledge. The request for evidence within the argument structure was understood by the students as a request for the source of the information used to generate the inference. This is an epistemological position dealing the validation of the inference. However, this is not a scientific, evidence based argument structure. Thus, the task did raise awareness for the need for evidence, but does not seem to have contributed to the wider aim of utilizing evidence in supporting one's claims. The concept of support was understood as a request for the validation of the source of the information and not as evidence supporting the claim. The prevalent argument structure consisted of a world knowledge inference validated by a reference to personal experience. The genre used in this activity consisted of a directed worksheet.

The Postcard Story

This multiliteracy product was the result of a story summarization process. The aim of this activity was to direct the students to summarize their understandings of the process of sand creation in both pictorial and written modes. The activity of creating pictorial and written narratives of the process of sand creation was preceded by a shared reading of a book, which personified one rock's journey to the shoreline. This shared reading created a forum in which knowledge relating to the process of sand formation could be both presented and exemplified. The activity of postcard story drawing and writing was designed as an activity that would allow the students to present the process of sand formation themselves. The process of postcard creation was conducted in two stages. First, the pictorial representations were drawn, and then on the back of the cards with the drawings the narratives were written. As a scaffolding process, the students produced pictorial sketches of the proposed postcards before drawing the final versions of the postcards. The pictorial sketches did show the development of knowledge of the process of sand formation. Five different narratives addressing the way sand is formed and the forces involved in this process were produced. The analysis of the final postcards in both their pictorial and written formats demonstrates a certain difficulty in completing this task within the time restrictions provided for it. The postcard stories were not completed by the majority of the students and the written component was limited, lacking explicit connections across cards. The disparity between the knowledge expressed in the pictorial sketches and the knowledge shown in the postcards would suggest that this is a representational rather than a knowledge problem. The genres used in this activity consisted of extended graphic narratives and extended written narratives.

Beach Animal and Plant Report

This multiliteracy product was the result of an activity designed to produce a written report about animals and plants living on the beach. The reports were written utilizing the information that had been acquired from reading encyclopedic descriptions of the different animals and plants that were chosen by the students. This activity was conducted in three stages. The initial stage consisted of finding a plant or animal of interest and then reading appropriate encyclopedic material relating to the animal or plant that had been chosen. This involved a comprehension process of the material that had been read and some note taking. The second stage consisted of writing a draft of the report. The report was to be written as a four-chapter mini-book. Each chapter was termed a "Topic." The idea behind this design seems to have been the development of a taxonomic structure for an informative text. The information found in the first stage would be reorganized around four specific topics that together describe and explicate the plant or animal of the beach that had been chosen. The last stage consisted of writing a final report. The final report followed editing suggestions by the teacher. In all thirteen students produced written reports. The reports provide a depth of information that is clearly organized on the chapter book and paragraph levels. Relevant information has been comprehended and synthesized from the encyclopedic sources and organized into topic headings. The overall reports provide clear information allowing a description of the animals described on a variety of parameters to emerge. The chapters were coherently organized using proper noun or pronoun repetition. Information was presented in form of taxonomy of information. The genre used in this activity was an extended informational report.

Oil on the Beach – Observation and Prediction Worksheet

This multiliteracy product was the result of an experiment designed to test hypotheses relating to the appropriateness of different materials for cleaning up oil spilt in the sea. The multiliteracy product was a worksheet that was utilized to direct, organize and summarize the experiment on oil spills. The worksheet directed the students to make predictions, check these in an observational setting and consider their conclusions from the observed data. The worksheet was designed to have three sections that worked in conjunction with the conducted experiment. The three sections of the worksheet were a prediction section, an observation recording section and a conclusion section. Completion of these sections was related to the stages of the small group experiment with students' first offering predictions, then recording the results observed in the experiment and finally reaching conclusions as to the best materials to use for oil spill clean-ups. The worksheet had the aim of directing a process of hypothesis testing. The students utilized the worksheet to organize their observations. Changes that were found between the prediction and the recorded observation demonstrated the role of evidence in hypothesis testing. The worksheet did not allow a range of responses to degrees of absorption for different materials to emerge. The students did rank the materials for their ability to absorb oil; however, the basis for this decision was not provided on the worksheet.

Summary of Research Findings

The objectives of the current research project consist of both practical and research orientated objectives. In this section, a summary of the main findings relating to the research objectives of this study will be presented. Beyond the in-depth qualitative description of the multiliteracy tasks of this unit, the research project has the aim of describing how scientific knowledge develops in this second grade classroom and to describe the role of literacy and multiliteracy in this process. Specifically, this research project attempts to answer the following questions:

1. What characterizes the process of substantive scientific knowledge development in this unit?
2. What characterizes the process of procedural scientific knowledge development in this unit?
3. What characterizes the process of written literacy scientific knowledge development in this unit?
4. What characterizes the process of visual literacy scientific knowledge development in this unit?
5. What is the role of multiliteracy in the development of scientific knowledge?

Summary of Substantive Scientific Knowledge Development

Overall, the process of substantive knowledge development documented in this unit can be seen as the development of a more scientific understanding of the nature of the beach. The facts learned consisted of seeing the shoreline as a collection of eroded materials of different sources and types, the idea that each of these grains traveled long distances to reach its destination on the beach, the concept that the grains of sand have specific observable and measurable properties, and that the beach is a complex ecosystem inhabited by a variety of animals and plants. This development of these substantive understandings transformed the students' understandings from an experiential, stereotypical and holistic understanding of the beach to a differentiated, scientifically informed and observation-based understanding of the sandy shoreline

Developmental Stages in Relation to Unit Tasks and Products

Several stages of this overall development of substantive scientific knowledge were documented through the analysis of the tasks and products utilized in this unit. The initial multiliteracy products of this course (Beach Picture Folder, Colored Map and the Photograph Description) demonstrated the students' experiential understanding of the shoreline based on stereotypical activities and contents of beaches. Through the activity of the Beach Bucket Scavenger Hunt there was a deepening of the understanding of the components of the beach. As seen in the Beach Bucket Finding List, the components of a beach included 19 new objects, which did not appear in the experiential description of the beach. This process was further extended by the process of describing a rock and a shell. As seen in multiliteracy products of 'My Favorite Shell" and "My Favorite Rock", specific objects found at the beach were considered in relation to their specific properties such as color, texture, weight, and pattern. Through the tasks of tool-based observation of sand, the concept of sand was changed. As seen in the Chapter Beach Books, The Directed Observation: The Unknown Sand, the Directed Observation: Sand on Stage and My Sand Summary, the concept of a beach consisted of a collection of "tiny bits of rock, shell and other material". The directed observation worksheets showed evidence of the process of close observation where sand was addressed not as a holistic entity but rather as a collection of grains of materials that each had specific properties such as color, size, weight, and magnetism and came from a variety of different sources. The next modification in substantive knowledge was the development of a concept of the process by which sand on the beaches was formed. Through a shared reading of a classroom reader students were introduced to a story, which personified and narrated the scientific process of sand formation as a journey of a single rock to the beach. As seen in the visual representations in the Postcard stories, the students internalized and then reproduced five different narratives of the process of sand formation. The final development in substantive knowledge that can be documented consisted of the extended understanding of a range of beach animals that live on the ecosystem of the sandy shoreline.

Summary of Procedural Scientific Knowledge Development

Procedural scientific knowledge was considered to consist of the development of modes of scientific thinking related with science and the development of specific skills associated with the tools and methods of empirical investigation and measurement. In broad terms, the development of scientific thinking consisted of the movement from a holistic and authority based approach to natural phenomena to a rudimentary form of observation-based conclusion. The process of scientific thinking development consisted of the development of several different cognitive abilities. The students learnt and utilized the conceptual components of observation – the ability to notice specific properties, the internalization of these criteria and the ability to organize and reorganize groupings and categorizations according to different observed properties. The students also learnt how to use observations in a series of scientific thinking patterns. On a basic level students were introduced and showed the ability to reproduce the concept of a process of sand formation. Students conducted observation based comparisons, made world knowledge inferences, and were involved in a rudimentary process of hypothesis testing. Students demonstrated the ability to use tools of observation and follow written and verbal instructions. Students demonstrated certain difficulties with the concept of explicitly connecting evidence to conclusions made and demonstrated a certain reliance on the teacher's authority and prior knowledge.

Developmental Stages in Relation to Unit Tasks and Products

Several stages of this overall development were documented through the analysis of the tasks and products utilized in this unit. At the beginning of the unit, as seen in the analyses of the activities of the Colored Map and the Photograph Description, the students presented experiential knowledge of their understandings of the beach. In these activities, it was seen that students deferred to the teacher's (or written worksheets) explicit statements rather than base their conclusions on any personal inferential or observational conclusions. In the first inquiry science task, the Beach Bucket Scavenger Hunt, students utilized cognitive abilities designed to develop observation and categorization skills. The analysis of the video data of this task showed students deeply involved in a process of noticing and grouping different objects found in the beach bucket. The process of noticing addressed named objects, materials and physical properties. This development of scientific thinking was further enhanced through the process of categorization and grouping. Oral discussion, argumentation and verbal reflection were all part of the categorization process. However, there was still a reliance on the teacher's authority in final decisions as to category grouping and definition.

The process of reorganization through categorization was further enhanced in the multiliteracy activities of the Evidence Categorization Activity and the Alive/Never Alive Categorization Activity. Both these activities involved inferential processing utilizing information gathered in the Beach Bucket Scavenger Hunt task. In the Evidence Categorization Activity, students were required to relate to the noticed objects found in the Beach Bucket Scavenger Hunt as evidence of types of things found in the beach eco-system. Thus, the objects were re-categorized and reorganized into the new categories. The Alive/Never Alive categorization task was based on the conceptual and graphic organization of a Venn diagram that went beyond previous categorization processes as it posed an overlapping area of dual categorization. Further evidence of the development of the noticing and observation process was found in the multiliteracy tasks of My Favorite Shell and My Favorite Rock. The descriptions of both the rock and the shell provided evidence of specific criteria of observation and the attempt to realistically represent the object that was observed. The concept of criteria for observation was utilized in the tool based directed observation recorded in the video data of the Science Inquiry of Sand. This process was conducted on a worksheet that directed the observation of sand using open noticing and the tools of a magnifying glass, a microscope and a magnet. All of the observations were recorded using a set of multiliteracy worksheets. Information gained from these directed observations was organized according to world knowledge, patterns of comparison and evidence based inferences

The most direct evaluation of the students' abilities to conduct an evidence-based inference was found in the Making Inferences worksheets. In these worksheets, students were required to generate inferences extending knowledge provided to them and then to state the evidence used in their conclusions. The students did produce inferences in most cases. However, a very specific structure of inferential argument was used. The students based their inferences on prior knowledge and did not provide evidence supporting the actual inference made; rather they understood the concept of evidence as the request to state "how they knew what they knew." In other words the majority of students provided a world knowledge inference and then said that they knew this because they had directly experienced it. A development in scientific thinking in a slightly different direction was the development of the concept of a process. Specifically the process discussed and then reproduced by the students was the process of sand formation. The video data of the shared reading and the analysis of the multiliteracy product The Postcard Story showed evidence of the development of the understanding of process as a network of cause and result relationships.

The final development in scientific thinking was found in the final multiliteracy product analyzed in this study. The Oil on the Beach – Observation and Prediction Worksheet was a worksheet that directed a process of scientific thinking. Specifically the process addressed was that of prediction (hypothesis generation) evaluated through empirical observation. The worksheet directed the students to specify their predictions and then to mark their empirical observations collected through a small group experiment. The worksheets did show a process of change from the prediction to the observations. Accordingly, empirical evidence was used to overturn prior knowledge and specific hypotheses were tested. The students were also required to reach conclusions based on the experiment and to explicitly state what evidence was used in order to support these conclusions. As with the inference making worksheets, the understanding of the relationship between evidence and conclusion proved problematic and not a single student actually presented evidence in support of their conclusions. Thus, at this final stage of the course, scientific thinking was demonstrated in the use of empirical data to overturn prior predictions (a process of hypothesis testing) and allow conclusions to emerge. But this was not a fully structured scientific argument of explicitly stated observational evidence supporting a claim that was made. It was a more rudimentary form that takes into account evidence but does not propose a clearly stated relationship between evidence and conclusion

In addition to the development of certain patterns of scientific thinking, the students also developed procedural knowledge of methods that were significant in active science inquiry. On a very basic level there was ample evidence in both the video data of the various tasks and the associated worksheets that students were fully capable of following instructions carefully both in the oral or written formats. This unit developed specific methodological knowledge, useful for the process of observation. In the Science Inquiry of Sand students developed an understanding of how to work with three different instruments, the magnifying glass, the microscope and the magnet. As seen in the video analyses of these tasks, the students explored the nature of the tool itself and how it worked. The associated worksheets that accompanied the use of these tools made sure that observations and the use of these tools was not left to the experiential realm but rather was translated into recordable observation. The use of these tools in an appropriate manner was shown to change the way sand was represented and allowed direct comparisons to be made. Patterns of comparison and rank order according to size or color are rudimentary forms of measurement.

Summary of Written Representation Development

Overall, the process of written representation development can be characterized as the development of greater control over the genre of scientific inquiry. The students' development moved from the use of simple lists to the ability to synthesize information and produce extended informational reports based on encyclopedic sources. The students demonstrated the ability to produce descriptive paragraphs and to use a variety of worksheets at different levels of conceptual complexity. These worksheets were seen to direct scientific thinking processes such as hypothesis generation and evaluation, categorization, comparison and contrast. There is evidence that literacy was difficult for this group of students. On the whole, the paragraphs written were short and had a series of specific linguistic difficulties that were addressed through the revision process. Students had difficulty writing the extended narrative and their first informative writing activity. Several different scientific genres were seen to develop during this unit, the use of lists in graphic formats, descriptive paragraphs and informational reports. Literacy was used to record observations, direct observations, make predictions and inferences, compare and contrast objects and find additional information. Of particular importance was the shift in the way objects were described following criteria-based observation. Students attempted to produce realistic observation-based descriptions of the objects observed.

Developmental Stages in Relation to Unit Tasks and Products

In the initial activities of this unit, students used lists to represent knowledge that they had acquired. In the Photograph Description students were asked to produce a descriptive paragraph of what they observed in a picture but they produced a list of objects without any linguistic connections. A more appropriate use of lists was found in the Beach Bucket Findings List. The list was used as a way of recording of the objects found in the beach buckets. A more developed use of lists was found in the Evidence Categorization Activity and the Alive/Never Alive Categorization Activity. In these activities, written lists were used in conjunction with the visual representation of distinct categories in the form of drawn circles.

Evidence of the development of descriptive paragraph writing was found in the My Favorite Shell and My Favorite Rock activities. In both these writing activities, a specific object was to be observed and described in writing (and in a visual format). The students produced coherent paragraphs consisting of relevant information in a clear organizational structure. The informational structure conformed to a list of observational categories – color, texture, weight, shape, pattern, descriptive associations and statement of wishes. The attempt was to clearly describe the object that had been observed. Further evidence for the ability to write descriptive paragraphs was found in the My Sand Activity. The written paragraphs were coherent, informationally relevant and well organized. All three descriptive paragraph activities had a component of process writing in them. The students produced drafts before they wrote final paragraphs. The final version included the proposed revisions of the draft which mainly addressed issues of linguistic form.

The ability to represent information in literacy was further extended in the Chapter Beach Book activity. This literacy activity produced an interesting disparity between the ability to design an informational structure for a four chapter (paragraph) length book and the ability to write an informational paragraph. Students demonstrated difficulties in writing an informational paragraph. The informational paragraphs produced by the students were very brief and lacked a clear organizational structure. In writing these paragraphs, the students seemed to rely on existing statements drawn from a worksheet that had been provided for the students. The ability to write an extended narrative was also seen to be difficult for the students in this class. The written component of the Postcard Stories was not well developed. The students did produce visual narratives to represent the process of sand formation, but when it came to producing a written version of the narrative, the students wrote very brief sentences providing a minimal description of the content of the picture. These written descriptions did not create linguistic connections across the picture panels. The descriptions created a narrative only in conjunction with the pictures themselves. By themselves these descriptions would not constitute a written narrative. Towards the end of the unit, the students' abilities to write extended informational reports were seen to improve. The Beach Animal and Plant Reports provided evidence of the student's ability to use encyclopedic information and to organize it into a four chapter (topic) length report. The encyclopedic information was synthesized and reorganized to match the different chapter headings.

Throughout the course, the students demonstrated the ability to fully utilize worksheets in their scientific explorations. There was a process of development in the worksheets. The earlier worksheets, such as the Beach Bucket Findings List, were used as directing and recording devices. The later worksheets, in addition to these two roles, also directed a set of more complex thinking patterns. In the Evidence Categorization Activity and the Alive/Never Alive Categorization Activity the process of grouping and categorization was directed by the worksheet. In The Unknown Sand worksheet and the Sand on Stage observation worksheets, in addition to directing and recording the students' observations, the worksheets directed a process of comparison in relation to other samples and rocks. Finally, in the Oil on the Beach: Observation and Prediction worksheet, the worksheet directed a process of hypothesis testing. In this literacy activity the worksheet itself directed this process by requiring students to record their predictions and then compare these with actual observations. Thus, students working on this worksheet simulated the basic scientific concept of using observations to qualify or change proposed hypotheses.

Summary of Visual Representation Development

Visual representation referred to any meaningful visual material produced or utilized within the classroom setting as part of the unit investigated in the current study. Two major types of visual information were used in this unit – visual representations in the form of pictures and visual representation in the form of graphic, symbolic shapes. Both these forms were used to represent scientific understandings and were seen to develop as ways of representing scientific understandings through the tasks and activities of the unit. Two genres of pictorial representation were used: descriptive pictures and narrative pictures. Overall, the process of visual representation development consisted of the movement towards observation-based representation and utilization of graphic symbolic forms for the notation of semantic relations among objects. The development of descriptive pictorial visual representation consisted of the movement from schematic representation based on learnt forms to realistic representations of specific objects. Students changed the method of visual representation following the development of observational abilities. The movement was towards realistic descriptive representation taking into account the specific observable qualities of the object being represented. Narrative pictures were found to develop from the imaginary use of narrative to the use of visual narratives to represent a scientific process. The students learnt how to use graphic forms to organize and reorganize their observations and to represent different relations among the listed objects. There is a direct connection between the development of observational abilities and the attempt to produce realistic representations of objects.

Developmental Stages in Relation to Unit Tasks and Products

At the beginning of the course, in the Beach Folder Pictures, the majority of the students used schematic representations for the objects presented. These schematic representations consisted of shapes that symbolically represented specific objects. However, later in the unit in the analyses of My Favorite Rock, 12 of the students attempted to produce pictures that represented the specific attributes of the object being observed. In these pictures, the unique contours, colors, and patterns of the specific rock were represented. The attempt in these pictures was not to provide a symbolic shape to represent the rock but rather to represent the unique aspects of the specific rock that was observed. Development was also found in relation to the use of narrative representation. In the early Beach Folder Pictures, narrative pictures were used to represent imaginary narratives of sea adventures involving attacking sharks or hidden treasure. The narratives represented action in a single picture. In the Postcard Stories visual narratives were used to represent a process of sand formation. The narratives covered three to four visual panels and represented the movement and changes of a specific object (rock, bottle or coral) from its initial place and state to its final destination on the sandy beach. The narratives created continuity across panels and thus allowed a more extended narrative to be produced. The actual narrative represented an understanding of the scientific description of how sand was formed and was not a personalized imaginary narrative.

Graphic representation also played a role in the development of scientific representational knowledge. The processes of grouping and categorization were represented through the use of graphic symbolic forms. These came in three different formats. On a most basic level, in the Beach Bucket Scavenger Hunt after having collected the objects that were to be grouped together, the students used a pencil to draw a circle around the objects on the table. This circle represented the unity of the disparate objects found within its borders. On the two worksheets associated with the Beach Bucket Scavenger Hunt, the Evidence Categorization Activity and the Alive/Never Alive Categorization Activity, this process of using graphic forms to demark grouping and categorization was further enhanced. The worksheets used drawn circles as defined spaces in order to represent specific categories. Students used the spaces to write their lists of objects. The Alive/Never Alive Categorization Activity used a Venn diagram that provided an overlapping space for objects with characteristics that covered both categories. The overlapping category of the Venn diagram posed conceptual difficulties for some of the students. But the difficulties found for this graphic representation actually showed that the graphic forms are understood and used as semantic markers of the categorization process.

The final development in graphic representation that needs to be addressed is the use of symbolic notation. The use of symbolic notation was found in the writing process of the Chapter Beach Books. Symbolic notation was part of the note taking process which supported the development of the books themselves. The specific notation used consisted of arrows and circles combined with named objects designating an inferential relationship among the objects presented. Symbolic notation was used as a short form to represent that certain objects were evidence of the presence of different people, animals and objects on the beach.

Summary of the Role of Multiliteracy in Scientific Knowledge Development

In very simple terms, the process of learning science as reflected in the analysis of the video data and the products created throughout this unit was seen to be a multiliteracy process which integrated oral, written, pictorial and physical modes of communication to develop procedural and substantive scientific knowledge. The process of learning science was directly tied to the multimodal forms of communications used in the classroom. The science inquiry approach to science teaching was intrinsically connected to a multimodal approach to instruction. Three recursive multimodal progressions characteristic of science learning in this unit were found and analyzed. These multimodal progressions were: the multimodal direction of inquiry science; the multimodal and multiliteracy negotiation of scientific understanding; and multiliteracy summary.

Multimodal Direction of Active Science Inquiry

One crucial aspect of any active science inquiry class is the ability of the teacher, teaching materials and course designers to produce a meaningful learning experience. In the current unit, this was addressed through a multimodal design that consisted of an interaction between oral discourse, physical activity and written worksheets. The oral discourse introduced the basic concepts and instructions for conducting the inquiry science activity, made sure students stayed on task, and provided a summarizing discourse presentation. Written worksheets directed the moment-to-moment activities of inquiry science and provided a framework for recording observations. The oral discourse provided an envelope within which the science activities were conducted, and the written worksheets made sure that the tasks were correctly paced and that the experiences were transformed into data that could be addressed and manipulated.

Multimodal and Multiliteracy Negotiation of Scientific Understanding

The attraction of inquiry science is its ability to engage students in simulated scientific activities. However, as with all such activities, the conceptual implications and meanings of the activity need to be directly addressed and made explicit to the students. Essentially, this is a process of multimodal translation from physical actions to verbal or visual symbolic conceptualizations. The process of conceptualization is the process through which the inquiry activity becomes scientific knowledge. In the current data, this process was seen to be a multimodal and multiliteracy directed process. The meaning of various activities conducted by the students was gradually directed towards the meanings considered important by the teacher (and the course designers) through a multilayered negotiation. A characteristic progression of this kind was the movement from physical activity to verbal discussion to written or visual representation. This process can be schematically described as the following progression of events: students are involved in the physical activity and make some initial observations; the teacher comes over discusses the findings and redirects or modifies verbally statements being made; these new understandings are then represented through a written or visual format.

Multiliteracy Summary

An important aspect of scientific learning is the ability to retain the central scientific concepts or processes that are being taught. In the current data set, multiliteracy was seen to play a major role in scientific concept and process retention. The summary of the major understandings of the science instruction was usually handled by the teacher addressing the whole classroom and, at a later stage, by the students themselves in the production of new representations of this knowledge. The form of the summary by the teacher consisted of a verbal, oral description accompanied by a series of written notes of the main points and drawn visualizations of the major points of the process. In some cases, the visualization would be the physical presentation of an object and the focusing of the students' attention on a specific component of that object. The multimodal summaries were complimentary, essentially summarizing the same material in two or three formats. The relation among the formats was one of reinforcement with each mode providing the same information but using its own mode of representation. Thus, information was on the one hand repeated but, on the other hand, allowed access from a different modality. In the students' multiliteracy reproductions of these scientific understandings, it was observed that information may have been better represented in one mode or the other. The presence of a multiliteracy summary and the option for students to represent knowledge in a multiliteracy format enhanced the students' ability to both acquire and express the learnt knowledge of a scientific process.

Summary of Findings Relating to Practical Concerns

In this section, a summary of the main findings relating to the practical objectives of this study will be presented. The research project has practical objectives concerning the classroom implementation and student evaluation of a specific subset of materials developed by the LHS development team. The specific objectives of the practical component of this research project consist of:

1. Based on a detailed analysis of the specific implementation of the "Shoreline Science" unit, the report will discuss the role of the instructor teaching this unit and will provide detailed information that can be used for the writing of an improved teacher's handbook.
2. Based on a detailed analysis of the specific implementation of the "Shoreline Science" unit, the report will present recommendations for the modification of materials used in this unit.
3. Based on a detailed analysis of the specific implementation of the "Shoreline Science" unit, the report will provide detailed information and recommendations that can be used to develop improved student evaluation procedures.

Summary of the Role of the Teacher

The video data collected from the first pilot study of the "Shoreline Science" unit and the analysis of the multiliteracy products utilized by the students in experiencing inquiry science make it clear that the teacher has a pivotal role in the development of scientific knowledge. In relation to the current data set, it is not an exaggeration to say that scientific knowledge development in this specific classroom was dependent on a series of roles that the teacher(s) enacted throughout the course. Five different teacher roles of significance were identified in the data analyzed for this study: designing and implementing inquiry science; providing conceptual understanding of inquiry science; directing students to appropriate informational resources; exemplifying and explicating scientific thinking; and providing literacy instruction and direction.

Designing and Implementing Inquiry Science

Inquiry science is dependent on the ability of the teacher to clearly design and implement the science activities within the classroom setting. As with other aspects of inquiry science, this involves a multimodal design that addresses the physical setting, direction for the students' physical actions and appropriate oral and written discourse. Essentially, all the elements of the multimodal classroom design need to enhance one another in order for the science activities to be implemented with the most instructional value. The physical components of the classroom need to be considered. Inquiry science activities require enough space to be actually conducted. In practical terms, this means combining desks and organizing them so that enough room exists among the desks in the classroom so that the teacher can easily move from desk to desk and children have enough room to do the required work. In addition a focal point for teacher led classroom discussion needs to be created. Since inquiry science is usually conducted as group work, thought should be directed at the composition of the different groups. The basic idea of group design should be to have a mix of students in each group so that strong and weak students could work together. This is particularly important when, as in the current case, there was a large English Language Learner component in the class. Inquiry science inquiry is not self explanatory. The procedures, methods, tasks and aims of the work need to be clearly explicated to the students for any meaningful activity to take place. This needs to be done at the beginning and end of class as providing clear directions and further supported by on-line verbal interaction with the students during the science activities making sure directions are followed and instructions understood.

Providing Conceptual Understanding of Inquiry Science

Science inquiry is conducted in order for students to acquire a substantive and procedural understanding of the scientific knowledge targeted within the unit. It is the teacher who actually directs the understanding of the various tasks conducted by the students and makes the inquiry activities meaningful in relation to the aims of scientific knowledge development that underpin the design of the science/literacy unit. As analyzed in the current research project there were three points at which the teacher's interaction was crucial for the development of conceptual understanding: initial contextualization, on-line feedback and the final summarization. The initial introduction includes explicitly addressing scientific concepts while connecting these to the personal experiences of the students. During on-line responses to student work, the teacher modifies and directs the students understanding of the phenomenon being studied. This direction of thinking may be subtle in the form of a repetition in more scientific terms of the statements that the students make and/or it may be more intrusive, providing a summarizing statement that verbalizes what the students are doing and what their findings are. The teacher's use of final statements makes explicit the specific understandings and concepts that are to be remembered and learned from the science activity.

Directing Students to Appropriate Informational Resources

By definition science is a historical, communal activity that has built a body of knowledge relating to a variety of natural phenomena. Students need to be aware of the existence, use and value of this body of knowledge. In particular, students need to become acquainted with those sources of knowledge that were designed specifically for children and can be useful in the development of scientifically based knowledge. Within the framework of the current data set two different instances of this aspect of the teacher's role were identified. These roles consisted of the presentation and explication of scientific vocabulary and the presentation and explanation of reliable and informed sources of scientific information. Essentially, the teacher functions as the intermediary between the community of scientists and the students within the classroom, allowing them access both to bodies of developed knowledge and to modes of representing scientific knowledge.

Exemplifying and Explicating Scientific Thinking

Inquiry-based science in the classroom is dependent on an understanding of the epistemology and thinking patterns of scientific inquiry. An epistemological understanding of science transforms the activities conducted in the classroom from a series of instructions to be followed into a way of constructing personal knowledge. The teacher has an important role in explicating and exemplifying the types of thinking that underpin scientific inquiry. In the current analysis, this role was seen to happen in two different ways. First, epistemology needed to be explicitly discussed as part of the introduction to each of the inquiry science activities. Second, the actual process of scientific thinking needs to be modeled for the class in relation to activities they have been involved in. The teacher's role consists of making the scientific thinking pattern explicit.

Providing Literacy Instruction and Direction

Literacy and other forms of representation are an intrinsic part of inquiry science. Specifically, literacy fulfills the roles of recording observations, directing the process of inquiry, summarizing understandings, allowing observations to be described and understanding processes. To a certain extent, inquiry science in the classroom cannot be conducted without literacy. The importance and special aspects of science literacy need to be addressed and negotiated by the teacher in the classroom both to enhance scientific knowledge development and literacy knowledge. The teacher fulfills an important role in this context. Students in elementary school may have little experience of the types of literacy task involved in science and, therefore, these need to be taught and scaffolded by the teacher. The data analyzed for the current study reveals several points at which literacy instruction and direction by the teacher becomes crucial. On the simplest level, the students must be able to follow written instructions and provide adequate responses to a variety of different questions. The teacher's role is to make sure worksheets are understood and to make sure they are being followed so that the inquiry science can be properly conducted and observations recorded. On a different level, literacy plays an important role in summarizing student understandings of scientific findings. The teacher's role consists of directing this process and providing appropriate formats for the creation of summaries. As seen in the current data set, descriptive writing was found to be easier and more accessible to students than either informative or extended narrative writing. Of particular importance for all these genres, as used in the context of scientific writing, is the relationship between the written representation and the external observations that it is based on. The teacher's role as a science-literacy instructor is to make the language reflect the actual empirical data of observation. Finally, the teacher also has the role of providing feedback on the formal aspects of the students' writing.

Summary of Multiliteracy Materials Modification

This section deals with the design of multiliteracy materials used in the multimodal environment of active science inquiry. The conclusions below are based on the analysis of the specific tasks and activities analyzed within the current research project. The presence of more than one modality was consistent throughout this unit and can be seen as a basic component of science inquiry. The aim of this discussion is to highlight those points of contact among the modalities and to make explicit significant issues of multiliteracy design. Four issues of design are summarized: compatibility in multiliteracy design, multimodality in representation, timing in a multiliteracy environment and the multiliteracy in scientific thinking.

Compatibility in Multiliteracy Design

Multiliteracy materials by definition are composed of different modalities, which integrate written and visual representations in the students' work. When these materials are used in the classroom during science activities, the additional levels of spoken discourse and physical action are added to the sources of information provided. An analysis of the video data and multiliteracy products produced in the current research project suggest that for both the teachers and the students there is a bias in favor of language. This situation, of the hierarchical position of language, can work against the promotion of the basic scientific understanding that conclusions need to be based on sensory information gathered in a systematic manner. Essentially, this is only a problem when there is a lack of compatibility among the different modes of information. If the spoken or written representations are at odds with the other modalities and are still presented as the understanding of the situation, then we have a situation in which empirical evidence is overridden and ignored. This occurred within the classroom studied and needs to be carefully addressed within the design of the materials and points of classroom discussion and feedback. A simple guideline for material development in this context is to consider each of the modalities as an equal information source and to see if an individual analysis of each modality reaches the same desired conclusion.

Multimodality in Representation

Scientific knowledge can be represented in different modalities. Of particular significance for the retention and comprehension of the development of scientific knowledge are the written and visual modes of representation. In the current research project, it was observed that the students' understandings were not necessarily equally represented in both of these modalities. In some cases, the written mode produced more evidence of student understanding, and, in other cases, it was the visual mode that was used to greater effect. To a certain extent, the data in the current study shows that under certain conditions there is a need to use one or the other modality for the presentation of information. Visual, pictorial representations that attempted to represent objects realistically seemed to work well for the development of observational skills. Written representations of the same object worked well in developing criteria for observation.

Pictorial representations were preferred for the description of a process. Graphic information was seen to work well in defining semantic relations. Written representations worked well in representing lists of findings and for synthesizing other literacy information. These differentiations of modality need to be considered in the design of multiliteracy materials so that each modality can be used to its utmost representational power. At the same time, this element of multiliteracy provides students with the option of storing and expressing their understandings in different ways which may suit their own cognitive styles of learning. Many of the activities integrated two modalities of response, and, even when one modality was requested, students provided another modality on their own. This issue of allowing multimodal responses is to be encouraged within the design of multiliteracy materials as it widens the options for both the student and the teacher to explore the student's understandings of the scientific content of the active science inquiry.

Timing in a Multiliteracy Environment

As seen in the various analyses of the different tasks conducted by the students in this unit, the learning of science goes through several stages and modalities. These different stages incorporate spoken, written, pictorial and physical actions each of which may serve a purpose in the overall development of scientific understanding. It was observed that in some cases not enough time was allowed for each of the modalities in order to fully finish the required work. Although the effective use of time is a general property of any classroom activity, it is particularly important in the design of the inquiry science classroom and its associated materials. A good understanding of the specific tasks and their components should allow more accurate estimation of the time each task takes and the associated usage of multiliteracy. For example, a component such as this verbal interaction needs to be taken into consideration in the design of the time allotted for different activities. This aspect of time was particularly salient in the writing tasks conducted by the students in the current study. For the extended writing exercises (the informative reports and the extended narrative), the students needed much more time than the time provided within the design of the exercise.

The Multiliteracy of Scientific Thinking

Scientific thinking is to a certain extent an exercise in multiliteracy. Scientific inquiry, scientific arguments and empirical findings are usually multimodal representations. In the analysis of the specific classroom studied in the current project, the students demonstrated a certain level of difficulty in understanding and utilizing the scientific argument pattern of evidence based conclusions. The difficulty related first and foremost to the epistemological understanding of the nature of evidence. The default mode of the students in this class seemed to be to accept the teachers explicitly stated position and to believe their own prior knowledge. Both of these positions are useful in the general classroom but can interfere with the process of science inquiry. The developers of the materials used in the unit studied in the current research project attempted to develop scientific understanding of the evidence-based conclusion. What was interesting in the current data set was that this did not work when the design that was used was based on the single modality of writing; but did work when the written modality was integrated within the context of a directed experiment testing proposed predictions. This suggests that the modeling of scientific thinking can be better achieved as part of the multiliteracy simulation of inquiry science and not as a divorced activity. The suggestion is that more work of the sort conducted in the final Oil on the Beach task be integrated within the various science literacy activities, thus allowing students more opportunities to develop an understanding of the scientific argument pattern of evidence-based conclusions.

Summary of Multiliteracy Evaluation Procedures

The series of analyses on the different multiliteracy products developed for the current study provide some understanding of the way scientific knowledge developed within the current unit. This analysis also provides some understanding of the types of knowledge that developed. This summary of findings describes the type of knowledge that should be evaluated as components of scientific knowledge development. Four types of scientific knowledge will be addressed: substantive knowledge, procedural knowledge, written representational knowledge and visual representational knowledge.

Substantive Knowledge of Science Evaluation

Of the four types of scientific knowledge addressed within this section, substantive knowledge is usually considered the most straightforward for evaluation. Substantive knowledge should consist of factual (scientifically informed) knowledge that can be expressed directly by the students. The analysis of the multiliteracy materials conducted in this research project does not change this basic assumption. What is interesting in the current analysis from the perspective of substantive knowledge development is that a difference was found in the substantive knowledge expressed through different modalities. The common approach to the evaluation of substantive knowledge is to use pen and paper with a particular bias towards the closed question format. The analysis of the multiliteracy products produced within the classroom demonstrates that a significant amount of substantive knowledge was expressed through visual formats and not necessarily through the written format. This may have significant implications for English Language Learners that may be able to express more substantive knowledge in a visual mode rather than a written one. It is a well documented phenomenon that the form of the question (open or closed) influences students' abilities to respond. The data in the current analysis suggests that the modality of the response also influences the response of the student. The evaluation of substantive knowledge development should take into account the option of providing visual as well as written modes of response. This may allow students additional representational options for expressing their understandings of substantive scientific knowledge.

Procedural Scientific Knowledge Evaluation

The development of scientific thinking in the unit was seen to consist of a movement from a holistic, authority based understanding to a rudimentary form of observation-based conclusion. The crucial shifts in this movement were the elevation of the cognitive processes of criteria based observation, grouping and categorization, thinking patterns of differentiation, comparison and causal connection, and simple hypothesis testing. For purposes of evaluation, each of these processes should be considered as an ability that needs to be evaluated through the presentation of evidence of competence. The approach taken within the current analysis was to define the core abilities associated with each component of procedural scientific knowledge. Below is a summary of the main components and criteria to be used in evaluating procedural knowledge:

1. *Proposed criteria for observation and noticing*
    - Demonstrates the ability to use relevant criteria for observation in a systematic manner.
    - Demonstrates the ability to notice and represent the specific qualities, properties and characteristics of the object or phenomenon being observed.
2. *Proposed criteria for the use of tools of observation*
    - Demonstrates an understanding of the properties that the observation tool measures.
    - Demonstrates the ability to observe accurately using this tool those qualities, properties and characteristics that the tool is designed to investigate.
3. *Proposed criteria for grouping and categorization*
    - Demonstrates the ability to physically, verbally or visually group objects together based on a shared commonality.
    - Demonstrates the ability to verbally provide a logical basis for the inclusion of objects within the defined group.
    - Demonstrates the ability to verbally defend the proposed grouping and categorization when questioned about grouping and categorization decisions.
    - Demonstrates the ability to group and regroup objects according to different principles for categorization.
4. *Proposed criteria for comparison and contrast*
    - Demonstrates the ability to systematically use the same set of criteria for the comparison of several objects or group of objects.
    - Demonstrates the ability to use observational criteria to define distinctions or commonalities in the objects being observed.
    - Demonstrates the ability to use written materials in conjunction with empirical observations in order to conduct comparisons and identify objects and groups of objects (or to provide evidence that falsifies identification).
5. *Proposed criteria for the construction of an empirical argument*
    - Demonstrates the ability to generate and record inferences and predictions concerning scientific phenomena.
    - Demonstrates the ability to collect and record relevant empirical observations in relation to the inferences and predictions that have been made.

- Demonstrates the ability to evaluate predictions and inferences in light of empirical observation.
- Demonstrates the ability to verbally explain, while using empirical evidence, the reasons for supporting or changing a proposed prediction.

6. *Proposed criteria for the understanding of a scientific process*
    - Demonstrates the ability to represent a cause and result relationship.
    - Demonstrates the ability to construct an extended global structure that includes several causal relationships organized as temporal relations.
    - Demonstrates the ability to follow and explain the stages of change of the specific process being learnt or investigated.

One final aspect of the evaluation of procedural knowledge that needs to be addressed is the role of multiliteracy. As with the discussion of substantive knowledge, the evaluation of scientific thinking should be based on a concept of multiliteracy since evidence of these abilities may be expressed through different modalities.

Written Literacy Knowledge Evaluation

The overall direction of written representation development in the data analyzed in the current research project consisted of the gradual development of the ability to handle larger units of information in a coherent fashion and to base this information on observation rather than prior knowledge. Throughout the unit, several different written genres were used. These genres consisted of written lists, worksheets, descriptive writing, narrative writing and informative writing. The current discussion of written representation evaluation will utilize the concept of genre to provide a framework for genre-specific criteria for evaluation. This level of analysis is textual and addresses the role of the genre in scientific knowledge development. The approach taken within the current analysis was to define the core abilities associated with each genre and to use these as a way to evaluate literacy abilities. In addition to the criteria set out below for each genre, criteria relating to orthographic and syntactic form need to be addressed in student writing at these grade levels. The same criteria addressing linguistic form on the word and sentence level used with other genre in the elementary school classroom should be used in the case of scientific writing and reading. Below is a summary of the genre and main criteria to be used for evaluating written literacy knowledge:

1. *Proposed criteria for written lists*
    - Demonstrates the ability to record objects or items in the written form of a list.
    - Demonstrates the ability to construct a list of items that have actually been observed and result from an empirical collection of data.
    - Demonstrates the ability to name or provide accurate information for the identification of the item or object on the list.
    - Demonstrates an understanding of the way physical placement of the lists represents semantic relations of difference and comparison.
2. *Proposed criteria for the use of written worksheets*
    - Demonstrates the ability to follow the instructions specified on the worksheet.

- Demonstrates the ability to provide the information required in the appropriate areas of the worksheets
- Demonstrates the ability to translate the written instruction of the worksheet into the required physical actions of the science inquiry.
- Demonstrates the ability to differentiate among observational, inferential, explanatory and evaluative responses required by the worksheet.
- Demonstrates the ability to navigate the information recorded on the worksheet and be able to verbally explain any recorded responses.
- Demonstrates the ability to reach empirically based conclusions using the information recorded on the worksheet.

3. *Proposed criteria for writing descriptive paragraphs*
    - Demonstration of the ability to describe in written form the specific properties, qualities and characteristics of an object.
    - Demonstrates the ability to utilize information obtained through empirical observation in the development of a written description.
    - Demonstrates the ability to accurately and realistically describe the object under observation.
    - Demonstrates the ability to present a systematic method of observation in the written description.
    - Demonstrates the ability to write coherent paragraphs with a clear organizational structure.
4. *Proposed criteria for informational paragraphs and reports*
    - Demonstrates the ability to read, comprehend and synthesize information from age-specific encyclopedic sources.
    - Demonstrates the ability to write coherent paragraphs using appropriate organizational patterns.
    - Demonstrates the ability to reorganize the information acquired from reading into a new organizational structure.
    - Demonstrates the ability to design an organizational structure for a four topic report.
    - Demonstrates the ability to assign relevant information to each of the different paragraph topics.

Visual Literacy Knowledge Evaluation

The overall development of visual representational abilities consisted of a move from schematic representations to the attempt to realistically represent objects based on close observation. In the science/literacy unit investigated in the current research project, three different visual genres were used. These consisted of descriptive pictures, narrative pictures and graphic organization. The current discussion of ways of evaluating visual representations will utilize the concept of genre to provide a framework for the genre-specific criteria for evaluation. The criteria address the role of these genres in the development of scientific knowledge. The approach taken within the current analysis was to define the core abilities associated with each genre and to use these as a way to evaluate literacy abilities. Below is a summary of the genre and main criteria to be used for evaluating written literacy knowledge:

1. *Proposed criteria for descriptive pictures*
    - Demonstrates the ability to provide a realistic representation of the object observed.
    - Demonstrates the ability to use information from an observation process in the visual representation of an object.
    - Demonstrates the ability to visually present accurate detailed information relating to the object being drawn.
    - Demonstrates the ability to visually represent a density of information resulting from systematic criteria for observation.
2. *Proposed criteria for narrative pictures*
    - Demonstrates the ability to visually represent a scientific process.
    - Demonstrates the ability to visually represent the changes in the state of object at different stages in the process being presented.
    - Demonstrates the ability to visually represent the forces (or causes) that direct the changes to the object in the process being presented.
    - Demonstrates the ability to visually represent detailed accurate information relating to the process being presented.
3. *Proposed criteria for graphic organization*
    - Demonstrates an understanding of the distinct drawn (or marked) circles as representing different groupings and categories of objects.
    - Demonstrates an understanding that overlapping circles represent distinct groupings and a group which contains aspects of both distinct categories.
    - Demonstrates an understanding that semantic relations can be represented symbolically using symbols such as arrows or physical positions on the page.

> *Note:* **This report has been edited and adapted in this web version by LHS staff. This analysis by David Hanauer of one classroom was undertaken at the start of the *Seeds of Science • Roots of Reading* development process, as the first unit, S*horeline Science,* began pilot testing. This research summary includes detailed information on and analysis of unit activities and student work, as well as close classroom video analysis. Based on the pilot test described in this summary, as well as on a second classroom pilot, followed by a national field test, this unit (and others in the series) will be revised and prepared for publication. It should also be noted that this analysis could unfortunately not include information on the nine project-originated student readers for this unit, as they had not been fully developed at the time. Several trade books and early reader drafts were utilized, but it remains for future studies to gauge the impact of the original student readers on the science/literacy character of curriculum and on student learning in both literacy and science.**