Drawing out Ideas: Student-Generated Drawings' Roles in Supporting Understanding of "light"

Yongcheng Gan
Ontario Institute for Studies in Education, University of Toronto,
252 Bloor Street West, Toronto, Ontario, M5S 1V6, Canada
yongcheng.gan@utoronto.ca

Abstract: Young children enjoy drawing, but it is an underused method of probing and supporting their understanding of scientific concepts. This paper investigates children's drawings of "light" and associated phenomena. The student-generated drawings of 22 children in grade 4 from a University of Toronto laboratory school, who used an online multimedia environment--Knowledge Forum® and were free to express their ideas in text or graphics with no instruction in graphics to advance their theories in science, are analyzed and four categories of roles that the drawings played in fostering deeper understanding of "light" are identified and examined. Exemplars of each category are analyzed and discussed. The results of discourse and content analysis showed that student-generated drawings supported (1) understanding of content area knowledge; (2) idea improvement and conceptual change; (3) progressive scientific inquiry for problem solving; (4) theory-building and modeling. A graphical literacy coding scheme was also used to quantitatively analyze the graphical data, and individual knowledge gains were explored. The results of varied analyses have shown that student-generated drawings played important roles in supporting deeper understanding of "light."
Keywords: student-generated drawing; deep understanding; optics; graphical literacy; knowledge building; Knowledge Forum; visual thinking; visualization.

Introduction

Several educators and researchers have urged that drawing be used more frequently to enrich and enliven science education (Taylor & Andrews, 1993). Hayes et al. (1994) suggested that children's drawings in science can contribute to the development of individual skills, knowledge and understanding.

Drawings have been used in a variety of ways when they have been used to probe understanding in science. Drawing activities have been successfully used to explore children's ideas about abstract concepts, e.g. "technology" (Rennie & Jarvis 1995), and more specific ideas, e.g. "evaporation" (Schilling et al., 1993). In other studies, drawing content has been quantified, as e.g. in research into children's drawings of a forest (Strommen, 1995). Yet other investigations have attempted to group children's drawings into levels of understanding. For example, Arnold et al. (1995) have shown how young children's ideas about the Earth as viewed from space developed from simple notions of a flat cylinder to a sphere. Other studies have focused on children's conceptions of cross-sections of features including the Earth (Lillo, 1994).

Drawing is a frequent activity in primary school classrooms. Apart from their role in art, drawings are often used to illustrate stories children have heard, read or written, or activities they have done. However, they have not often been used as a means to probe children's understanding of scientific concepts, although their use has been recommended for this purpose in primary science curriculum materials (for example, Bird & Diamond, 1978; Schilling et al., 1993). Such an approach should have considerable potential for subjects like science and mathematics. However, for this purpose, drawings need to communicate children's understanding. In other words, children must be able to produce drawings which accurately represent their ideas and are interpretable by peers.

Drawing is as rich a source of evidence as language and a window on the thinking of children in all areas of the curriculum. It is depressing that drawing is recorded so little value in a school system and is a minor mode of communication, certainly secondary to writing and speech, in education (Brooks, 2005).

Young children enjoy drawing; but the power of drawing as a tool for learning and for recording thinking in classrooms is unaware of by educators (Brooks, 2005), and it is an underused method of support their understanding of scientific concepts (Dove, et al.,1999). There appears to have been no systematic attempt in general science education at the primary or secondary level (Lowe, 1987) and has been little systematic research into the processes of making meaning through drawing in the context of classrooms (Brooks, 2005).

Visual thinking and graphical literacy

Aristotle once stated that thinking is impossible without image (cited in Stokes 2002). Felder and Soloman (2001) suggest that most people are visual learners, and that if sufficient visual content were included in learning materials students would retain more information.

Visual thinking was defined as processing information through images instead of words (Olson, 1992). West (1997) states that visual thinking may be a superior way to solve problems and create models. West mentions the importance of making mental models of reality; he says that visual thinking helps the construction of mental models, and that modeling can be connected with creative thinking and learning. Visual thinking will be important in giving creative new answers to problems.

Visual thinking is extremely important in children's thought/idea development. Freud (1965) thought that before the process logic and language, children's primary thought processes are based on images. In addition, text is more abstract with many interpretations; while an idea represented by a picture is concrete. Thus, visual thinking is better than text for communicating experience. Barry (1997) suggests that non-linear visual thinking has a creative power and natural intelligence; while written language has the serial nature in which ideas follow each other in a fairly regulated order. Therefore, the opportunities for spatial manipulation of ideas are limited.

Student-generated drawing is defined as student-created graphical representations of sequential, causal, comparative, chronological, oppositional, categorical, and hierarchical relationships among concepts (Cifuentes & Hsieh, 2004; Wileman, 1993). Students' notes are graphical representations if the concepts are presented in different form of graphics (Cifuentes & Hsieh, 2004). Graphical representation is a factor in scientific understanding (Earnshaw & Wiseman, 1992; Peltzer, 1988), and it is also an important part of becoming a creative thinker (De Bono, 1995; Torrance & Safter, 1999). Given the power of graphical representation as a study strategy and the limited graphical literacy skills among learners, an orientation is essential to prepare learners for using visual techniques to represent interrelationships among concepts. With appropriate scaffolding for students, young learners can construct meaningful concept representations and progressively internalize visualization as part of their study strategy (Bliss, Askew, & Macrae, 1996).

Graphical literacy refers to the ability to interpret charts, maps, graphs, and other visual presentations that are commonly used to supplement the prose of textbooks, nonfiction trade-books, and newspapers (Readence, Bean, & Baldwin, 2004). Graphical literacy can be defined as the ability to construct, produce, present, read and interpret visual messages (tables, bar graphs, line graphs, circle graphs, drawings, diagrams, flow charts, timelines, editorial cartoons, maps, photographs, posters, videos, etc.). Dual coding theory (Paivio, 1986, 1991), the theoretical foundation of graphical literacy, explains the picture superiority effect on the basis of two important assumptions (Rieber, 1996). First, if information is coded both verbally and visually, the chances of retrieval are doubled. The second assumption is that words and pictures activate mental processing in very different ways. Pictures are far more likely to be coded both visually and verbally, whereas words are far less likely to be coded visually. Thus, according to the dual coding theory as well as the integrative model of text and picture comprehension, presenting pictures together with text can facilitate learning because pictures help learners to construct mental models that are essential for comprehending the information to be learned and thereby enlarge the retrieval possibility of this information (Clark & Mayer, 2002).

Graphical representation and visual thinking are two important components of graphical literacy. Mental model is the internal image of visual thinking; graphical representation is the externalization of visual thinking.

Graphical literacy is thought of as "by-product of knowledge building" (Scardamalia, 2003). The relationship between knowledge building, visual thinking and graphical literacy can be presented in Figure 1.

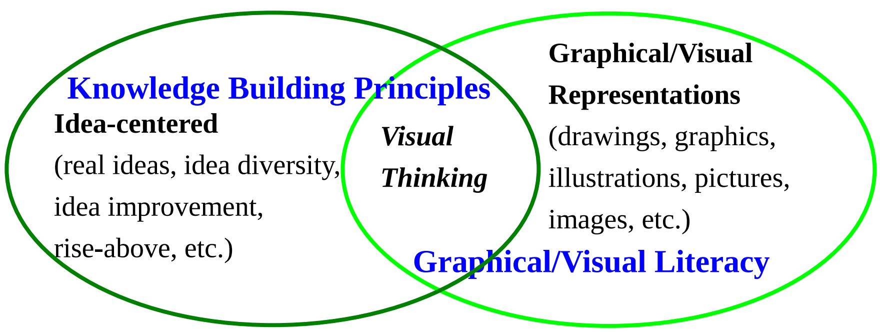


Figure 1: Graphical/Visual Literacy as By-product of Knowledge Building.

Understanding and deep understanding

Learning with understanding is a "sense making" activity and a process in which a student tries to make sense out of new information by connecting it to prior knowledge and establishing relationships among ideas. Understanding develops as a student uses his/her prior knowledge to construct meaning out of new information. As a student makes new information sensible, his/her knowledge about the topic not only increases quantitatively, but changes qualitatively by becoming more differentiated and elaborated. The result is a representation or mental model that structures the conceptual knowledge. Some researchers view understanding as an ability to think and act flexibly with what one knows. Understanding is not simply building an idea, but being able to use the idea in various ways.

From the view of cognitive sciences, "deep understanding" generally refers to how concepts are "represented" in the student's mind, and most importantly, how these concepts are "connected" with each other (Grotzer, 1999). Representations are generally made in the form of images in simple cases, and in the forms of models in more abstract situations. Thus, deep understanding of a subject involves the ability to recall many connected concepts at once, where every single concept has a deep meaning in itself. Not seeing the connections between interrelated concepts leaves the learner with a feeling of mindless thinking. When a learner "makes sense" of new material he is able to make the connections between different concepts (Ester, 2006).

Wittrock (1990) stressed that successful understanding requires learners to actively construct relationships between the text and knowledge and experience, and to invest their effort at generating headings, summaries, pictures, tables, metaphors, and analogies during or after students participated in authentic ways: questioning, disagreeing, debating and finding new levels of understanding. Wiske (1994) found that understanding grows through the exchange of ideas in the classroom.

Gardner (1993) believed that schools should try best to teach children for understanding, or in a manner in which students learned concepts and principals and could demonstrate that knowledge by applying what they had learned to new problems or situations. Perkins & Blythe noted (1994, p. 6) that most school activities merely build on students' prior knowledge yet do not demonstrate any understanding of what they have learned. The usual classroom activities don't spend enough time on demonstrating that students show an understanding of the topics being covered. Students "lack the capacity to take knowledge learned and apply it appropriately in a different setting (Brandt, 1993)." Gardner & Boix-Mansilla (1994) said such learning is merely "superficial knowledge." Gallagher (2000) stressed that traditional instruction helps students gather facts about scientific ideas but does not help create a deeper understanding of the subject or demonstrate how to apply those concepts to the real world. "The vast majority of effort is devoted to helping students acquire information deemed essential as part of the knowledge base of science. Only a small part of class time is devoted to helping students make sense of the new information and make connections among the various components of these elements of scientific knowledge in a way that leads to understanding." (Gallagher, 2000)

Student-generated drawings' roles in deep understanding of science

Learning with multiple representations has been recognized as a potentially powerful way of facilitating understanding for many years (Ainsworth & Van Labeke, 2002). Visual representations made abstract concepts "easier to understand and internalize" (Mejia-Flores, 1999, p529-530).

Forman (1996) found that drawing was used as a "thinking activity" rather than "drawing activity" to explain the facts and theories of objects and natural phenomena. In the early stages, drawing is used as a tool for thinking about developing ideas whereas in the later stages it is used as a vehicle for communicating the refined outcome of that thinking. Drawing reveals useful information and children's insights into the world around them: a picture is worth a thousand words. Drawing is utilized for expressing children's understanding and constructing their learning. When students construct their own drawing, they need to develop an understanding of the concepts they study before they can represent their thinking. Rich & Blake (1994) indicate drawing can be used before reading to activate background knowledge and to prompt discussion. Drawing is also used to generate ideas, get feedback from others, and make changes before writing. Drawing is a tool for young children to reflect what they have observed, experienced, inquired about or are thinking about (Chang, 1996; Katz, 1998).

Julie and Barbara (1999), in their study, emphasize the role of graphical representations in their paper: graphical representations facilitate comprehension, learning, memory, and inference. First, graphical representations may be attracting attention and maintaining motivation. Next, graphical representations may save words by showing things that would otherwise need many words to describe. Graphical representations can also make internal knowledge external, available to a community to consider and revise. Finally, graphical representations have been used to promote inference and discovery by making the underlying structures and processes transparent.

Drawing promotes young children's science learning in many ways. These include hypothesizing through drawing, ways of inquiring (e.g. consulting books, exchanging ideas with experts and people from the community, observations, and thinking), disseminating what they have learned through drawing (e.g. writing), literacy (e.g. reading), and language enhancement (e.g. talking, discussions, exchanging points of view) (Ni Chang, 2005).

1. Drawing supports understanding of content area knowledge

In the learning process, drawing enhances the understanding of new knowledge. Forman (1998) used the term "negotiated learning" in describing the process of learning new knowledge and using drawing as a tool of learning. Research has demonstrated that pictures are helpful in acquiring and retaining knowledge (Goolkasian & Foos, 2002; Horng, 1981; Levin & Lesgold; 1978; Pressley & Levin, 1983). Carney and Levin (2002) regarded pictures as adjunct aids for the processing of text information. They help learners to perceive, understand, and remember the information to be learned. There is evidence that young children can communicate scientific observation through their drawings (Hayes & Symington, 1984; Hayes, Symington, & Martin, 1984). Drawing has been identified as a viable way for students to develop conceptual understanding (Edens & Potter, 2001). Researchers have also described the use of student drawings as tools to identify main ideas and generate summary statements of text materials (Rich, 1994). Specifically, student-drawn text illustrations seem be most effective in situations that relate to conceptual recall, problem solving, and explanation of systems or processes (Mayer, 1993, 2001).

2. Drawing supports idea improvement and conceptual change

Although there has been a considerable volume of research on children's ideas development, one underused technique to probe their thinking is that of eliciting ideas through children's drawings. Evidence suggests that primary school children enjoy drawing activities in science lessons (Hayes et al. 1994). Drawing is also a useful alternative form of expression for children who have difficulty expressing their ideas verbally (Rennie & Jarvis 1995). Moreover, some ideas, e.g. the color of light, rainbow and image formation, etc., are more easily communicated through drawings than written descriptions. Thus, students can present their ideas and build-on peer's ideas with drawings; a series of drawings during a period of time can reflected students' idea development and improvement.

Drawing can display students' misconceptions in science learning. Forman (1999) states that drawing to learn in science is to understand the mechanism by which children, in the act of drawing their theories, gain a better understanding of their misconceptions and thereby reconstruct their misconceptions into more sensible theory (Forman, 1999, p.150).

3. Drawing supports progressive scientific inquiry for problem solving

Progressive inquiry entails that by imitating practices of scientific research communities, students are guided to participate in extended processes of pursuing their own questions and explanations (Hakkarainen, 2003). An important aspect of progressive inquiry is to guide students to set up their own research questions and working theories. Participation in progressive inquiry can be facilitated through web-based collaborative learning environments that provide sophisticated tools for supporting inquiry process as well as sharing of knowledge and expertise (Hakkarainen, 2003).

Rieber (1994) suggests that problem is a non-linear system. Thus visual thinking, which is also non-linear, may facilitate problem solving; and visual presentation provides a holistic understanding which can not be conceived with words alone (Plotnick, 1997).

Drawing is considered to be one of the important heuristic strategies for mathematical problem solving (Larkin & Simon, 1987; Schoenfeld, 1985). Drawing may help solvers advance their problem solving processes (Diezmann & English, 2001), and it can sometimes give solvers the critical information that directly leads to problem solutions (Hershkowitz, et al., 2001). Some researchers recommend that in order that drawing can be meaningful to solvers, solvers should make drawing themselves (van Essen & Hamaker, 1990).

4. Drawing supports theory-building and modeling

The value of models and modeling to science education has always been increasingly recognized in science education (Giere 1991, NRC 1996). At present, models and modeling are considered integral parts of scientific literacy (Gilbert & Boulter, 1998; Gilbert, S., 1991; Gilbert, J., 1993).

Webb (1993) described a model as a formal representation of a problem, process, idea or system and it is never an exact replica, but represents one or more aspects of the structure, properties or behavior of what is being modeled. White (1993) suggests that models allow the development of a simplified representation of a phenomenon to be produced and therefore allows for the concentrated study on special features of that phenomenon. Thus models are used to simplify and idealize a complex real-world phenomenon in order to gain a better understanding.

Jonassen (1999, p. 227) intended that building model foster students' scientific thinking. The process for building the ability to model phenomena requires (1) defining the model; (2) using the model to understand some phenomena; (3) creating a model by representing real world phenomena; (4) making connections among its parts; and finally (5) analyzing the model for its ability to represent the world. Students can learn science concepts through theory building and modeling with visualization such as student-generated drawings.

Knowledge building and Knowledge Forum for deep understanding

Many educators have adopted knowledge building pedagogies (Scardamalia & Bereiter, 2003) to engage students in science learning that leads to deeper understanding of the subject matter (Lamon, et al., 1996).

Understanding is a sense-making, meaning-making, and knowledge-building activity. It results from knowledge building practices in which a learner constructs new relationships and connections among facts, ideas and theories. If students are to come to understand that science is a process of communal knowledge building, then they should construct, discuss, and debate their understandings of science together, just as scientists do in a scientific community. Therefore, they can take collective responsibilities to foster higher-level understanding of subject matters.

Through knowledge building discourse, students' contradictions, inconsistencies, and limitations of explanation become available and force them to perceive conceptualizations from different points of view

(Miyake, 1986). Deep conceptual understanding is also fostered through explaining a problem to other inquirers (Hatano & Inagaki, 1992). Through this kind of process, inadequacies of one's understanding tend to become more salient.

Knowledge building community, which characterizes practices of scientific communities such as exploration of and arguing about ideas and theory-building and modeling, can only be achieved in an interactive learning environment that allows for a more free exchange of ideas among all participants. Knowledge Forum is a web-based, multimedia and collaborative learning environment that provides a situation and environment conducive to using visual thinking to learn science, in which information, ideas and concepts can be connected by using different representational formats (textual and pictorial) with drawing tools. Students can manipulate drawing tools with ease, and can perform subsequent revision and dynamic linkage of ideas and concepts. These drawing and painting programs are powerful expressive tools for learners to visually articulate what they know, and to make their knowledge structures more easily interpretable by other viewers (Jonassen, 1996). Skilled learners can use drawing and painting tools for graphical generation to facilitate making sense of their ideas and producing an organized knowledge base (Jonassen, 1999). When the drawing and painting programs are used as "cognitive tools" for mindful engagement, learners' thinking processes can be supported, guided, and extended (Derry & Lajoie, 1993). Moreover, a change in emphasis from passive copying or study pictures to active construction of scientific representations, as a general principle, has the potential to make learning in science more meaningful and better integrated. Thus, Knowledge Forum is used as a collaborative learning environment for deep understanding with graphical representations.

This study focuses on student-generated drawings as an avenue for exploring children's ideas development and understanding of content area knowledge: light. Thus the research questions relevant to the exploration of students' understanding of light using drawings were as follows: (1) what roles do the student-generated drawings play in understanding of "light"; and (2) whether or not the children's drawings actually foster their deeper understanding of "light."

Methods

1. Participants

Participants were 22 students (11 girls and 11 boys) from a University of Toronto laboratory school, who studied science using Knowledge Forum in grade 4 (Sept., 2001-June, 2002). In grade 4, students studied physics: light and biology: symbiosis, biome; history: medieval. Students drew many pictures in their notes in Knowledge Forum to show what they learned, to express their understanding about a subject, to discuss and debate their ideas, and also to describe the experiments they did inside and outside the classroom. All notes that students wrote were stored in Knowledge Forum database.

2. Course requirements and context for drawing

Course requirements: The Ontario curriculum of Science and Technology for grade 4 requires students (1) demonstrate an understanding of the characteristics and properties of light (e.g., natural and artificial light sources; light travels in a straight path, bends as it passes from one medium to another, and is reflected off shiny surfaces); (2) investigate different ways in which light are produced and transmitted, and design and make devices that use these forms of energy (e.g., prism; shadows; optical devices); (3) demonstrate, investigate certain materials that transmit, reflect, or absorb light (e.g., water and prisms that bend light;

mirrors and polished metals that reflect light; transparent/translucent/opaque materials).

Context for drawing: The primary topic that children studies in grade 4 was ‘light’, with which children experienced every day. Exploring “light” in the context of the classroom and Knowledge Forum that brought each child’s personal experiences with shadows, rainbows, colors of light, images, and so on, into an arena where spontaneous concepts were progressively extended into more scientific concepts (for example, the notion of image formation, the law of light reflection, colors of light, and the formation of rainbows). The children had many different ideas about how light travels and why there was a half-circle of rainbow in the sky, etc. Bringing the many different ideas into knowledge building discourse in Knowledge Forum and many activities and experiments in classroom meant that the children were able to communicate different or conflicting ideas with peers. Differing ideas emerged in the interactions helped to raise the questions that provided the impetus for further exploration by individuals and small groups of children. Drawings with captions gave the children a reference on how to elaborate their ideas and build theories and models. Through shared reviewing, as well as discussions, the drawings prompted a deeper understanding of the concepts of light in question. For example, the differences amongst the five theories of how light travels, became evident through drawings and through comparison of the different drawings. Comparing theories against different criteria helped the children to group and categorize in more complex ways; ways that acknowledged the deeper understanding of scientific concepts. The children were encouraged to formulate thought-provoking questions and to explore these questions either in small groups or independently and to “rise-above” their share understanding. Drawing was spontaneous but supported by drawing tools in Knowledge Forum as a meaning-making tool. This topic was spontaneously extended to include explorations of natural and artificial light, convex and concave lens, cameras and photography, photosynthesis, and so on.

Over the one year of educational work reported in this study students were engaged in knowledge building--the creation and continual improvement of ideas through transformative discourse (Scardamalia & Bereiter, 1994). Knowledge Forum, a knowledge building environment, was integral to their work. It includes tools for graphical as well as textual representation of ideas. Students choose the representational form best suited to the expression of their ideas. In knowledge building practices, students assume collective responsibility for communicating, elaborating, evaluating, and improving ideas, working in a public forum where they build on, comment, and in other ways help each other advance their understanding, They received no instruction in use of graphics, but are supported in the expression of ideas by peer feedback and an easy-to-use graphics palette that allows them to co-author and revise graphics.

3. Data collection and analysis

This paper reports on one aspect of a longitudinal case study of 22 students’ classroom based activities for deep understanding of optics that employed an interpretive methodology. This aspect is the exploration of student-generated drawings to foster understanding of the nature of light.

The researchers were permitted to access into the one-year database (Sept., 2001 -- June, 2002), and examined all the cases of the notes and graphical representations in Knowledge Forum. Multiple sources of data were collected and qualitative approaches are adopted to support the internal validity of the study which included all the notes with graphical content in all views students wrote in science learning, and the 22 “Portfolio” views that each student wrote for reflecting learning process and results, and the teacher journal for teaching reflection in the view: “Calendar of Inquiry.” The quantitative methods that were adopted included analysis the variation of graphical data to determine the students' perceptions of light.

Content analysis (Chi, 1997) for qualitative analysis was used to assess the quality of the notes' text and graphical content in grade 4 and analyze students' understanding level of light. A coding scheme (Gan, et al., in press) (see Table 1), which are composed of seven components, was designed to assess the extent to which they use graphics and advance in graphical expressiveness, and was also used for analyzing their understanding with graphical representations in this case study; each graphical representation was rated for each dimension: Basic, 1 point; Intermediate, 2 points; Advanced, 3 points.

Table 1: Graphical Literacy Coding Scheme.

Category	Specification
1. Graphics Production/ Drawing Skills	Use of line, dot, shape, color, basic shape, etc; Combinations of different color, shape, label, title, etc.; Complex or abstract graphics conveying harmony, clarity in conceptual content, etc.
2. Graphical Representation	Use of a graphical representation to convey a concept, theory, model, experiment, procedure, etc.
3. Resources Reference	Use of references and links to source material of peers or from the Internet to reference rather than copy graphics.
4.Captions	Use of clear, correct and accurate captions to complement and elaborate ideas, theories and models in pictures.
5. Revision/ Elaboration	Revision or elaboration of pictures or relevant captions over time to provide increasingly clear and accurate accounts.
6. Aesthetics/ Clarity	Use of color, layer, rendering, etc. to make graphic attractive; effective use of titles, labels, tags, and other devices to create pictures that are reader-friendly and accurate.
7. Judgment/ Reflection	Use of interpretive comments and summaries to convey the essence of graphical representations, including processes conveyed by the picture.

Findings and discussion

The drawings of 22 children in grade 4 are examined and four types of functions that the drawings played in fostering deeper understanding of "light" are identified and examined through discourse and content analysis. Exemplars of each type are analyzed and discussed as follows:

1. Drawing supports understanding of content area knowledge

In science education, recommendations are offered for using drawing to direct learners' attention to illustrations, stimulate the use of visualization, and increase content area knowledge (Britton & Wandersee, 1997). Stein and Power (1996, p. 66) also advocate drawing as both a tool for learning and a means to express knowledge, and credit drawing in classrooms with the ability to force "students to think."

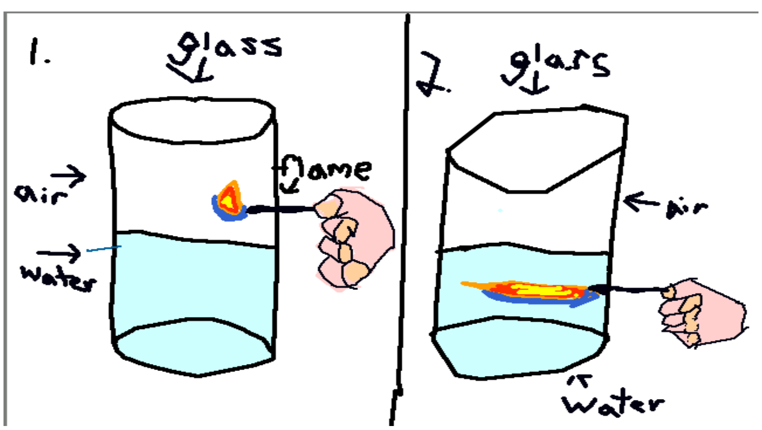
1) Drawing supports observational processes of scientific experimentation

Student-generated drawings have been promoted as a strategy to improve students' memory, observational processes, and imagination in science education (Steele, 1991; Stein and Power, 1996). Dempsey and Betz (2001) consistently recommend that students use drawing as a strategy to improve observational processes in science learning. They argue that drawing is a useful strategy because it helps students see the details and subtle properties that distinguish to-be-learned scientific specimens—a skill critical in scientific study. Student-generated drawings on experiments make students "instill habits of closer observation and awareness" (Freeport School District, 1976, p. 5), force them to "study closely a small section of nature" (p. 5), and draw attention to details and specifics.

One advantage of depicting an experiment visually is that students can simultaneously see the experimental elements and relations. Drawing is spatial, and can display all the relations discussed in the text simultaneously. Text, by contrast, is read in sequence and requires memory to keep all the parts in place. Thus, drawing is perceived as a simple, practical means of recording the children's observation of an activity in elementary science learning.

There were 24 drawings that students had drawn for the experiments conducted inside and outside classroom, accounting for about 22 % of total graphical representations, which meant students liked to depicted their experiments and results with drawings.

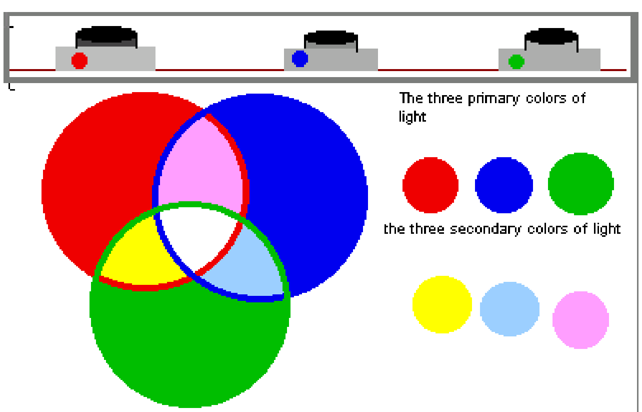
Figure 1-1 and Figure 1-2 are the drawings of two experiments that students conducted. In Figure 1-1, two students presented how flame turned to be flat when observed through water. The two parts of the drawing are the graphical representation of before and after the flame is placed under the water; the comparison makes peers see the differences in detail, and make it easier to understand. Another two students (Clare and Rebecca) also did "the pencil in water experiment" and wrote a note with a drawing. These drawings instigated students to explore the scientific conception "refraction of light" in learning "concave and convex lens" later, in which the law of light refraction was hid behind the bending light of these experiments.



[**Problem:** Bending light] by: Elana, Nathalie.

I did an experiment on Bending Light. The flame is behind the glass. When the flame is out in the air, it looks normal. When it is next to the water, the flame seems to expand. **[I need to understand]** why the flame expands under the water.

Figure 1-1: bending light experiment.



[**Problem**: Mixing colors of light] by: K.L.

We had three projectors with cellophane colors on the cover. They all shone on a big screen. When we shone red and green we got yellow. When we shone blue and red we got magenta. When we shone blue and green we got cyan.

Figure 1-2: Mixing colors of light.

Figure 1-2 recorded the results of mixing colors with three projectors. The drawing that displayed the three primary colors and three second colors (yellow, magenta and cyan) played an irreplaceable role that text could never did to make clear what cyan or magenta is for the students who were not familiar with the second colors; and in this drawing they really saw these colors by themselves, and then further understood the theory of mixing colors.

2) Drawing supports understanding of scientific concepts and theories

An important perspective of drawing is that it is an effective tool for presenting scientific concepts, laws and it makes students easier to these concepts. Drawing can help children comprehend and learn about concepts (Katz, 1998).

Figure 1-3 and Figure 1-4 are two drawings of the law of light reflection. The two students compared the reflection of light to a "ball" bouncing off a flat plane. Figure 1-3 showed how light is reflecting in different angles (A, B, C, and especially, D in straight angle), through which student clearly "saw" the theory. The scales in the protractor in Figure 1-4, combining the expository text, visually showed the law of light reflection: "angle incident equals the angle of reflection."

[**Problem**: How does light bounce off a flat mirror?] by: K.L.

[**My theory**] is that light acts like a tennis ball hitting a flat wall. If you are flashing a light at a mirror, the light would hit the mirror and bounce off across from you. When you are straight in front of the mirror, the light would flash right back to you. [**New information**]I learned this by trying it.

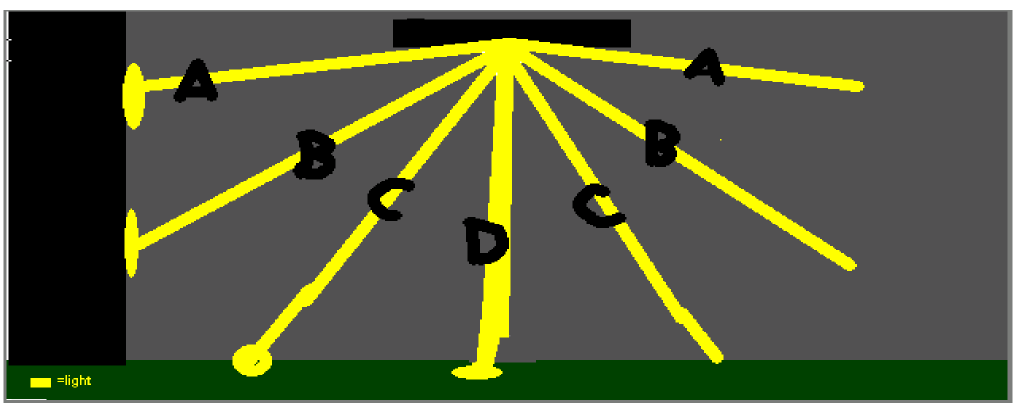
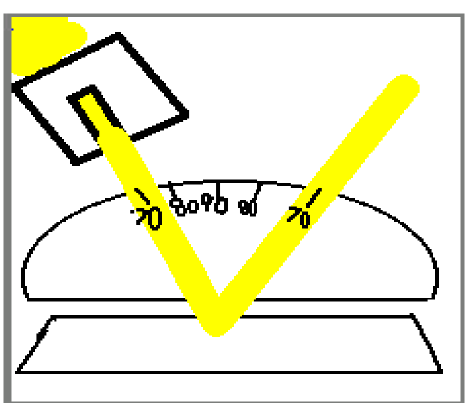


Figure 1-3: the law of light reflection.



[Title: Light is like a ball.][**Problem**: How does light bounce off a flat mirror?] by: K.L., Nathalie.

The angle incident equals the angle of reflection.

Figure 1-4: the law of light reflection.

3) Drawing supports text comprehension of scientific knowledge

Rich and Blake (1994) described using drawing with fourth and fifth grade remedial readers to improve both text comprehension and knowledge acquisition. Students in these classrooms were taught to use drawing to represent main ideas and to combine drawing with words. In addition, they made the important point that the drawing strategy was relatively easy to learn. Many believe that drawing supports young students in making the transition from oral to written forms of expression (Hubbard, 1987; Karnowski, 1986). Drawing is used to generate ideas, get feedback from others, and make changes before writing. Moore and Caldwell (1993) concluded that learner-generated drawing was an effective prewriting strategy. Drawing facilitated thought organization and was easier to edit than writing.

Graphics, like drawing, and words both have individual and unique attributes as methods of communicating information. Graphics are concrete representations of things that have been seen or imagined. When a viewer studies a graphics, nearly instantaneous recognition and meaning can occur because visual information requires less processes of decoding than does written language (Paivio, 1991; Sadoski & Paivio, 2001). It is assimilated holistically as a complete unit of perception with simultaneous processing of all its parts (Sinatra, 1986).

Graphical representations are known to foster the immediate and delayed retention of facts contained in the accompanying text (Levin, et al., 1987), and are more effective than text for communicating complex content because processing graphics can be less demanding than processing text. Plotnick (1997, p.3) listed several advantages of constructing visual representations of text, such as (a) visual symbols are quickly and easily recognized; (b) visual representation allows for development of a holistic understanding that words alone cannot convey.

Placing graphics near related text can improve learning (Clark & Mayer, 2002). Mayer compared learning about the science topics where text was placed separate from the visuals with versions where text was integrated on the screen near the visuals. The research has shown that the integrated versions were more effective (Clark & Mayer, 2002).

Pilot studies have indicated there is promise in Knowledge Forum in a way that focuses on comprehending difficult texts (Scardamalia, 2003). Different groups of students engage in collaborative interpretation and analysis of text in different ways such as drawings or pictures. Then the task becomes to craft "building-on" notes that tie together meanings into more complete constructions.

The students in grade 4 studied image formation through field trip by visiting a studio to learn about photography. The following drawings (see Figure 1-5 and Figure 1-6) helped students understand how to focus light to take a picture, and more importantly, helped the note author to organize this writing and aided other students to understand the expository text. The captions and labels in the drawings were very helpful for peers to understand the process of image formation. If there was only the text left in the note, without the two drawings and their text tags, other children might be difficult to understand how the picture was formed in the camera; that is why a Chinese proverb says "a picture is worth a thousand words." Hence, when using drawing to communicate their ideas, it is a better way to annotate the drawing with captions, combining with the explanatory text in the note to increase the effectiveness of the communication.

[**Problem**: What is the speed of the shutter?] by: Cooper, C.L.J.

The speed of the shutter on the camera makes a picture visible and great. The shutter if it's too slow can let in too much light, so the picture turns white. If the shutter is too fast it will make the picture turn out black. When the shutter closes with light a mirror in behind it will go down making the picture will illuminate and the picture last seen will turn out on the film.

If there is a lot of light then you want the shutter small so too much light does not get in. If there isn't a lot of light then you want it open a lot so you can see the picture.

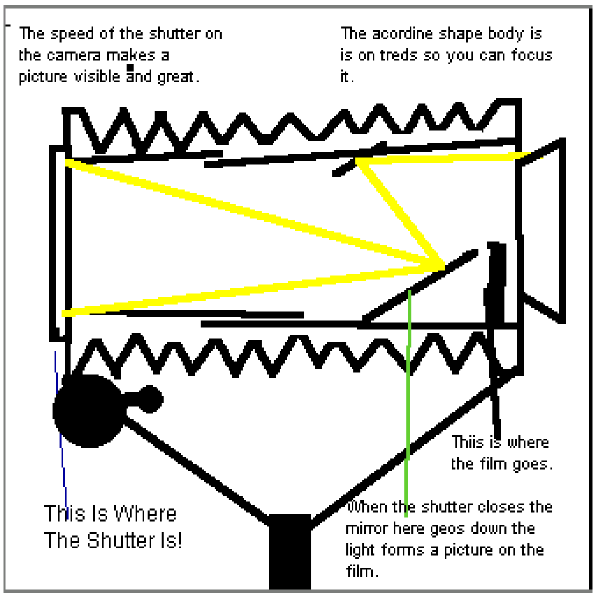


Figure 1-5: Image formation.

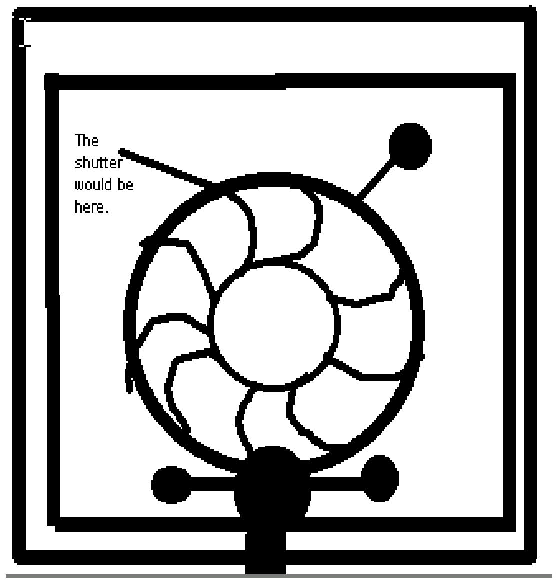


Figure 1-6: the shutter of camera.

2. Drawing supports idea improvement and conceptual change

Earlier research in the field of science education shows that the students' views on underlying concept structures do not align with the current scientific perspectives (Lowe, 1999). It is readily accepted that students bring a range of alternative personal frameworks that might be subsidiary and often contrary to the accepted scientific view. It is important to elicit these ideas as an initial stage in a learning process that engages students in knowledge building discourse, helping them move towards an understanding of the less personal, more acceptable scientific concepts and theories of optics. In the process of knowledge building, drawing was used to present their understanding, build new ideas and improve the ideas. When children draw, they can revisit their learning and rethink what has been addressed and expounded in class (Chang, 1996).

Children's drawing also can be used as an informal assessment tool to identify and address learners' misconceptions (Van Meter & Garner, 2005) and concept changes (Edens & Potter, 2001). Dykstra, Boyle, & Monarch (1992) asserted that conceptual change is a progressive process of refinement of students' conceptions, and proposed a taxonomy of conceptual change consisting of differentiation, class extension, and re-conceptualization. Similarly, Niedderer & Goldberg (1994) described conceptual change as a process of change from the learner's prior conceptions to some intermediate conceptions, then to scientific conceptions.

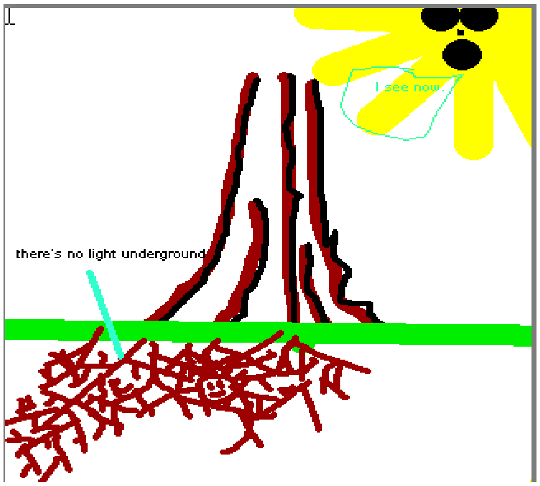
1) Misconceptions or misunderstanding:

Before conceptual change can take place, misconceptions that students possess have to be made explicit. This first step will be vital to uncover the students' misconceptions. Children's drawings often reveal misconceptions, which if undetected may otherwise act as barriers to further learning. If mistaken concepts are not identified and challenged, children will fail to recognize other examples and extend their knowledge in different settings.

For many students in elementary school, the light is just "there", shadows "belong to" objects or "come from" them in bright light and periscopes help us to "see over" things (Osborne et al., 1990; Driver et al., 1994). Students have considerable experience of light and its effects but are unlikely to have given real consideration to how to explain these. In the beginning of studying the formation of shadow, the students had had much their own experience and prior knowledge as follows (see Table 2).

Table 2: Students' misconceptions and prior knowledge on "shadow".

Questions	Misconceptions	Examples
What is a shadow?	A shadow is (1) an inexact reflection of object; (2) belongs to object or come from it. (3) Everything has a shadow.	[Judy] A shadow is an inexact reflection of your body doing everything that you're doing…. Your shadow touches you wherever you touch the ground. For example, if you stood on your head, your shadow would touch you at your head. [Cooper] see Figure 2-1 and its caption.
Why do shadows exist?	A shadow can exist underground.	[Elana] Light does go underground … so that means that the light can get to the roots and make shadows.
Why shadows are big and small (long and short)?	(1) A shadow is bigger when an object is closer to light source. (2) A shadow is smaller then the object. (3) A show is bigger in the morning and smaller in the evening (4) The size of a shadow depends on the sun's brightness.	[A.M.] when you get closer to the light you get a bigger shadow because you're covering up more of the light. [W.K.] **Problem**: Why is a shadow smaller then your real size? [Katlyn] [**My theory**] is that… if the sun is beaming the most in the morning you will have a very big shadow; later on in the afternoon you will have a smaller shadow then you had in the morning. I also think that if it is really early in the morning your shadow will be very faint. [M.R.] [**My theory**] Say that its morning the sun is just rising so the angle of the sun is not too strong so our shadows are small. Then it's mid-afternoon, so the sun is up in the air so it beams down on us with more power, so it creates a larger shadow… [Natalie] [**My theory**] is that in the morning or in the evening a shadow is long because the light is not as strong so the shadow is able to cover more space. [**My theory**] about the rest of the day is that the sun is closer to us so the sun is stronger.



[**Problem**: Why do shadows exist?] by: Cooper.

I think shadow[s] exist because they show you things are there. Everything has a shadow unless it's underground.

Figure 2-1: the shadows attached the trunks.

In Figure 2-1, the shadows (the black lines) are touched the tree trunks (the red lines). The student thought everything had a shadow and a shadow showed "the things are there." The drawing showed the students didn't yet understand the cause and effect of the shadow formation. The following drawing (see Figure 2-2) also showed the wrong locations among the sun, the tree and the shadow, in which the shadow was, mistakenly, standing, not lying on the ground.

All these initial drawings with expository text in notes then provided a basis for further drawing involving the exploration and elaboration of these first emergent, primitive misconceptions.

[**Problem**: What is a shadow?] by: Clare, Daniel.

[**My theory**] is that a shadow is sunlight that reflects off your body and makes almost the same shape but at different times either it's smaller or bigger. …… When sunlight is in different places, there are different shapes so that makes a lot of different shadows when light. If you have a big tree and afternoon sun the tree will look like its three feet tall. But in the morning a small tree will look bigger than it really is, …

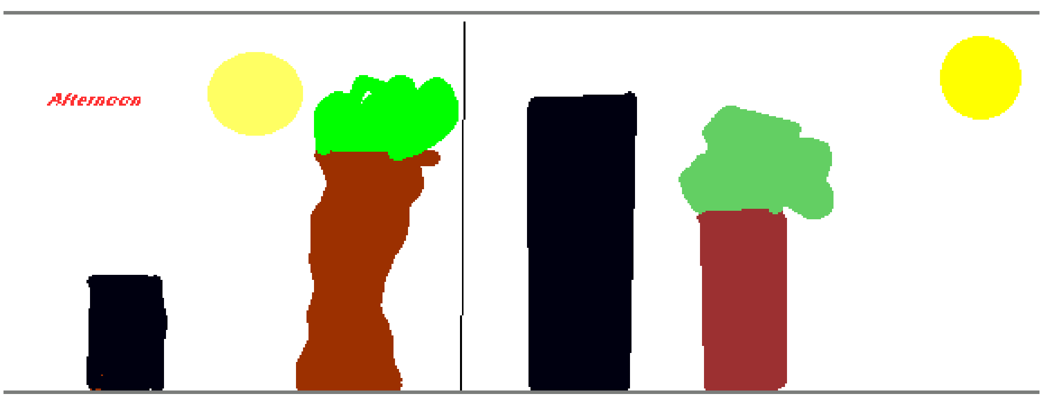


Figure 2-2: the shadow of tree in the afternoon and morning.

2) Immediate understanding

Misconceptions are narrow explanatory frameworks (Vosniadou, 2002) that are different from the conceptions of expert scientists. If students want to understand the well accepted explanatory frameworks of today's scientists, they need to reorganize their misconceptions. Because misconceptions are often incorrect, they tend to impede learning of scientific knowledge with deep understanding. Repair of students' mental models requires conceptual reorganization, also known as conceptual change (Chi & Roscoe, 2002).

Fensham, Gunstone, & White (1994) contended that conceptual change is rarely an abrupt change, but more often “an accretion of information and instances that the learner uses to sort out contexts in which it is profitable to use one form of explanation or another.” They called this “conceptual addition” because old ideas are not abandoned, but revised incrementally.

In the “immediate understanding” stage, students partially understood the concepts with some mistakes. When studying light, children often focus on the object and the effect (shadow), without clearly considering the location of light source and what happens in between light source and the object. In the following drawings (see Figure 2-3 and Figure 2-4), although student A.S., and students C.O. and S.L. clearly displayed the shape and location of shadow: one on the ground and the other on the wall, one important thing that they didn’t show was the location of light source, because it’s the relative location of the light source and the object (person in these cases) decided the location, size and shape of the shadow.

[**Problem**: How does a shadow work?] by: A.S.
[**My theory**] is that it bounces off light and shines.

Figure 2-3: A girl’s shadow.

[**Problem**: how are shadows created?] by: C.O., S.L.

[**I need to understand**] how are shadows created? [**My theory**] is that light hits your body and it stops so there is a dark patch on a wall shows where the light stops.

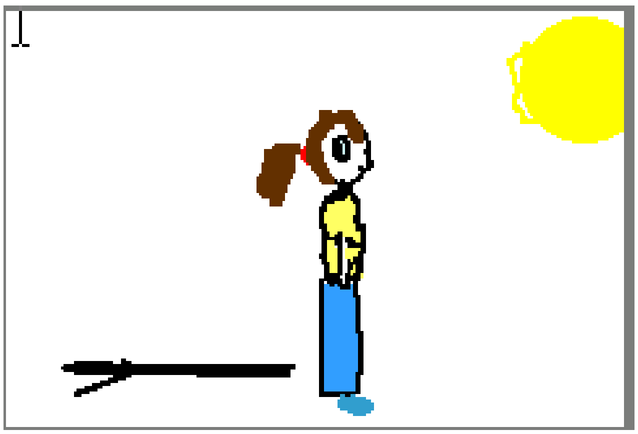
Figure 2-4: A man’s shadow on the wall.

3) Correct understanding

It is important to engage students in tasks that actively verify their mental models and falsify their misconceptions. Making predictions of experiment outcomes is one strategy in science experimentation to test mental models. By fostering awareness of inconsistencies and contradictions through making predictions of experiment outcomes, learners will be more willing to change their thinking (Watson & Konicek, 1990). The comparison between the experimental results and the predicted outcome helps the learner to be aware when a conceptual shift is needed.

After 10 weeks' study (Feb. 8--Apr. 19), students gradually reached correct understanding of the formation of shadow. In Natalie's note, in response to the question: "Why are shadows sometimes small and sometimes big?" she answered with her experience of having traced her shadows and its size at a camp in the afternoon: "[My theory] is that the sun was in a certain place." To the same question, S. L. mentioned two things: "Light in different places" and "it might have to do with where you are." When answering the question "Why do shadows exist?" Natalie responded: "If there is no light there can't be a shadow."

To clearly understand the formation of shadow, students should know the relevant locations of light source and the opaque objects. With drawings, the relationship of the three things can be clearly displayed.



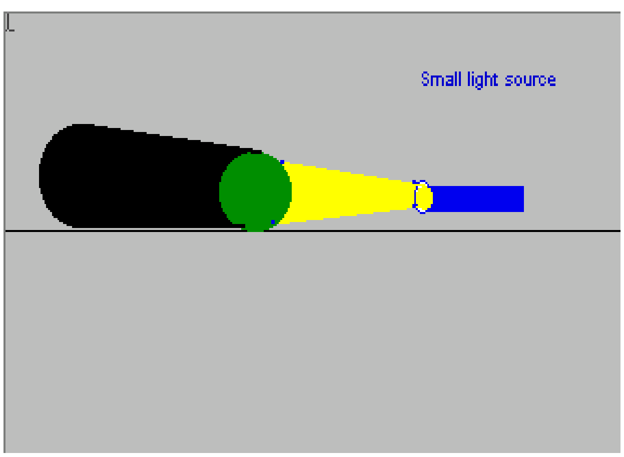
[**Problem**: How do you make a shadow?] by: M.R.

[**My theory**] is that if you are standing in one place and it was very hot outside that the natural light (from the sun) is say, beating on your back and your body is in the way of the sun-light and were the sun light couldn't reach a shadow remains.

Figure 2-5: A girl's shadow.

In Figure 2-5, M. R. clearly displayed the three important components: the light source (the sun), the opaque object (the girl) and the shadow, and their relative locations.

In Figure 2-6, K.L.'s drawing displayed the relationship of light source (torchlight: artificial light), the opaque (green ball) and the black shadow (on the wall) correctly. Specifically, the light ray and black shadow shape were visually presented.



[**Problem**: What is a shadow?] by: K.L.

[**New information**] Shadow = a darkness made when light shines on to an opaque (nontransparent) thing. If the light shines on a[n] opaque object it is impossible for the shadow to be on the same side the light is coming from unless there is a mirror. The sun also causes the Earth to throw a huge shadow into space….

Figure 2-6: A ball's shadow.

In the end, the co-authored note of students C.O. and S. L. showed that students had fully understood the formation of shadow (see below). The final learning achievements summarized by the 22 students in their own

Portfolio view also certified this conclusion. The correct understanding of the shadow formation paved the solid base for students to study the next content area knowledge about "solar eclipse" and "moon eclipse", and the concepts of "umbra" and "penumbra." This transfer of learning to a new problem is good evidence of understanding.

[**Problem**: Long and short shadows] by: C.O., S.L.

[**New information**] we learned that a shadow is created by the sun or artificial light hitting an opaque object. Shadows change size either depending on the size of the object or the light source, say, the suns position. Shadows are usually black….A shadow is always attached to the opaque object that formed it. There is only a shadow when there is light all around you. If it is all dark you could not make a shadow. If the sun is shining in front of you your shadow is behind you because your body is blocking the sun light that is hitting you and the shadow is the sun light that you block on that angle.

Thus, from students' learning perspective, the idea that light travels in straight lines is crucial to explaining phenomena such as how a shadow forms or how we see things. Being able to think in this way and to represent light source, object and shadow on drawings allows student to develop explanations and predictions in a wide range of contexts, for example, studying "eclipse" phenomena.

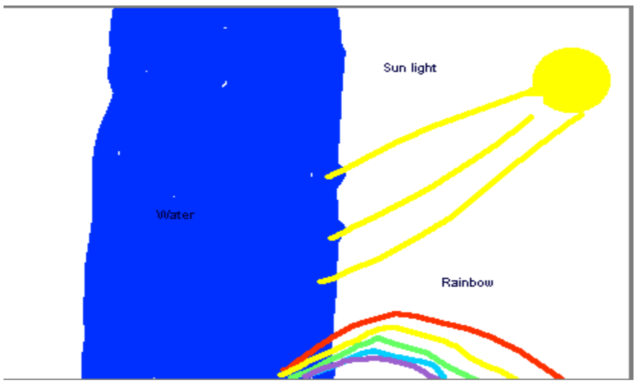
3. Drawing supports progressive scientific inquiry for problem solving

Hakkarainen (2003) concluded in his study that 10- and 11-year-old children, collaborating within a computer-supported classroom, could engage in progressive scientific inquiry into increasingly deep levels of explanation. He contended that an essential aspect of progressive inquiry is to set up questions or problems that guide the process of inquiry. The curriculum, Wiske (1997) wrote, "must involve students in continuing spirals of inquiry that draw them from one set of answers to deeper questions and that reveal connections between the topic at hand and other fundamental ideas, questions and problems." In other words, they are ideas that can be explored in depth. The drawing activity, which is an important way for young children to make sense of their world, appeared to stimulate the formation of questions.

Another important aspect of inquiry is to generate one's own explanations, hypotheses, or conjectures for the phenomena being investigated (Carey & Smith, 1995; Perkins et al., 1995; Scardamalia & Bereiter, 1994). According to Thagard (1988, p. 44), explanation can be seen as a cognitive process of providing or achieving understanding: students demonstrate their understanding by offering explanations.

With regard to progressive inquiry for problem-solving, graphical representations may first help learners to understand the situation described in the problem statement and thus to correctly represent its meaning in a situation model (Nathan, Kintsch, & Young, 1992). Moreover, with regard to the acquisition of problem-solving knowledge in domains like physics the added value of abstract graphical representations has been acknowledged (Shah & Hoeffner, 2002). These types of visualizations are said to be effective in that they facilitate specific inferential processes needed for some learning tasks (Larkin & Simon, 1987). As well as providing new information, graphical representation can represent information in a simplified or organized form so that it can be conceptualized or mentally transformed in search of a problem solution more easily.

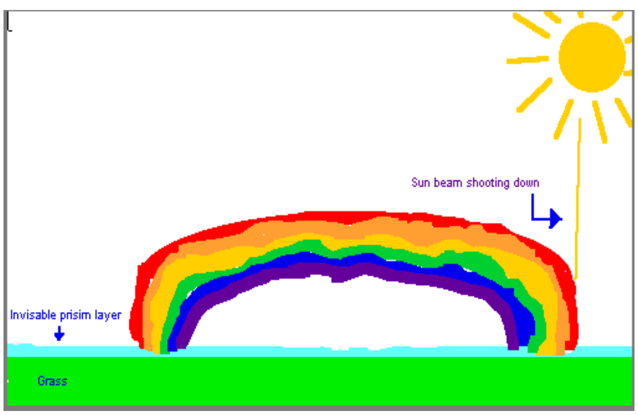
In the following student-generated drawings with expository text, progressive scientific inquiry for problem solving was evident in the explanation of rainbow formation, in which students raised their own questions, set forth theories, provided new information, and posed emergent questions that needed to be explored further. In progressive inquiring the question “what is a rainbow?” 16 students wrote 27 notes, including 5 co-authored notes. There were 12 drawings by 8 students, accounting for 44% of total 27 notes. Half of 16 students participated in the inquiry using drawings.



[**Problem**: What are rainbows?] by: Clare.

[**My theory**] is that rainbows are a mix of sun and water that makes a reflection of colours.

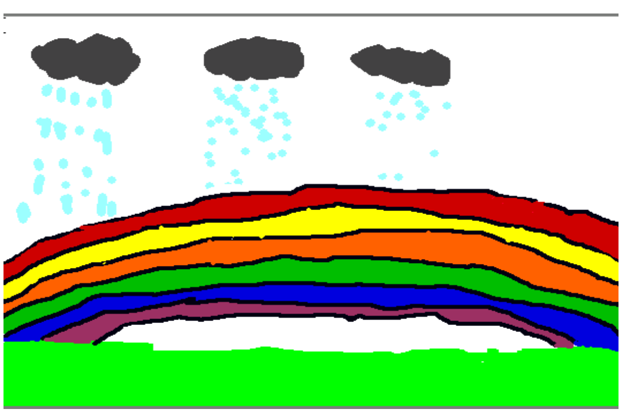
Figure 3-1: Rainbow formation.



[**Problem**: how are rainbows made?] by: M.R.

[**My theory**] is that after it rains the sun light creates an invisible form of a prism. The light reflects and makes a rainbow.

Figure 3-2: Rainbow formation.

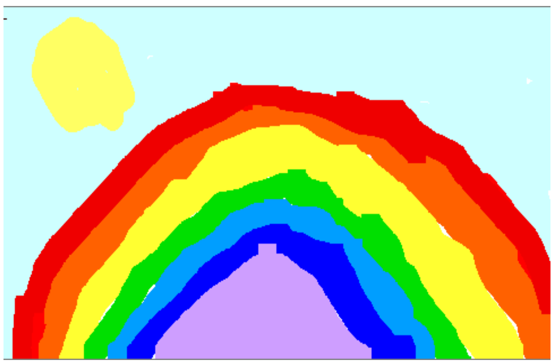


[**Problem**: What are Rainbows made out of?] by: J.H.

[**My theory**] is that rainbows are made out of rain, clouds and sunlight to make a rainbow.

Figure 3-3: Rainbow formation.

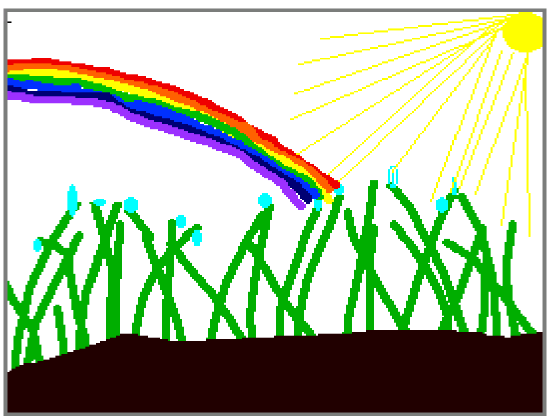
Three progressive inquiry stages for problem solving were identified through analyzing the inquiry thread of 27 notes. At the first stage, students initially asked the question "how rainbows were made?" and started the process of inquiry. They explored solutions to the question with some misconceptions. In Figure 3-1, the drawing could not show "What are rainbows?" The dislocations of the sunlight, water (water column, but not water droplets) and rainbow (only 5 colors with wrong sequence) showed student Clare didn't understand the mechanism of how rainbow forms, and he was confused the meaning of 'reflection' with 'refraction.' In Figure 3-2, student M. R. mistook that it was the sun light, not the water droplets that created an invisible form of a prism layer that was just "floating over the ground grassland." In Figure 3-3, although the rain droplets were drawn, the rainbow only had 6 colors at an incorrect order. The three drawings showed that students also held a misconception about the sequence of the rainbow colors. Some students started drawing a rainbow with red as the top color, but the rest of the colors after the first color varied in other drawings.



[**Problem**: What are rainbows made out of?] by: Elana.

Rainbows are made by water that is still lingering around the trees and bushes.

Figure 3-4: Rainbow formation.



[**Problem**: What are Rainbows made out of?] by: K.L.

[**My theory**] is that the sun shines through the raindrops after storms that react as prisms that make a rainbow.

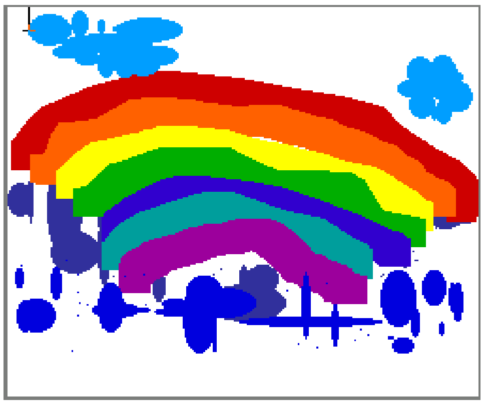
Figure 3-5: Rainbow formation.

[Title: How a rainbow works] [**Problem**: What is a rainbow?] by: K.L, Rebecca.

The sun shines through the water droplets that act like a prism. The colors that are visible are called the Visible Spectrum. Different colors of light travels in different speeds [in water droplets]. The violet light travels the slowest...

Figure 3-6: Rainbow formation.

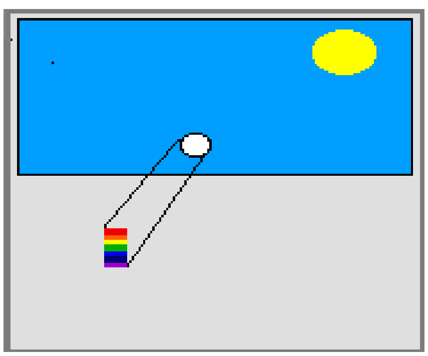
At the second stage, students continued to raise questions and build their theories which led them to the deeper understanding that the rain droplets split sunlight to make a rainbow. Based on this understanding, students raised further questions of what they needed to know such as: How can a big thing like a rainbow "be activated by mere raindrops?" (S. L.) "There are lots of colors of the rainbows, why are they always in the same order?" (Katyln). "Why do rainbows always take the shape of a semicircle?" (S. L.). In Figure 3-4, the sequence of seven colors of the rainbow was correctly displayed; and the student Elana realized that the raindrops "lingering" in the air formed the rainbow. In Figure 3-5 and Figure 3-6, the rainbow formation was presented; the expository text could correctly depict the mechanism of the rainbow formation within the knowledge of grade 4.



[Title: How do you make a rainbow?] [**Problem**: Rainbows] by: S.L.

…One of the things showed was a fountain with a sculpture of a person holding a statue of a globe. There was a wall behind it. There were lights under the water. When the water came down from the top of the fountain it formed a rainbow against the wall! When it rains what does the light hit to make a rainbow?

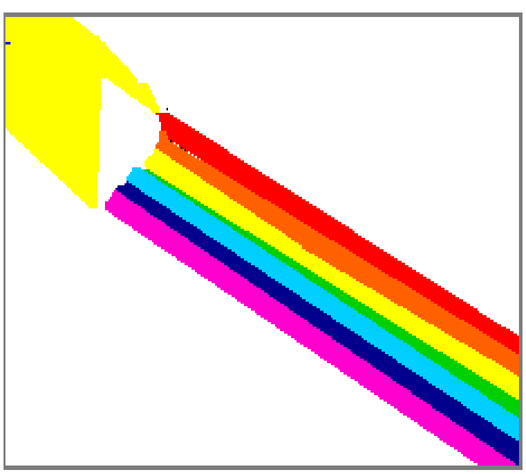
Figure 3-7: A rainbow in a fountain.



[Title: Square rainbows][**Problem**: The shape of the rainbow] by: K.L.

I have a fake crystal on my window that makes a square rainbow!

Figure 3-8: Square rainbow.



[Title: video: Makes a rainbow] by: Velinda, M.R. Video: April 16-17

Title: Makes a rainbow

Source: Magic school bus

-The colours of the rainbow come out according to the length of the light waves.

-Red has the longest light wave, and violet has the shortest.

- If blue light hits an object the light bounces into our

eyes and creates the object to be blue.
Figure 3-9: Makes a rainbow.

At the three stage, students deepened their understanding by observing a fountain outside of school (see Figure 3-7), conducting an experiment (see Figure 3-8) and going on a field trip and watching a video (see Figure 3-9); Through these drawings, children communicated and shared their experiences (Morrow, 1997; Seefeldt, 1999) and participated in social learning with their peers (Halliday, 1975). These experience and experiments with drawings aided to deepen the understanding of what they had studied.

[Title: Rainbow rise-above] [**Problem**: how are rainbows made?] by: K.L., A.M.

[**Our Understanding**] there is 7 colors red, orange, yellow, green, blue, indigo, and violet. Rainbows are made by leftover raindrops on bushes and trees that act like a prism that casts a rainbow.

[**What we still do not understand**] is that why are rainbows so big on such small raindrops but so small on a prism that's bigger than a raindrop.

Figure 3-10: Rainbow rise-above.

The rise-above notes with a drawing (see Figure 3-10) integrated students' understanding through summarizing seven notes on rainbows, and raised a deeper question: "why are rainbows so big on such small raindrops…..?", which was worth to be explored further. The notes in the 22 Portfolio views also showed that all students were able to reflect the correct sequence of the rainbow colors after the subsequent drawings and inquires.

This study showed that 9- and 10-year-old children are capable of engaging in processing of scientific inquiry at a deeper level of explanation instead of being bound to surface-level phenomena with drawings. The interaction in Knowledge Forum characterized practices of scientific communities, for example, the exploration of and arguing about ideas and theories (Kuhn 1993) of "how rainbow is made out of." This can only be achieved in participant environment that allows for a more free exchange of ideas and views among all participants.

Drawing plays an important role in students' progressive science inquiry. Drawing represents ideas and help students acquire scientific knowledge. Drawing can also reveal the levels of students' inquiry as well as their understandings. When students are in the journey of the exploration of rainbows for understanding scientific concepts, their drawings can expose what they (don't) know, what they would like to know, and what they have learned. With the aid of drawings, students can increase science inquiry skills.

The very act of drawing helps to clarify their understanding of the optical problem, determine how they might set about resolving them and to bring tentative solutions to the surface of the mind. This exploratory style of drawing is usually a "conversing with yourself." (Garner, 1992). Its function is to help clarify the drawer's ideas for her/himself.

4. Drawing supports theory-building and modeling

Researchers and educators in science learning have begun to focus on how students conceptualize and use theories and models in science (Kawasaki, et al., 2004), which is based on the recognition that a major activity of scientists is building, testing, and evaluating theories and models of natural phenomena (Lehrer, Horvath, & Schauble, 1994). In fact, the scientific exploration itself has been depicted at its essence as a process of designing and constructing theories and models for their conceptual, theoretical, and predictive value (Penner, Lehrer, & Schauble, 1998; Stewart, Hafner, Johnson, & Finkel, 1992). Thus, science education should focus on practicing how theories or models can be used by students to develop, extend, and test ideas (Carey & Smith, 1995). Such focus would provide students a basis for applying the process skills to build, explore, and evaluate their own ideas about natural phenomena. Moreover, a theoretical explanation may have more significant influence on advancement of students' conceptual understanding when it is adopted in the progressive scientific inquiry and provides an understandable answer to students' own question.

However, theory-building and modeling can be powerful learning tools for helping students understand a complex phenomenon, and help students' critical thinking skills. To build models and erase misconceptions, visualization including drawings, pictures, and schematics can be important (Klemm & Iding, 1997). Drawings can be used to explore more abstract concepts (e.g. the movement of tectonic plates (Dove, et al., 1999)) and models, and make them easier to understand.

In the following cases of constructing models of how light travels, students engaged in a process where their understanding of how light is traveling was distributed across their models, graphical representations, which became tools to examine, and were part of their understanding of light events. Following descriptions will look closely at how students understood scientific concepts, using drawings in Knowledge Forum to support theory-building and modeling, which were identified as two particularly important tools of knowledge creation in science (Kawasaki, 2004).

There were 60 notes including 21 graphical representations in the view "How light travels." There were 50 notes that focused on addressing "how light travels," in which there were 45 notes relevant to building five theories and models, including 20 drawings for theory-building and modeling. In total 50 notes, there are 21 notes for "Wave theory (WT)"; 11 notes for "Straight-line theory (ST)"; 6 notes for "Combo theory (CT)"; 6 notes for "Ripple theory (RT)"; one note for "Particle theory (PT)" (see Table 3).

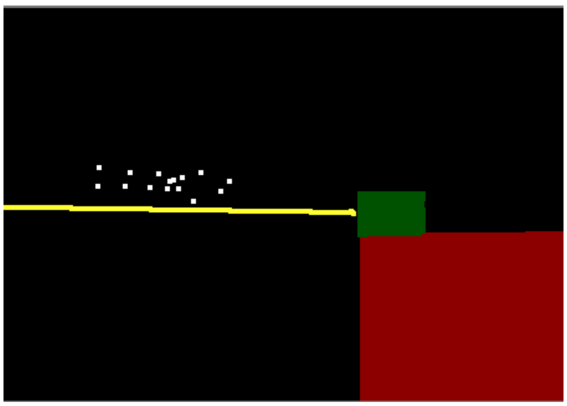
Table 3: Notes and graphics on building and modeling five theories of light traveling.

	WT	ST	CT	RT	PT	none	Total
Notes	21	11	6	6	1	5	50
Graphics	8	4	4	4	0	0	20
Graphics/Notes	38.1%	36.4%	66.7%	66.7%	0.0%	0.0%	40.0%

1) Straight-line theory

The doing of science is essential to science learning, and there are many facets of doing science. It is currently believed that students are active agents in the understanding of the natural world. The best way is by involving students in practices that give them a chance to participate and practice.

With conducting an experiment of how light travels (see Figure 4-1), two students built their theory with a simple model, following up with other students' participation through questioning and debating with new facts and other theories and models. In this graphical representation of the experiment, two students tried to understand the straight-line nature of light traveling through simplification and idealization of the real world into a simple experimentation and model, using the "baby powder" that was very familiar to them.



[**Problem**: How light travels?] by: J.H., C.L.J.

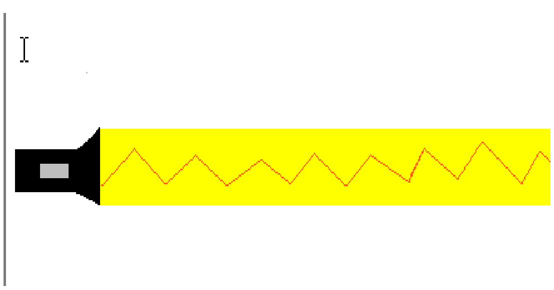
Light travels in a straight line. If you don't believe me try it by putting a flashlight in a shoebox, make a hole in the shoebox where you're going to put the flashlight, turn off the lights, turn on the flash light and put baby powder where you are flashing the light at. Then you'll see light travels in a straight line.

Figure 4-1: Straight-line theory.

2) Wave theory

When students first begin to build a theory or model, they typically have their own mental model of what the final graphical representation should look like, which comes from their daily experience (Barnett, et al., 2001). However, by gathering information from their partners, textbook, Internet, field trips or other resources, and by engaging in discussions with their peers, students develop new shared meanings, in which, analogue is a useful way to build a model and express the explanation of a theory. The following three notes are examples of the "Wave theory" with two drawings presenting two models.

In the first note, student J. H. figured out that light was traveling like a wave by analogue of a "heat wave" (see Figure 4-2). In fact, this drawing not only presented the wave theory, but also the straight-line theory. In second note, student C. L. J. presented the wave nature of light-traveling with a frequently-used shape "zigzag." In the third note, student C. L. J. presented "Thomas Young's experiment" from an authorized resource and conducted the same experiment by himself for demonstrating the wave theory. Figure 4-3 played an important role that the text couldn't do alone for students to understand the wave theory and the text in the note clearly and in detail.



[**Problem**: Why I think light travels in a wavy line.] by: J.H.

[**My theory**] is that light travels in a wavy line because if you drive behind a bus you'll see heat that look like a wave.

Figure 4-2: Wave theory.

[Title: ZIG-ZAG] by: C.L.J.

[**I need to understand**] Let's just say if the light travels in zigzag motion what makes the zigzag go up then what makes it stop and go down.

[Title: 1801, Thomas Young's experiment.] by: C.L.J.

[**New information**] In 1801, Thomas Young showed that light travels in a wave. He did that by an experiment. This is what he did. He took a single light source and took a board and cut two pinholes in the board, and then he shone the light through the pinholes. On the other side of the wall the light shows a pattern. It goes light, light, dark, light, light, dark, etc. What I mean is that instead of only making two light spots on the wall, he proved that 6 light spots were created. This proves that light must travel in a wavy line. If light traveled in a straight line, he should only have made two light spots on the wall. I did this experiment in class and got the same results. I used straight lines in my drawing to show how the wavy lines travel.

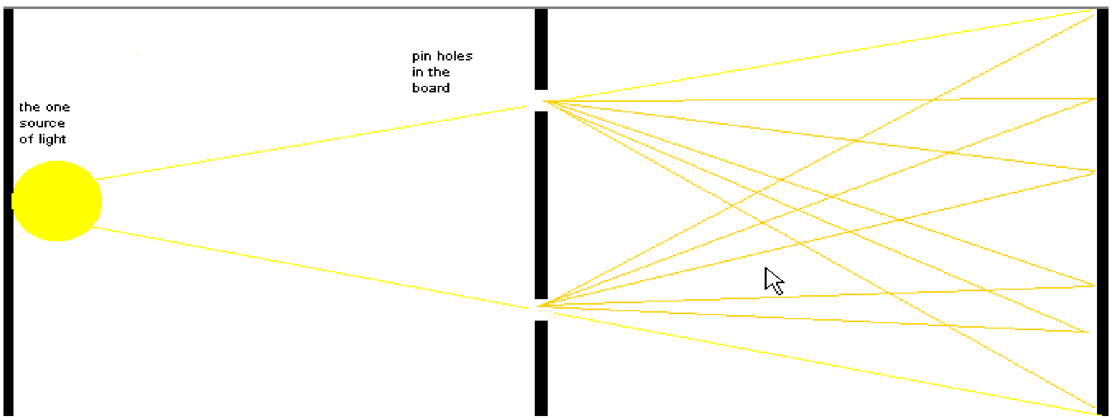
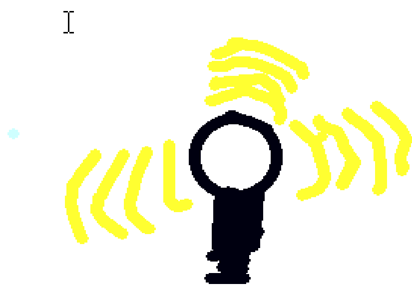


Figure 4-3: Thomas Young's experiment.

3) Ripple theory

Models used for theory building are expressed through written description or presented by student-generated drawing. However, can children communicate ideas for which they do not have a concrete, visible object? The evidence suggests that they can. Symington(1981) found that many children aged five to eight years added a stem to their drawing of a leaf even though the stem was not visible. Although Barrett and Light (1976) would call this type of drawing "intellectual realism", rather than "visual realism" (which would represent the object according to what was actually visible), it demonstrates that young children are able to convey logical ideas.

Just as mentioned above, analogue is an important way for children to learn a new concept and to reason an unknown thing from their experience. In Figure 4-4, student Clare displayed the model of the "Ripple theory" from daily experience that every student had, and reasoned that two rays of light cannot clash into each other by observing two water waves didn't hit each other.



[Title: How does light travel?] by: Clare.

[**My theory**] is that light travels in a ripple waves like when you hit the water with your hand when you throw two rocks into the water they don't hit each other they overlap each other. Here is a picture to explain it more.

Figure 4-4: Ripple theory.

4) Combo theory (wave and straight-line theory)

From a learning perspective, the act of theory-building and modeling allows students to engage in a design process that begins with a set of tentatively accepted theories that can evolve into coherent understandings represented in their models (Roth, 1996; Sabelli, 1994). As a result, theory and model building activities have become more commonplace in inquiry-based science learning because it has been recognized that an important activity of scientists is building, testing, and evaluating models of natural phenomena (Hestenes, 1992). Figure 4-5, the upper part presented the "wave theory" and the bottom part the "straight line theory," was a graphical representation of the "Comb theory" and expressed an important understanding: "… light has aspects of both straight lines and waves. …It depends on how you look at it. Or what your experiment is trying to prove," by integrating two theories (the "Straight-line theory" and the "Wave theory"). It presented the student Nathalie got a deeper understanding of the advanced nature of light into the scientific view.

[Title: Two theories.] [**Problem**: how does light travel?] by: Nathalie.

When we had the class debate, I was the one and only student who was not on a side because my theory was light travels in waves, but the waves go in a straight line and the debate was between straight line and waves. And now we have lots of ideas from the debate and we don't know which one is right. [**My theory**] now is light travels sort of like this: Light travels in a straight line but appears to be wavy or light travels in waves but appears to be straight. That means that light has aspects of both straight lines and waves. **[Evidence]** It depends on how you look at it. Or what your experiment is trying to prove. In our class we have seen experiments that prove both that light travels in straight lines (box with powder and shadow experiments) and wavy lines (Thomas Young experiment).

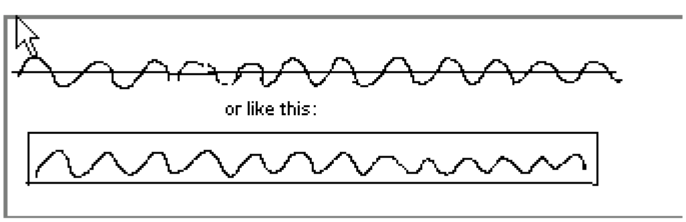


Figure 4-5: Combo theory.

5) Particle theory

The "particle theory" is beyond the content of curriculum and is a little hard for grade 4 students to understand the nature of wave and particle of light; thus, in the course of knowledge building talk, there was only one note to mention this theory from authoritative resource and student Clare didn't use drawing to present this theory. But the discussion was useful for further study in future. The following inscription demonstrated the evidence that children can communicate concepts or ideas for which they do not have a visible object (Krampen, 1991).

[**Problem**: how does light travel?] by: Clare.

… we had a debate and here are some jot dots that I wrote: …not only does light move in waves it also moves with a flow of little particles. Scientist calls these particles photons. The particles contain the energy that makes up the energy of light. …light is both waves and energy (transmitted with particles).

6) The integrated display of five theories

Children use representation to develop their own theories of their understanding of what they know (Forman, 1994, 1998). The following five drawings (see Figure 4-6), which are simple, visual and easy to understand and memorize, were a student's graphically summarization of the five theories in his Portfolio note, presenting the final results of collective theory-building and modeling and the share understanding of how light is traveling.

Matthew H.'s understanding of light!!! [In his Portfolio view]

[How light travels] Our class has many theories about how light travels. We have 5 theories: 1. Ripple; 2. Wave; 3. Wave in tube; 4. Particle; 5. Straight.

Figure 4-6: Integrated display of the five theories of light traveling.

This finding suggests that young students can build proper models with drawings which in turn foster discussion and exploration of complex scientific concepts of optics. This analysis also demonstrated Driver et al. (1996)'s finding that students' use of "theory" moves from a descriptive state, or phenomenon-based reasoning, where ideas are not different from experiments (for example, Figure 4-1 and Figure 4-3), to relation-based reasoning, where students come to believe that one can find ultimate proof for particular theories (for example, Figure 4-4). They also identified a relatively rare but important student reasoning practice based on modeling, where students recognize that theories might need to be changed in light of new evidence or new views (for example, Figure 4-5). We found that students began to move from their initial phenomena-based approach to a more relation-based perspective through progressive scientific inquiry which required them to build theories and models (for example "My theory is"), and test these hypotheses (for example "My evidence", "New information") for one school year. The scaffolds, such as "My theory is", "I need to understand", etc, are the explicit guidance for how to participate successfully in the building and negotiation of scientific theories and models.

5. Individual students' understanding and knowledge gains

In grade 4, students created 470 notes in total, with 123 student-generated drawings in 13 views. The average number of drawings per student was 5.5, and the ratio of drawings to the total number of notes was 26%. All the drawings in grade 4 were analyzed for level of understanding (see "Graphical Representation" in Table 1) with level of understanding of expository text (see "Caption" in Table 1). A drawing in a note was a unit of analysis, so two drawings in a note were viewed as two units of analysis. Each drawing with captions was inspected and then placed into one of three scales according to the level of understanding it displayed (inter-rater reliability over 30 sampled graphical representations $r = 0.84$, with differences resolved through discussion). Students' total scores in each category were calculated, and the significant correlation was observed between "Graphical Representation" and "Captions" (Pearson $r = .914$, $p < .01$); the strong link between these two variables indicated that, by generating drawings in a community space, a student could better express his/her personal knowledge or understanding of inquiry topics, and vice versa. Another Paired *t*-tests of students' total scores in each category showed significant increases ($p<0.05$) between grade 3 and grade 4 (Gan, et al., in press).

Conclusions and implications

This research has demonstrated that children can represent their ideas about light successfully using drawings with written text. Drawings appear to be especially useful for young children to produce graphical representations of complex system, or abstract ideas, such as the image formation, and the ripple theory. These findings suggest that drawings could prove an effective medium to enable children to express their understanding of light, which may range from simple ideas concerning objects such as flashlight, for example, to complex ideas concerning theory building and modeling such as the "combo theory."

The researchers found that where drawings were produced they all were readily interpretable. This suggested that all children who produced drawings were at the "visual realism" stage of development (Cox, 1993). Moreover, Children's drawings are representative of general cognitive, or concept, development, not simple maturational development (Seefeldt, 1999, p. 205). Children produce their drawings from what they know rather than what they see (Piaget & Inhelder, 1956).

The results of discourse and content analysis showed that student-generated drawings support deeper understanding from four perspectives: (1) understanding of content area knowledge; (2) idea improvement and conceptual change; (3) progressive scientific inquiry for problem solving; (4) theory-building and modeling.

Knowledge building facilitates discourse, question-posing, and hypothesis formation, by allowing students to construct and manipulate drawings of their shared understandings that all of their peers can access. It is important to note that these drawings and the accompanying discourse are not static, but fluid and open to questions as each student brings to bear their individual knowledge and attempts to integrate it with the shared understanding embedded in their current construction. Through knowledge building discourse and encouraging students to take collective responsibility (Scardamalia, 2002) in science learning, rather than pushing them to simply accept existed conclusions in textbook, we supported these grade 4 students to achieve deeper understanding of light with drawings in Knowledge Forum. In this study, although students didn't received instructions in use of graphics, it was the knowledge building environment that favored them to advance their knowledge with a variation of methods. Just as Scardamalia, et al., (1992) mentioned that students using Knowledge Forum have shown significant gains in literacy even without any special attention to it. Naturally, graphical literacy as one kind of multiliteracies is a "by-product of knowledge building" (Scardamalia, 2003).

Additionally, the Grade 4 teacher played important roles in online and classroom activities of knowledge building. He was an experienced knowledge building teacher, and practised knowledge building pedagogy and approaches into classroom learning and online discussions as follows: (1) creating a risk-free learning environment conducive to knowledge building in which students were encouraged to take collectively responsibility for their own knowledge advancement and for that of their peers. The teacher encouraged students to raise questions, build theories, and record findings in scientific inquiry and knowledge building discourse in which elaborating intuitive ideas and exploring deeper understanding were valued (Zhang et al., 2007); (2) working as a knowledge building facilitator. The teacher didn't predefined learning tasks or activities, but let student progressively identified what they wanted to explore and elaborated what they needed to learn. He engaged in online discussions with students and raised thought-provoking questions (16 of total 19 notes) for students' further exploration; (3) facilitating students' collaboration and reflection. The teacher encouraged students to collaborate opportunistically to "rise-above" collective knowledge through face-to-face and online discussions. He often posed reflective questions, such as "what are our knowledge advances?" to promote students' reflection on their knowledge advances (Zhang, et al, 2007); (4) assuming himself as a knowledge builder. Not only did the teacher encourage students recorded their knowledge building objects and artifacts into database, but he also worked as a design researcher, recording (sometimes videotaping) students "knowledge building talks" and writing down his progressively refined teaching approaches to and reflections on knowledge building into his own e-Portfolio view: "Calendar of Inquiry."

It is worth pointing out that assessing understanding is a difficult thing. Understanding exists in degrees; not in an all or none state. Partial understanding is the norm in most matters. On most matters, a person's understanding is somewhere between two extremes with absolute ignorance on one end and deep understanding on the other. It was also recognized that using drawings to assess understanding would have limitations. Strommen (1995) found that children's drawings of forests yielded less information than interviews. One difficulty for assessing understanding is that drawing is an open technique and consequently is difficult to score reliably (White & Gunstone, 1992). Another is that graphical representation is partly limited by their drawing ability; or may be incomplete because they didn't draw some parts. Thus, a better way is assessing drawings combining with other methods such as written text, interview, classroom observation, and pre-post-test for probing students' understanding. Lastly and unfortunately, there were no control class and data for comparison. Therefore, these limitations were taken into account in the interpretation of the results.

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