Journal of the Korean Association for Research in Science Education Vol. 25 No. 1 (Special Issue), pp. 41~56 (2005)

Investigating Student's Understandings of Light Using Dynamic Science Assessment Method

Soo-Young Lee
(Technical Education Research Centers)

ABSTRACT

Assessing students' knowledge can be a challenging endeavor, as researchers attempt to capture the full complexity and potential development of children's ideas. In this study, the Dynamic Science Assessment (DSA) method (Magnusson, Templin, and Boyle, 1997) was employed to investigate 9-12 year old students' understandings of light, while engaging in multiple tasks with a flashlight with various reflectors and mirrors. The results showed that DSA was effective in providing an opportunity to establish a Zone of Proximal Development, in addition to diagnosing a student's prior understanding. Throughout the interview, a student showed a conceptual model of light as being a solid single entity whose shape can be determined by the shape of the casing of a flashlight. However, as DSA provided phenomena that could not be explained by his unitary model, the student began to re-examine his original conceptual model, and attempted to revise it. This study addressed how Dynamic Science Assessment can help us better understand, not only students' current state of understanding, but also a potential development of understanding in their ZPD. In that sense, this study argues that we should pay more attention to the instructive role of classroom assessment that can promote and support further development of students' deeper understandings.

Key words: dynamic science assessment, ZPD, light, reflection, conceptual change

I. Introduction

Standardized assessments of students' understanding have been a hot issue in the recent science educational reform movement in the US. Between 4th and 8th grade, American students fall behind on international norms (e.g., TIMSS and PISA). In order to develop an internationally competitive workforce, the No Child Left Behind Act (http://www.ed.gov/nclb) strongly emphasizes accountability by requiring States to implement statewide accountability systems covering all public schools and students, which must be based on challenging State standards, annual testing for all students in grades 3-8, and annual statewide progress objectives ensuring that all groups of students reach proficiency within 12 years.

The heavy emphasis on standardized tests, however, has resulted in many drawbacks in terms of students' actual learning of content. Studies have found that high-stakes testing has led to an emphasis on increased coverage of disparate topics, narrowing the range of instructional practices, test preparation, and increased use of drill and practice (Haney, 2000; McNeil &

---

*Received on 29 December 2004

**Soo-Young Lee (soo-young_lee@terc.edu)

Valanzuela, 2001; Smith, 1991; Powell & Skoog, 2000; Firestone & Mayerowitz, 2000). Other studies have shown that teachers in high-minority classrooms, under pressure to improve student test performance, are more likely to teach test-taking skills, to increase emphasis on specific tested topics, and to dedicate a large proportion of time to test preparation (Madaus & Clarke, 2001; Settlage & Meadows, 2002).

Nevertheless, no one can argue the importance of assessment in learning and teaching. The question is what the purpose of assessment should be. Why are we assessing our children's understanding? Assessment should not be the end point of instruction as a means to check whether students have mastered certain concepts and skills or not. Rather, a larger goal of assessment should include informing teachers where students' current understandings are, and furthermore, helping teachers to further advance students' understanding. What students are assessed in a test is known to impact what they learn in the classroom. Shavelson, Baxter and Pine (1990) pointed out the important relationship between assessment and curriculum by saying that, "Good instructional activities can be translated into assessments; good assessments can be used as instructional activities." In other words, assessment should be integrated as part of the curriculum. To this end, this study will explore an instructive role of assessment that illustrates the potential development of students' learning through guided assessment beyond merely measuring what they already know.

Ⅱ. Theoretical Background

Dynamic Assessment and Sociocultural Constructivism

Traditionally, the nature of assessments has been considered static, in that it measures what students know or do not know at the time of assessment. This static view of assessment was informed by psychological theories in the 1960s that stressed individual cognition and developed tests that minimized social influences. On the contrary, sociocultural constructivist perspectives emphasize the importance of social interaction and mediation in co-constructing thought, ideas, knowledge, and learning that is influenced by social phenomena. Sociocultural constructivist perspectives view assessment as dynamic in its nature.

The term, Dynamic Assessment, was first coined by Feuerstein (1979) and it characterizes "approaches in which the performance of the individual being assessed is mediated or guided by another individual to determine the individual's potential to profit from assistance or instruction" (Palincsar, 1998, p. 366). Dynamic Assessment addresses the learning potential of a leaner when he or she is assisted or guided by another more knowledgeable individual(s). Dynamic Assessment has been utilized in various domains of psychology, speech/language, and education, that focus on the ability of the learner to respond to intervention (e.g., Budoff, 1987; Campione & Brown, 1984; Lidz, 1987; Lidz & Elliot, 2000).

Dynamic Science Assessment

In this study, an interactive interview method called Dynamic Science Assessment (DSA) (Magnusson, Templin, and Boyle, 1997) was employed to explore students' understandings of the nature of light.

Magnusson *et al.* (1997) argue that investigating conceptual change requires observing changes as they occur, like recording a movie, rather than a snapshot of what they know at one point. The Dynamic Science Assessment (DSA) interview process creates a means to observe these changes. The inclusion within the interview of discrepant phenomena provides an opportunity to establish a Zone of Proximal Development (ZPD, Vygotsky, 1978). Magnusson *et al.* (1997) described this zone as one that allows the student and the interviewer to develop a shared understanding of the problem. In a ZPD, the more expert individual (e.g., a teacher) changes cognitively as he or she develops understanding of the perspective of the other individual (and perhaps the problem and its solution as well), and the individual with less expertise (e.g., a student) changes cognitively through the process of coming to learn how to solve the problem albeit with the assistance of the more expert individual. In order to structure the transition from the known to a ZPD, an interview protocol that includes relevant problems must be developed.

If scientific knowledge is to be investigated, then the assessment should be framed by the practices of the scientific community (e.g., Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). In developing a DSA, the included tasks and the students' interactions with those tasks are the first focus. It is suggested that the assessment should include several, related, commonly-encountered phenomena. This allows students to easily address prior information to help with the formulation of a problem's solution. Discrepant events should be included in order to create a challenging environment which facilitates the development of a ZPD. The second focus is on the performance and the interviewer's role in the assessment. It is not sufficient merely to pose questions. The entire process must include a strategy to have students elaborate on the reasoning behind their answers. The interviewer must provide conceptual guidance. This guidance will help to focus the interview on relevant scientific concepts. Magnusson *et al.* (1997) asserted that the following expectations must be signaled: (1) concepts are consistently applied when appropriate, (2) different concepts will be coherent with respect to one another, and (3) a small number of concepts provide a complete description/explanation of aspects of the physical world. These three C's - concept, coherence, and completeness - allow the assessment to address the concepts developed by the student, once the ZPD is entered. This study protocol design and assessment utilizes the three C's to attempt to analyze students' conceptual understanding of light.

Students' Understandings of Light

Light is an integral and indispensable part of our everyday experiences. However, conceptions of light are often taken for granted, or it is left to the students to construct their own conception of the nature of light. Watts (1985) pointed out that teachers and textbooks seldom give a definition of what light is, beyond how it is connected to a 'form of energy.' Much research has been done on students' conceptions or misconceptions of light (Brickhouse, 1994; Feher & Rice, 1988; Fetherstonhaugh & Treagust, 1992; Monk, 1991; Rice and Feher, 1987; Watts, 1985). For example, working with 9 to 13 year olds (n=110), Rice and Feher (1987) engaged students in tasks and discussions that focused on light propagation and image formation. The tasks involved transmitting light from different shaped sources through large and small holes to create images on a screen. In clinical (semi-structured/think-aloud) interviews, children were asked to predict and then explain with diagrams of their own creation, the light's behavior under several different conditions of light source (crosss-haped or T-shaped) and aperture size. Comparing the children's explanations to expert scientific explanations, the authors (Rice and Feher, 1987) were able to identify children's misconceptions (e.g., light emanates from a source in only one direction, in bands of horizontal parallel rays; light rays shrink to squeeze through a pinhole but get bigger on the other side) as well as some missing concepts. On a subsequent study of students' conceptions of shadows in relation to light, Feher and Rice (1988) reported that "only about one-quarter of the children we interviewed had a clear conception that a shadow is the absence of light. Most of the children spoke of the shadow as if it were the presence of something that has material characteristics." Brickhouse (1994) also found that children's observations of light helped them to develop a limited theory about light that was largely useful in explaining classroom investigations. However, this theory of light was less helpful for the children to understand shadow phenomena and was too limited to explain out-of-classroom observations of light and shadows (p. 639). Both studies showed that though concepts of light are often introduced early in elementary schools, students often have limited understandings of the scientific conceptions of light and shadows that are necessary to explain natural phenomena of light.

Ⅲ. Methods

Subject

A total of six children (from 9 to 12 years old, 3 girls and 3 boys) were interviewed to investigate their understandings of light using the DSA protocol. This paper, however, reports results from an interview with Terry, who was an eleven-year-old boy at the time of the interview. Terry's case was chosen because his active participation and engagement with the materials and phenomena showed a great potential development of a ZPD. While results from the all six participants will be reported later in other papers, we believe Terry's case best illustrates how DSA can be used to explore the development of students' understanding through a ZPD that is constructed by given tasks (phenomena), and an interaction between an interviewer and an interviewee.

The Protocol and Its Tasks

The interview was conducted in a darkened room where all necessary materials were prepared on a table for the participant to manipulate (see Appendix). The entire interview took about 70 minutes and was videotaped for later analysis. The interview protocol was developed by a group of researchers including the author of this paper. First, we reviewed previous literature to survey well-known students' conceptions and misconceptions regarding light. Second, target concepts of light to explore using DSA were identified (e.g., light is a form of energy, light travels in a straight light, light is emitted in all directions, light striking a surface can reflect). Third, various students' tasks were developed to elicit the target concepts identified in the previous step. The protocol was refined through comments from experts in various fields, including teachers in an elementary school and a physics professor.

The assessment of this study focused on phenomena that could be created using a common flashlight. This decision was based on the assumption that almost every child has explored the workings of a flashlight at some point. Therefore, students had a base of prior experience from which to work. Other researchers' work on children and light reported that "darkness appeared to be as an important part of students conceptions as light (Driver, Squires, Rushworth, and Wood-Robinson, 1994, p. 128)." This statement suggested a possible examination of the interaction between light and a dark surface. Further discussion within the group led to the idea of exploring the different properties of various colored reflectors. This protocol (see Appendix) was designed to explore two related areas of understanding light, yet remaining flexible for unexpected responses from children. Indeed, the original protocol was modified as the interview progressed, and these modifications will be discussed in the results section. Throughout the protocol, the interviewer followed DSA goals of assessing student knowledge (both what students think and why they think it), offering perturbations to challenge their knowledge (and move them into a ZPD), and being flexible in questioning in order to allow the students to initiate concepts.

In the first section of the protocol, exploration of the nature of light, was initiated through prediction of where light from a flashlight might reach. Following a brief discussion to determine that in fact the student was familiar with the workings of a flashlight, the student was asked to predict where a screen might be placed in order that light from the flashlight, mounted on a stand, would strike the screen. The student was asked to verbalize the prediction as well as physically place the screen in the predicted location. After the screen was placed, the student was asked to use a colored marker to draw on the screen what would be seen. The light was then turned on, and the actual image on the screen was traced. The student was asked to explain both drawings (predicted and actual images) with respect to the representation of light (difference in image, accuracy of prediction). This first section of the protocol was intended to see how the student represented light (beam, energy, etc.), and to explore concepts of light traveling, and intensity as functions of distance.

Then, the student was asked to consider the role of the reflector in the workings of the flashlight. Cued into the features of the screen image, the student was asked to predict what would be seen with various refelctors such as chrome, black, white, other colors, and a deeper chrome. There was a specific concentration on the nature of the reflector. Would it be recognized as a mirror? In the case of each reflector, the student was asked to predict, both verbally and graphically, what would appear on the screen. The actual image was also traced on the screen, once the light was turned on. The purpose of the various reflectors was to provide discrepant events (perturbations) to allow movement into a ZPD related to reflection.

Specific guidance was incorporated into these various tasks in order to facilitate the development of the interviewer's understanding of the students' representations. Strategies used included prompting for the use of specific terminology, focusing on possible conflicts between predictions and actual occurrences, suggesting of details of the phenomenon that may have been overlooked, and summarizing the student's representations for confirmation.

Approach To Data Analysis

The data obtained from the interview came from a videotape of the interview, field notes recorded by the interviewer and two observers, follow-up recollections of the observers, and drawings the student made during the DSA. Subsequent viewings of the videotape allowed us to target key moments in the interview where the student's statements seemed critical. These areas were transcribed for further analysis and informally coded for grouping with one of the target concepts. From these transcriptions, notes, and video, our research group developed interpretations of the meanings of the statements. A consensus was reached on several broad areas of analysis: drawings of the student's representations of a phenomenon, the verbal descriptions and explanations, the specific language use of the student, and the student's general level of confidence in these representations. These areas of analysis were applied to themes that developed as a result of this interview.

Emergent Content Analysis of the Interview

DSA data was analyzed using an emergent content analysis approach, which is a form of content analysis (Miles and Huberman, 1994; Weber, 1990), since the purpose is to capture the content of what is represented by students. The emergent representations of students' understandings resulted from a recursive process of constructing, comparing, and refining specific descriptions of students' ideas from task to task, as well as in comparing students' ideas to currently accepted scientific knowledge.

The first step of the analysis was to underline any data (e.g., text or diagrams) that provided insights about student's ideas in relation to the targeted concepts. The second step was to determine the conceptual areas about which the underlined sections provided insights. For example, every time the student said or drew something that indicated his or her views about the nature of light, it would be marked or "coded", using that phrase. After coding was completed, similarly-coded sections were compiled, and the process of creating representation of the information began. A qualitative data analysis software was used (NVivo, http://www.qsrinternational.com/).

Ⅳ. Results

Revisions To the Protocol

A major surprise was the degree to which the interview protocol was changed during the DSA. While working through the interview, Terry developed new phenomena to help explain his understandings of the nature of light and reflection. Two new tasks were added to the explorations: the mirror and the inverted reflector. Both of these tasks allowed Terry to elaborate on his explanations.

Results

The analysis was organized into three separate themes: 1) Terry's representation of light as a single entity, 2) the nature of reflected light, and 3) the existence of both primary and secondary light. Each theme will be discussed separately with regard to the relevant concepts developed in the assessment.

Light as a Single Solid Entity.

Throughout the interview, Terry represented light as a single solid entity. Although some drawings showed multiple lines of light (see Figures 1 through 3), Terry stated that these lines were indicating the directions of light's travel path, rather than multiple light rays. This "unitary" model may imply that Terry perceived light acting as a singular object that can be manipulated. This conception was clearly seen during his created phenomenon using the inverted reflector.

Following the work with the other reflectors, Terry wanted to try to use an additional reflector to attempt to reshape light to a narrow beam, like a laser. He placed an inverted cone over the end of the flashlight and predicted that the hole in the reflector would produce a single bright point of light on the screen. When he was asked how this would work, he explained that "the light would be reshaped by the reflector". When he turned the light on, the results were almost exactly opposite from that of his prediction. When faced with these unexpected results, he had difficulty accepting them. However, he decided that the shape of the reflector must have had an effect. At this point, the interviewer inserted a sheet of paper between the inverted reflector and the flashlight. Terry predicted that it would affect the image but could not explain why he clung tenaciously to his concept of the singularity of light. He was convinced that light could be shaped.

Another area where this model could be clearly seen was during Terry's discussion of how light came from the flashlight bulb. While examining the reflector and bulb, he stated, "light can come out all the ways you can see" (Figures 1 and 2). As a part of this discussion, there was an implication of infinity without an articulation of the actual term. He drew arrows to indicate direction but specifically stated that "they [multiple arrows in his drawing] were all part of the same piece of light."

Terry also attributed the circular shape of the image to the shape of the flashlight. When asked if a square flashlight would produce a square image, he agreed. Since Terry perceived light as a unitary entity, he said that "light can change its shape according to the shape of the flashlight."

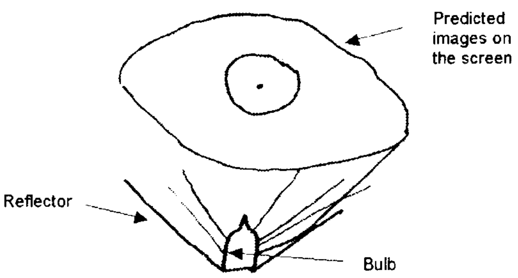

Fig. 1. Light from the flashlight and predicted images on the screena

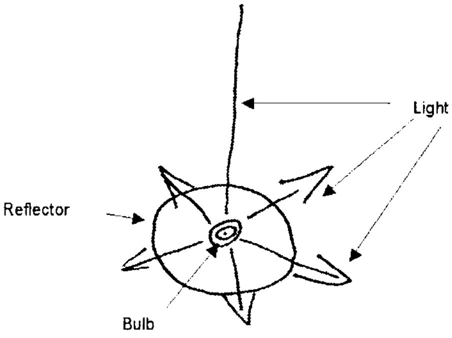

Fig. 2. Terry's representation of a flashlight bulb, reflector, and light

The Nature of Reflected Light.

Terry's discussions of the phenomena generated through the use of the various reflectors provided several clear conceptions of the nature of reflected light. In order to present this data clearly, each phenomenon will be examined separately.

1. Chrome reflector (standard flashlight): On the first task, Terry's predictions about the location of the image on the screen were generally accurate. The image included a series of concentric circles of varying brightness. When asked to explain, he attributed the central bright spot to light coming from the end of the bulb. The outlying circles were the result of this central light reflecting (his own term) back into the flashlight and then being reflected out by the reflector (Figure 1).

2. Mirror (Terry's idea): Terry decided that he could best explain reflection by using a mirror. There was one handy, so he was allowed to use it to frame his discussion. The general sense of this experiment was that light had to be present for an object to be seen in the mirror. He explained that "you could shine a light on the mirror and illuminate an object." This was tried. Angles were discussed, and at first he stated that a 90 degree angle was needed. However, when the interviewer changed the angle of the flashlight, and still, the object was seen, Terry agreed that the angle could vary. Terry stated that "all you had to do was line the light up with your eyes, and aim it where you saw the objects' reflection in the mirror." This would result in the light striking the object. This task illustrated Terry's beginning of the development of an understanding of relationship between light and vision.

3. Black Reflector: Terry predicted that he "would only see a bright center part because light could not reflect off black." When the results were not what he expected, i.e. light was darker in the middle, he decided that his original idea about the light coming from the end of the bulb was incorrect. He readily agreed that something else was happening. This led to an examination of the flashlight and a new idea. His new idea included two parts. Some light on the screen was "sneaking out" without hitting the reflector. Also, the light hitting the black reflector was not escaping. This is when Terry explained about the light leaving the bulb.

4. White Reflector: Terry predicted a similar result to the chrome reflector. When the image was similar to that from the black reflector, he was puzzled. He eventually concluded that the white reflector was not a very good mirror. There was a long discussion here of darker light.

5. Deep Chrome Reflector: This reflector was handmade and its surface was not very smooth. There were some interesting aberrations in the image that Terry attributed to light doing something "funny." He explained this by stating that "the light was curving after it hit the wrinkles (see Figure 3)." This deep cone also prompted a discussion of focusing light like a laser. Terry stated that "if you could make a cone narrow enough, you could create a laser." This discussion involved some high-level concepts of reflection.

6. Red Reflector: Terry was allowed to select a color for a reflector. He predicted that an image similar to the black reflector would result. This proved to be the case. However, there was a colored tint to the light. This coloration was associated with the phenomenon of darker light.

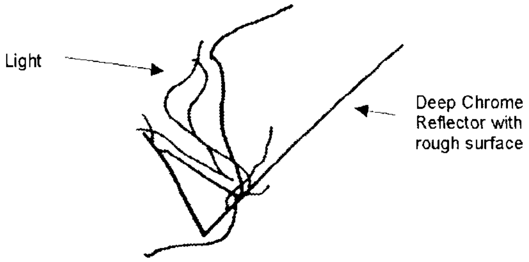

Fig. 3. Light from the deep chrome reflector with rough surface

Primary and Secondary Light.

An extremely interesting conceptualization was Terry's view of darker light. As the interview progressed, there were many images on the screen that showed light with differing degrees of brightness (for example, Figure 1). When asked to explain these different areas on the screen, Terry did not use the term "brightness" consistently, although prompted to do so. Over and over, he returned to a description of the darker areas as an area containing "dark light." There seemed to be a connection between the amount of light and its degree of darkness. This is consistent with previous studies on children's conceptions of shadow as dark images, a presence of something rather than an absence of light (Feher & Rice, 1988).

Ⅴ. Discussions

Terry's understanding of light and related concepts, though not completely in alignment with the ideas of scientists (e.g., dark light), was nonetheless quite good for his age-developmental group. At times, his lack of scientific language hindered his explanations of his thoughts, but he was able to demonstrate his ideas through other non-verbal means. More striking than his knowledge of light was his ability to construct a model based on theory, and flexibly revise it based on anomalous data.

Concept of Light

Throughout DSA, Terry constructed a model of light. Terry thought the light came out of the flashlight as a solid single entity whose shape was determined by the shape of the casing of the flashlight. He remained loyal to this model throughout the interview, though at the very end he was presented with contradictory data as he tried to "force" the light into a narrower beam by placing an inverted reflector cone over the end of the flashlight. With the unexpected results, Terry started to re-examine his original ideas of light as a single entity but was not able to develop an alternative concept that is more acceptable in the scientific community during the DSA. Although Terry was not able to advance far enough to develop scientifically acceptable concepts during DSA, this certainly illustrated that he entered a ZPD and moved from his original consistent model toward a new or revised concept.

Within his consistent model of light, we also noted several instructional "remnants" from prior experience with light. When asked to describe how light came from the bulb, Terry responded, "all the ways you can see." This phrase suggests that he was presented with the concept of infinity in previous instruction, but had not fully incorporated the ideas into his conceptual framework. In other words, Terry was able to verbally represent a concept of light infinity from what he was told in a school, but this concept of infinity was not found in his model of unitary light. In addition, Terry's drawings showed instructional remnants as well; he drew multiple rays coming from the light bulb and traveling in different directions. However, he did not link these representations with the single beam of light in his conceptual model. Until Terry was challenged with the unexpected phenomena, he had two incoherent conceptual models (i.e., light is everywhere and travels in every direction vs. light is a single beam that can be shaped by the shape of the flashlight), not recognizing a discrepancy between two concepts.

At the end, one of his drawings (Figure 3) showed what happened to light as it interacted with the "wrinkles" on the homemade silver reflector. The single incoming beam was "somehow split or multiplied (in Terry's words) into several curving rays," which indicate a change of his original unitary single beam model of light. These points of contradiction could be excellent starting points for further instruction. The discrepant events, such as images from the inverted reflector and the rough surface reflector, allowed him to enter his ZDP and develop a new understanding of light. This is a case illustrating how DSA can serve not just an assessment of students' current state of understanding but also as an instructional means to foster desirable learning that would be accepted by the scientific community.

Working like a Scientist

Terry's interaction with the DSA phenomena was consistent with the procedures used by scientists. He was very procedural in building his own model to understand light. He devised a method of testing which was logical and scientific, he approached the situation with rational thought, using his prior knowledge on the subject, and he used newly presented data to revise his own model. These are the practices that can be found in a community of scientists (Latour and Woolgar, 1986). However, Terry had knowledge gaps that did not allow for full understanding in alignment with formal physics knowledge. It is important to note how Terry dealt with his gaps. To him, his methods of inquiring were consistent, and the gaps were either not yet perceived, or filled in with other reasoning. The gaps were in (1) language, and (2) physics subject matter knowledge.

Language

Terry had a good grasp of several concepts and the vocabulary to describe the phenomena observed. He had a good understanding of reflection, self-initiating a segment of the interview where he used light and a mirror to accurately describe reflection to the interviewer. He also understood to a limited extent reflectors, and used that terminology. Terry also introduced the concept of a laser when discussing beam focusing, and attempted unsuccessfully to focus the flashlight beam as well. He also used the terms "fading" and "spread out" to describe what happens to light as it travels away from the source.

For several other concepts, Terry either implied knowledge of the concept, or used representations of them, but did not have the terminology. For example, the interviewer introduced the terms "brightness," which Terry used only inconsistently after that, preferring to talk about areas that were "less dark" or where "dark light" was visible. The use of darkness as a measure of light intensity is consistent for children in this age range (Guesne, 1985). "Intensity" was also introduced by the interviewer, but was not used by Terry. The interviewer also talked about "beams" of light, which Terry both agreed with and drew in his representations (e.g., Figure 3), but this language did not affect his conceptual model of a single beam light, as opposed to multiple beams. The term "infinity" was never used, although, as stated before, some of Terry's statements may be showing his previous exposure to the concept. Finally, Terry talked about light "curving" or "sneaking out" of the edges of the flashlight, consistent with his extrusion model, but inconsistent with scientific knowledge.

Physics Subject Matter Knowledge

Other gaps in Terry's model were caused by a lack of physics subject matter knowledge.

Although his background knowledge of light and physics was impressive to the researcher, he did have some inconsistencies with formal physics knowledge. Most impressive, however, was his ease with methods of reasoning consistent with formal physics. He showed signs of previous active thought and deep reflection on science concepts he had learned in school, and approached the DSA phenomena with a logical empiricist mindset.

It is noted that by engaging in a series of related tasks of DSA, we were able to observe Terry's development of both scientific content knowledge and procedural knowledge of scientific inquiry. For example, Terry was allowed to explore different phenomena other than originally designed in the protocol. By observing how Terry chose certain materials (e.g., mirror) to work with, and describing a rationale behind his predictions, DSA could elicit his reasoning processes. As Schwab (1964) pointed out both substantive structure (which includes concepts, ideas, understandings, principles, and propositions that characterize the discipline) and syntactical structure (which refers to the methods researchers use to achieve their goals) of knowledge are equally important to understand a discipline. DSA can provide opportunities to observe and foster both knowledge structures students are engaged in.

Ⅵ. Implications and Limitations

What do the results of this study imply for both research and practice in science education? In constructing the DSA interview protocol, prior knowledge of the student interviewed gave us an advantage in maximizing the potential of the questions. The interviewer knew the student well, allowing Terry to feel comfortable with the assessment. This familiarity also allowed the interviewer to move Terry's thinking into the ZPD with ease. Another factor is the knowledge base of the interviewer, both in terms of knowing the child, but also in subject matter and pedagogical content knowledge. Expert knowledge in concepts of light and how children represent them allows the interviewer to better understand the ideas presented by children who may be struggling to represent concepts of varying agreement with scientific knowledge. In DSA, the role of the interviewer and his or her content knowledge of a given topic as well as knowledge of cognitive development of students are critical. The interviewer or the guide should be able to diagnose students' developmental progress at each response and provide an appropriate scaffolding based on the diagnosis. Another important role of the interviewer during DSA is to assist students to clarify and elaborate their ideas, and make them confident of their ideas. In many cases, although students are able to give an answer to a problem, this does not always mean that they have a proper understanding of a concept. By probing students' ideas further, and helping them to explicitly elaborate their ideas, students' understanding can be fostered through DSA practices. Making students' thinking visible is an important notion to remember.

In addition to the important role of the interviewer, assessment tasks also should be carefully selected. In order to form a productive ZPD where students can make maximum progress with assistance or guidance from a more knowledgeable individual, first, DSA tasks and materials should be familiar to children. When events, tasks, and materials are familiar to children, they more easily engage in a range of cognitive activities. At the same time, tasks should be challenging so that children can construct a ZPD. If a task is too easy so a student can perform the task without any guidance, the student does not need to construct a ZPD. This is a crucial difference between a traditional assessment and DSA. DSA concerns the potential development of students' understanding; in other word, it concerns how far students' understanding can reach, instead of where the current understanding is now. Thus, DSA tasks should provide challenges such as discrepant events that do not match with students' expectation and students can not easily explain the events with their current understanding alone. However, if the level of difficulty is too high, students may give up engaging in assessment tasks. Thus, assessment tasks should also be flexible enough to be modified by an interviewer based on the level of students' understandings. In addition, assessment should include several related tasks so that students have multiple opportunities to confirm, reject, or modify their ideas while conducting assessment. For example, in this study, Terry's understandings of light were challenged and re-examined while he was engaged in various but related tasks with a flashlight. First, he was asked to use a regular flashlight. Then, new variables were added one by one such as different shapes or different colors of a reflector. When Terry encountered discrepant phenomena that did not match with his expectation; those were the moments when he entered his ZPD and moved along with the help from the interviewer.

A limitation of this work is in its design for a specific target group or age range. Terry was a "hands-on," inquisitive child who would be eager to take apart the flashlight. This same interview, however, did not work well with younger students in a pilot study. The younger students were brought into the ZPD at a point during the first phenomenon, which was sooner than we expected. Thus, this interview had to be changed by focusing more on the first research question in order to fit younger children's concepts.

Since the current study reports the results from one case study, generalization of the results regarding students' understanding of light can not be made. Nonetheless, the purpose of this study is not to make a generalized claim about students' understanding of light per se. Rather, the study illustrates how an alternative assessment called Dynamic Science Assessment can be practiced with a broader implication for research on the development of the learner's scientific understanding. DSA can be applied to any disciplines or topics.

Dynamic Science Assessment and challenging of children's ideas about the nature of light has implications for classroom practice. Being able to spend focused, one-on-one time with students allows for maximum assessment of their knowledge and potential knowledge. However, in a class full of children, the time needed for such personal attention may not be easy to find. Therefore, the balance between an in-depth assessment of students' understanding, which requires time and effort to focus on individual students, and a broader formative assessment of the majority of students in a classroom should be carefully exercised.

This study described how Dynamic Science Assessment can help us better understand not only students' current state of understanding but also a potential development of understanding in their ZPD. In that sense, the classroom assessment can play a role not only in checking whether students have certain understanding or not, but also promoting and supporting further development of deeper understanding. However, in many classrooms, the latter role of the assessment as an instructional means is often overlooked. This study can serve as a starting point for the further investigations of the critical and multiple roles of classroom assessment in schools. Given recent debates about the usefulness of high-stakes assessment and how much those assessment practices are able to inform curriculum and pedagogy, Dynamic Science Assessment can provide an alternative way of measuring students' understandings and in turn, contribute to our knowledge base of curriculum, pedagogy, and instruction.

References

Brickhouse, N. (1994). Children's observations, ideas, and the development of classroom theories and light. *Journal of Research in Science Teaching*, 31(6), 639-656.

Brown, J., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.

Budoff, M. (1987). Measures for assessing learning potential. In C.S. Lidz (Ed.). *Dynamic assessment: An interactive approach to evaluating learning potential* (pp. 173-195. New York: Guilford.

Campione, J. C. & Brown, A. L. (1984). Learning ability and transfer propensity as sources of individual differences in intelligence. In P.H. Brooks, R. Sperber, & C. McCauley (Eds.). *Learning and cognition in the mentally retarded* (pp. 265-293). Hillsdale, NJ: Lawarence Erlbaum.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas.* London: Routledge.

Feher, E., & Rice, K. (1988). Shadows and anti-images: Children's conceptions of light and vision. *Science Education*, 72(5), 637-649.

Fetherstonhaugh, T., & Treagust, D. F. (1992). Students' understanding of light and its properties: Teaching to engender conceptual change. *Science Education*, 76(6), 653-672.

Feuerstein, R. (1979). *The dynamic assessment of retarded performers: The learning potential assessment device: Theory, instruments, and techniques.* Baltimore: University Park Press.

Firestone, W. A., & Mayerowitz, D. (2000). Rethinking "high stakes": Lessons from the United States and England and Wales. *Teachers College Record*, 102, 724-749.

Guesne, E. (1985). Light. In R. Driver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 11-32). Philadelphia: Open University Press.

Haney, W. (2000). The myth of the Texas miracle in education. *Educational Policy Analysis Archives*, 8(41).

Latour, B., & Woolgar, S. (1986). *Laboratory life: The construction of scientific facts.* (2nd ed.). Princeton, NJ: Princeton University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge, MA: Cambridge University Press.

Lidz, C. S. (1987). *Dynamic assessment: An interactional approach to evaluating learning potential.* The Guilford Press, New York.

Lidz, C. S., and Elliott, J. G. (2000). *Dynamic assessment: Prevailing models and applications.* Amsterdam: JAI/Elsevier Science.

Madaus, G. F., & Clarke, M. (2001). The adverse impact of high stakes testing on minority students: Evidence from 100 years of test data. In G. Orfield & M. Kornhaber (Eds), *Raising standards or raising barriers? Inequality and high stakes testing in public education.* New York: The Century Foundation.

Magnusson, S. J., Templin, M., & Boyle, R. A. (1997). Dynamic science assessment: A new approach for investigating conceptual change. *Journal of the Learning Sciences*, 6 (1), 91-142.

Miles, M., & Huberman, M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage Publications, Thousand Oaks.

McNeil, L., & Valanzuela, A. (2001). The harmful impact of the TAAS system of testing in Texas: Beneath the accountability rhetoric. In G. Orfield, & M. L. Kornhaber (Eds). *Raising standards or raising barriers?* New York: Century Foundation Press, pp. 127-150.

Monk, M. (1991). Generic epistemological notes on recent research into children's understanding of light. *International Journal of science Education*, 13, 255-270.

National Center for Educational Statistics (2004). Trends in International Mathematics and Science Study. Retrieved from http://nces.ed.gov/timss

Organisation for Economic Co-operation and Development (2004). Programme for International Student Assessment (PISA). Retrieved from http://www.pisa.oecd.org

Palincsar, A. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology*, 49, 345-375.

Powell, R. R., & Skoog, G. (2000). Middle level integrative curriculum reform: A study of teachers' epistemological theories. *Research in Middle Level Education Annual*, 23, 1-34.

Rice, K., & Feher, E. (1987). Pinholes and images: Children's conceptions of light and vision. *Science Education*, 71(4), 629-639.

Schwab, J. J. (1964). Structure of the disciplines: Meanings and significance. *The structure of knowledge and the curriculum*. G. W. Ford and L. Pugno. Chicago, Rand McNally & Co.

Settlage, J., & Meadows, L. (2002). Standards-based reform and its unintended consequences: Implications for science education within America's urban schools. *Journal of Research in Science Teaching*, 39(2), 114-127.

Shavelson, R. J., Baxter, G. P., & Pine, J. (1990). Performance assessment in science. *Applied Measurement in Education*, 4 (4), 347-362.

Smith, M. L. (1991). Put to the test: The effects of external testing on teachers. *Educational Researcher*, 20(5), 8-11.

Vygotsky, L. S. (Ed.). (1978). *Mind in society: The development of higher psychological processes* (Edited by Cole, M. John-Steiner, V. and Souberman, Eds.). Cambridge, MA: Harvard University Press

Watts, M. (1985). Student conceptions of light: A case study. *Physics Education*, 20, 183-7.

Weber, R. (1990). *Basic content analysis: Quantitative applications in the social sciences.* Sage Publications, Thousand Oaks.

Appendix: Partial Interview Protocol

Reflection: Angles and Effects

Materials:

Flashlight: mounted in cradle to maintain alignment
Screen: self-standing with clips for graph paper
Variety of reflectors: Standard chrome. Black, Deep chrome, and White (students to color)
Black paper working surface (3x3)
Metric ruler
Colored pencils
White china marker
Chalk dust
[All actual experimentations take place in a darkened room on the black paper working surface.]

Objective:

To examine student thinking about light and the nature of reflected light.

• Phenomenon #1 – Flashlight shining light on screen

Room should be darkened. Hand student screen, place flashlight on black surface.

1. (a) Where do you think you would place the screen so that light from the flashlight would shine on it when I turn the flashlight on?
   (b) Why do you think that would be the place?
   (c) What is going to happen?
   (d) Where is the light going to go?
   (e) Could you draw what you think we' ll see?

Let' s try it and see!

Turn the flashlight ON.

2. (a) What do you see? Was your prediction correct?

Let' s trace the actual image.
[Interviewer should note what the student is tracing -- inner light? outer light?]
   (b) What would you say this tells us about light?

3. (a) Where would you say the light is right now? Show me everywhere that there is light from the flashlight.
   (b) Why do you think that [the light is there]?

If participant says the only place there is light is on the screen:
   (c) How do you think it got there?
   (d) How do you think we can see the light if it is only on the screen?

Turn the flashlight. OFF

4. (a) Is there something else that we can do to see where the light is? Do you have any ideas about what that is?

If YES:

(b) Tell me what we can do?
(c) How did you know that?
(d) Why do you think that works?

If NO:

(e) What we can do is clap these erasers together to get chalk dust in the air.

5. (a) What do you think we will see when there is chalk dust in the air?
(b) Why do you think that?

Let's try it and see.

Turn the flashlight ON.

6. (a) What do you see? Was your prediction correct?
(b) Why do you think this is what we see?
(c) What do you think this tells us about light?

• Phenomenon #2 The Mirror

[This was added during the interview as a response to the participant (Terry)'s particular interest in a mirror and reflection.]

1. How does a mirror work?
2. Where should we put the flashlight to illuminate this object?
3. Can you trace the path of the light?
4. Does the angle matter (between the flashlight and the mirror)?
5. How can the mirror see an object?

• Phenomenon #3 Exploring the flashlight

Let the participant take a part the flashlight, and examine the light bulb and the reflector.

Up to now, we've been working with a regular flashlight.
Here's a collection of cones (let the participant select the terminology) we can put around the bulb. Maybe we can start with black, then try other colors, finish with the deep silver reflector.

Place a black reflector

1. What do you think will happen when we turn the flashlight on?
2. Why do you think that?
3. Can you draw what you think will appear?

Turn the flashlight ON.

1. What do you see? Was your prediction correct?
2. Did you see a difference using the black cone?
3. Can you describe what you see?