行政院國家科學委員會專題研究計劃成果報告

建構國中物理網路化教學環境之研究

子計劃一：國中物理網路課程之發展與研究

計劃編號：NSC 88-2520-S-032 -007 -
執行期限：88 **年** 4 **月** 1 **日 至** 89 **年** 7 **月** 31 **日**
主持人：錢正之　淡江大學教育科技學系

Introduction

Qualitative understanding has become an important issue in physics education. Researchers find that being able to solve numerical problems does not guarantees students' understating on the same principles used in the problems. That is, simply asking students to apply appropriate equations to calculate the desired answer does not ensure the understanding of physics. This result applies to high school students as well as science and engineering major students in college level. Therefore, different types of physics exercise in addition to the end-of-chapter textbook problems are needed to help students understand the meaning and thus apply the physics principles in real life or in their careers.

The Physics Reasoning Laboratory (PRL) project, as the title suggests, focuses on the qualitative reasoning activities with mathematical equations. When discussing about conceptual understanding and mathematical equations, there seems to be a dividing line separating these two areas. When teaching concepts, equations are expected to be avoided. On the other hand, equations are only used for finding numerical values of a problem. It is true that mathematical formulas can be used to calculate the quantitative values. However, the beauty of physics principles is to use very simple forms (such as equations and graphs) to describe the world. The "description" part of the principles are usually emphasized less than it deserves in physics courses.

When learning refraction, the Snell's Law $n_1 \sin \theta_1 = n_2 \sin \theta_2$ is the most important equation. If you ask students what causes mirage and rainbow or why you miss the fish if you point directly to the fish in the river, their answer is "refraction." However, if you further ask them: Can you use the principle learned in refraction to explain these phenomena? They might tell you those equations are not used for explaining these phenomena, but for calculating certain types of problems as provided at the end of the textbook. To ensure students' understanding of this equation, two questions are needed to be addressed. First, after learning the Snell's Law, can students apply this equation to determine qualitatively the direction of refracting beams by reasoning rather than memorizing the results (such as "when light beams travel from slow medium to fast medium, the refracting beams bend away from the normal line")? Second, can students apply the Snell's law to analyze the causes of many phenomena such as mirage or rainbow rather than simply saying "these are caused by refraction"? In this article, refraction is an example to illustrate how a mathematical equation (Snell's Law) is used as a conceptual analyzing tool. Only can an equation be used to describe or analyze real phenomena, the equation is considered meaningful for students. Otherwise, those physics equations leaned are only meaningless algebraic exercises.

Literature Review

Meaning-making is the center of constructivism. To help students construct their own knowledge, students must actively participate in the learning process. However, constructivist learning depends on cognitive activity rather than behavioral activity (Robins & Mayer, 1993), and most successful programs in high order thinking prescribe cooperative learning and meaning-constructing activities (Resnick, 1987). For example, in a computer based learning environment, students use mice to select the contents they want to read, or type the answers in a question sheet for a test. Although students seem to actively work with the computer, it is the type of behavioral activity. To help students engage in learning, the computer is no more an information provider to present the content or judge students' answer such "Correct, very good." or "No, try again." Instead, computer programs should be designed to engage students in the thinking process such as "Is this a correct answer? How do I modify my model to correct this result?" (Chien, 1999).

Another important issue about a thinking curriculum is the relation between content knowledge and the thinking skills. From Gagne's perspective, thinking is a "high order" skill at the top of the learning pyramid. Does this classification suggests, in science teaching practice, that we can teach students simple facts first and leave thinking later? Cognitive researchers believe even in elementary school reading or mathematics courses thinking is a necessary part (Beck, Omenson, & McKeown, 1982; Keplan, Yamamoto, & Ginsburg, 1989). That is, thinking should be embedded in the content leaning in any age and any subject areas (Resnick & Klopfer, 1989).

To teach a subject, especially when thinking activities are expected within the subject learning, these contents should be carefully reorganized. Shulman (1986) suggests a category of Pedagogical Content Knowledge (PCK) to distinguish the understanding of content specialists and that of the content educators. He believes that the content should be carefully reorganized and presented in the way to make it comprehensible for students. In physics learning, Van Heuvelen (1991) suggests that physics knowledge can be presented in four forms: verbal representation, pictorial representation, physical representation, and mathematical representation. And these various forms should be interconnected to each other (since they are just different forms representing the same property) to help students develop deep understanding of physics.

Instructional Design

This web-based refraction module is composed of four sections. The first section introduces the meaning of Snell's Law. This section reinterprets the quantitative derivation of Snell's Law by tank simulation to explain how to reason about the refraction phenomena qualitatively. The second section discusses how the image is formed in our eyes. The third section and forth section use the skills leaned in the previous two sections to analyze different phenomena with different wavelength and different media.

<u>Law of Refraction Revisited</u>

The law of refraction (or Snell's Law) describes how the light beam refracts when passing the interface of different materials. In the introductory physics textbook (for example, Halliday, Resnick, and Walker, 1997), the Snell' s law is derived from the Huygens' Principle. In fact, this derivation explains why the light beam refracts when passing the interface of two different media. There are two important keys in this derivation. First, when a wave front partly goes from the air into the water, the half in the air travels faster than the half in the water. Second, the same light beam travels in different media with different speeds, however, the frequency is not changed. With the given information above, the relation of angle of incidence and the angle of refraction is determined. In short, the bending property of refraction is caused by different travel speeds.

Therefore, a car is used as an analogy to help students determine the direction of refraction beam. Students are asked to answer the following situation: "Consider you are driving a car or playing a toy car. For some reason if the left wheels move faster than the right wheels, to what direction will the car turn?" Most students are able to determine that the car is turning right when left wheels move faster than the right wheels. In a similar case, if a tank is moving from the highway to the sand beach, the tank would become slower. When a tank moves from the highway to the beach with a non-perpendicular angle, the tank would turn to the direction that the wheels travel slower.

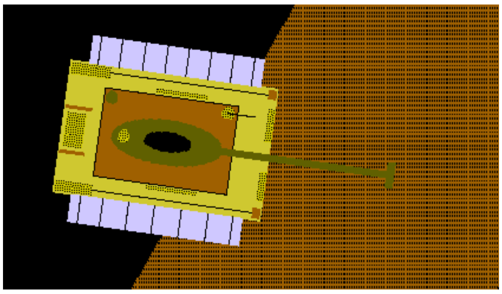

Figure 1. Using a tank as an analogy to illustrate the refraction caused by different speeds.

This simple fact, in fact, is the basic idea of the derivation from the Huygens' Principle to Snell's law. Because one half of the wavefront moves faster and the other half moves slower, the light beam must turn toward the slower side. After realizing why the light would turn, students are given different cases to apply this rule. In the following exercises, students are given sand areas with different shapes and asked to apply the above rule to determine how the tank would turn when passing these areas. These shapes represent the prism and concave lens and the paths of the tank represent how the light would bend when passing these optical instruments.

Image Formation

The second section explores how refraction affects the images we see. The discussion begins with a familiar experiment. This question was, in fact, asked by a science teacher:

"According to the Snell's Law, the refracting light is supposed to bend downward. How come we see the image of the coin flows upward?"

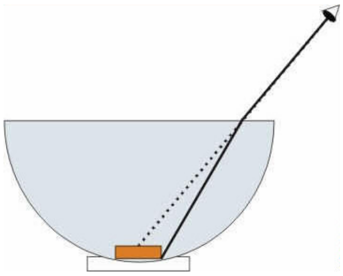

Figure 2. A coin in a bow with water

This question triggers a problem: Simply determining the direction of refracting beam is not enough to successfully explain the phenomena we see. To connect the bending light to the image in our eyes (or brain), we need to know how the image is interpreted in our brain.

At the beginning of the discussion, "Are eyes emitters or receivers" was discussed again. This idea was actually already taught in the textbook. However, research indicates that even students have learned new ideas in science classes, they might still use their old idea when the concept does not appear in the standard test. The question asked about the coin in the bow again reveals this already known problem.

Three rules and exercises were summarized about image formation.

(I) Images determined only by the part of refracting beams received by our eyes

In a bright room, objects receive light from all directions and refracted the light to all directions. The refracted lights received by our eyes determine what image we see in our brain.

(II) Assumption of straight light path.

In our daily life, we see most objects without any refraction effects. Gradually, we judge objects' sizes, distances, shapes, and so forth based on the way we see objects. In other words, our brains are used to judge the above information assuming that lights travel in straight path.

(III) Extension of the last path

Because only the refracted light in our eyes determines the image, and our brains are used to judge object images without light bending, the images' size and location seen are determined as the extension of the last portion of the refracting light.

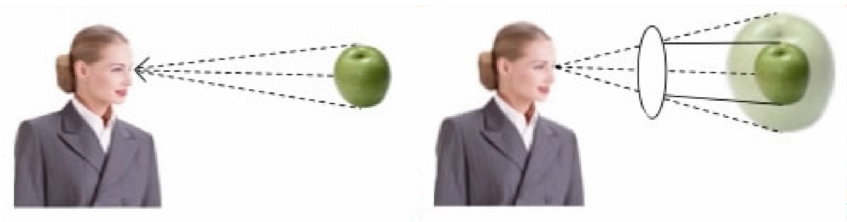

Figure 3. The light path with and without a lens and the images seen by observers

Hands-on Analyzing Exercises

In the previous two sections, students learn how the light bends when passing different media and how the bending light affects the image we see. In the following sections, students use the above principles to analyze some refraction phenomena. The exercises were designed with guided questions to help students apply the learned concepts in the real life phenomena. In general, the analysis process includes three steps: (1) analyze the environment where the phenomena occur, (2) determine the bending direction qualitatively with the law of refraction, and (3) determine the image's location or appearance with the rules of image formation. In the example of mirage, students first determine the air's densities on a lake (or in the desert) to determine the speeds of light in different altitudes. With this information, students then determine the path of the light beams from the object to the observer. Last, students extend the last refracting beam to locate the image of the object. And this is why we see the mirage phenomena.

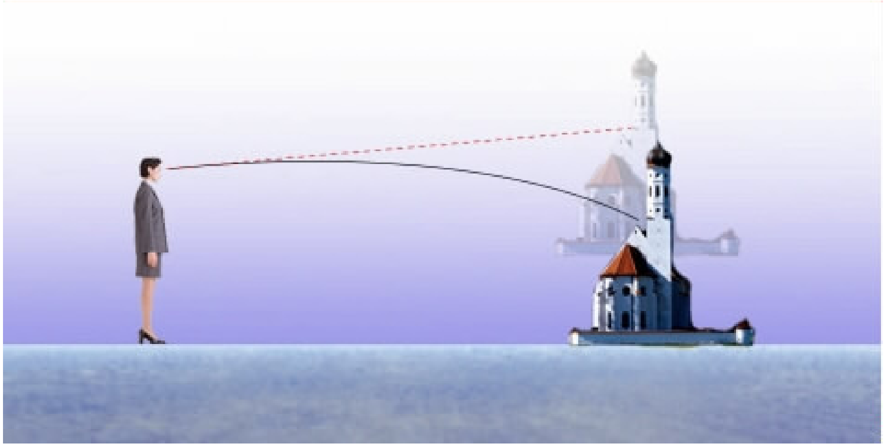

Figure 4. The sketch of mirage

Discussion

The module emphasizes the qualitative reasoning of refraction phenomena. Through this example, many fundamental principles and equations can be used for reasoning purposes, rather than just a calculation tool. When discussing about qualitative understanding, many people regard it as "facts without equations". And equations' purpose is for quantitative use only. However, if we carefully study the meaning of the mathematical principles, they can be very powerful tools in daily reasoning without the presence of numbers.

Reference

Beck, I.L., Omenson, R.C., & McKeown, M.G. (1982). An instructional redesign on reading lessons: Effects on comprehension. Reading Research Quarterly, 17, 462-481.

Chien, C. (1999). **教育理論演進對 CAI 設計與教學的影響—以科學教育為例。** [The impact of instructional theory change on CAI design and implementation in science education.] Curriculum and Instruction Quarterly, 2(4), 25-42.

Halliday, D., Resnick, R., & Walker, J. (1997). Fundamentals of Physics Extended (5th Ed.). New York: John Wiley & Sons.

Keplan, R.G., Yamamoto, T., & Ginsburg, H.P. (1989). Teaching mathematics concepts. In L.B. Resnick & L.E. Klopfer (Eds.) Toward the thinking curriculum: Current cognitive research (pp. 59-82). Alexandria, VA: Association for Supervision and curriculum Development.

Resnick, L.B. (1987). Education and Learning to Think. Washington, D.C.: National Academy Press.

Resnick, L.B., & L.E. Klopfer (1989) Toward the thinking curriculum: Current cognitive research. Alexandria, VA: Association for Supervision and curriculum Development.

Robins, S.,& Mayer, R.E. (1993). Schemma training in analogical reasoning. Journal of Educational Psychology, 85, 529-538.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2), 4-14.

Van Heuvelen, A. (1991). Learning to think like a physicist: A review of research based instructional strategies. American Journal of Physics, 59(10), 891-897.