



College Student Learning of Pinhole and Plane-Mirror Knowledge with a Guided Inquiry Instruction

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Abstract: College level students consistently provided incorrect responses to questions about image formation with various optics instruments. The purpose of this study is to compare the changes in students' pinhole and plane mirror knowledge before and after a guided inquiry instruction. Teaching methods including structured hands-on activities under instructor guidance were implemented in the class. Twenty-four undergraduates participated in the study and changes in their responses to the three pinhole and five plane-mirror questions were investigated with multivariate and univariate analyses of variance with repeated measures. The results revealed that student responses to pinhole questions has changed significantly and the changes occurred in students' responses to plane mirror items were noticeable. Guided inquiry instruction appears to be effective in helping students in organizing and structuring their knowledge on the nature and formation of pinhole images as well as in advancing students into plane mirror systems.

Key words: Optics teaching, Pinholes, Plane-mirrors, Inquiry-based methods

Özet: Üniversite öğrencileri optik nesnelere görüntü oluşumu sorularında devamlı bir şekilde yanlış cevaplar ortaya koymaktadırlar. Bu çalışmanın amacı öğrencilerin iğne deliği ve düzlem ayna bilgilerindeki değişimleri rehber eşliğinde sorgulama temelli bir eğitim öncesi ve sonrasında karşılaştırmaktır. Kullanılan öğretim metotları öğretmen rehberliğinde uygulamalı aktiviteleri kapsamaktadır. Yirmi dört öğrenci bu çalışmada yer aldı ve üç iğne deliği ve beş düzlem ayna sorusuna verdikleri cevaplardaki değişimler tekrarlı ölçümler için çok ve tek değişkenli varyans analizi kullanılarak incelendi. Sonuçlar öğrencilerin iğne deliği sorularına verdikleri cevaplardaki değişimlerin anlamlı, ayna sorularına verdikleri cevapların fark edilebilir düzeyde olduğunu göstermektedir. Rehber eşliğinde sorgulama eğitimi öğrencilerin iğne deliği bilgilerini organize etmek ve yapılandırmalarına, ayna sistemlerinde ilerlemelerine yardımcı olmuştur.

Anahtar kelimeler: Optik öğretimi, iğne delikleri, düzlem aynalar, rehber eşliğinde sorgulamalı eğitim

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Introduction

There have been studies on student understanding of pinhole and plane mirror images. Galili and Hazan (2000) investigated naïve ideas of pinhole image formation among teacher-training college students and found that the students had difficulty in explaining the shape of the pinhole image when the orientations of the light source, the mask and the screen with each other were altered. Rice and Feher (1987) studied with children on pinhole images and found that children could not predict the image of different geometric objects.

Goldberg and McDermott (1986) investigated naïve ideas related to the plane mirrors among college students before and after the instruction and founded that the students frequently employed a naïve understanding of reflection of light called “the line of sight” to predict the location of the image in plane mirrors and had the difficulty in revealing the field of view of an object in the mirror. Croucher, Bertamini and Hecht (2002) claimed that college students with pre-instruction knowledge had difficulty in answering plane mirror tasks familiar to the real life situations and preferred reasoning with naïve optics ideas rather than formal knowledge such as the idea of line of sight versus the law of reflection. Bendall, Goldberg and Galili (1993) and Galili, Bendall and Goldberg (1993) revealed that prospective teachers had difficulty in explaining image formation in the mirrors and construing an appropriate explanation for the reflection of light. Langley, Ronen and Eylon (1997) stated a similar result from their study with college students such that the contexts of sight has a strong effect on the student reasoning about optics events and eventually student pre-instructional ideas including plane mirror happen to be fragmented and incidentally after-effects of this unstructured and unorganized knowledge base could be expected on the post-instructional knowledge. Ronen and Eylon (1993) studied with 10th graders on plane mirrors and stated that poor differentiation between image formation from image observation and an incorrect understanding of field of view were not uncommon.

Students, starting at early ages, have unlimited experiences with light and optics events which are ubiquitous in daily life and sooner or later students’ involvement with them will induce intuitive and biased conceptions about how people see things, how light moves, and how plane mirrors work (Eshach, 2003). Previous optics related studies revealed student informal ideas sourced by the sight-based understanding rather than vision-based reasoning are powerful and could exist even after an instruction (Langley et al., 1997) and emerges easily when there is an observer in the question context (Galili, 1996; Galili et al., 2000). This paper approaches

students' difficulties related to optics in a way that each optics instrument requires specific knowledge related to its working. Eventually, student responses to optics questions can be expected to vary naturally with the instrument in question. Particularly, when there is an observer which is an inherent part of the question.

There have been efforts to establish the effectiveness of innovative optics teaching methods. Model-based instruction (Allen, White & Frederiksen, 1995) addressed essential role played by human eye in image formation and integrated the eye into the instruction to develop student understanding with light-ray configurations. The eye-model basically made students conscious of the function of the eye. Simulator-based instruction (Reiner, Pea & Shulman, 1995) helped student in understanding the light-ray configurations for various optics instruments in a technology supported classroom.

Hirn and Viennott (2000) stated that "classically valued strategies" (p.362) and traditional teaching methodologies could not help students in improving formal knowledge of geometrical optics. Without a satisfactory teaching on optics, students are not likely to raise their knowledge of widespread optical phenomena. This paper is also positioned on the fact that science teaching with inquiry-based methods can help students in learning science concepts more deeply as well as developing their scientific knowledge (Sandoval, 2005). Inquiry as a constructivist approach enhances the students' mental and physical participation in the learning process (Minner, Levy & Century, 2010) and enforces reorganization of the science classroom in terms of the roles of the students, teachers and classroom materials. The images of teaching science as inquiry stretched along a broad continuum from teacher-directed structured and guided to students-directed open inquiry (Crawford, 2000; Crawford, 2007; Brown, Abell, Demir & Schidt, 2006). Moreover, the reorganization of the student roles and responsibilities oblige a radical change in the traditional functions of the teacher and textbook as the sources of information (Duran, McArthur & Hook, 2004). The inquiry approach relieves the students from the role of salient auditing which a traditional course design approves of and casts a new role of active player or the constructor of the knowledge.

There have been studies on the science faculty and college student understanding of inquiry (Brown et al., 2006; Rogers & Abell, 2008; Forbes & Davis, 2010). However, prevailing state of affairs in science education at all instructional levels is the limited practices and examples of inquiry-based learning environments (Crawford, 2007; Keys & Bryan, 2001). Design and

enactment of innovative examples will be a grounded support to assist science faculty members in implementing inquiry as a teaching method (Duran et al., 2004; Windschitl, 2004; Sadler, Burgin, McKinney & Ponjuan, 2010).

This paper approached the classroom inquiry-based instruction as a collective endeavor of the students and instructors intensified on the students' group work and hands-on activities therefore opportunities can emerge in the class to share ideas, discuss opinions and construct conclusions based on evidence and observations under the guidance of the teacher (Wolf and Fraser, 2008). Also the paper recognizes the absence of strategic connection between the students' hands-on activities and the conception of substantive science content in the instructional design (Crawford, 2000) as a drawback limiting the efficiency of inquiry-based instruction and obstructing student knowledge articulation. Such a strategic connection can be achieved along with student work on explanation and justification of the phenomena upon which inquiry has been made (Brown et al., 2006). Therefore any measures which carry the students beyond the experience with materials toward a conceptual understanding governing the nature of materials must be an instructional objective.

The Study

The study took place in an inquiry-based physics course at a large midwestern university in the U.S. The aim of this study is to analyze the changes in student knowledge of optics for different instruments and look for significant changes before and after an inquiry-based instruction. The problem of the study was that were there any significant changes in student correct responses to the pinhole and plane-mirror questions before and after the guided inquiry instruction? Particularly, the study is interested in investigating the changes in student pinhole and plane mirror knowledge expected to occur after a guided-inquiry instruction. The study hypothesized that student responses to pinhole and plane mirror questions will change significantly after the guided inquiry instruction; and as a consequence student knowledge of pinholes will be more organized than the student plane mirror knowledge because the existence of the observer is a component in plane mirror questions. The study will have significance in addressing and comparing the degree of how organized students' knowledge for pinholes and plane mirrors before and after the instruction are. A minor contribution of this study will be in describing a college level introductory level optics course designed and practiced by the instructors.

Instructional Methods and Activities

The subject matter related to pinholes and plane mirrors corresponded to 3 weeks in the total course duration and practiced in two sessions of total 5 hrs per week. Twenty-four college students enrolled in the introductory-level physics course for non majors and divided into two different sections as groups of 4. The instruction time was spent equally on the pinholes and plane mirror activities. One primary instructor and two graduate assistants taught each class session. Guided-inquiry-based learning methods were implemented during the course. Rather than lecturing and cookbook type experiments, students in each group designed experiments, made observations, evaluated the results of optics experiments, and lastly defended their findings to the instructors.

The sequence of the instructional activities, engineered by the instructors, is shown in Figure 1. These activities are categorized as daily instructional, weekly instructional, and assessment activities. The daily and weekly activities were primarily designed to assist students in learning optics concepts however assessment activities were only used as grade student optics learning. Daily activities were essential in guiding the students toward the formal conceptions of the pinhole and plane mirror knowledge. Weekly activities are utilized for the evaluative purposes included assignments about the topics studied in the class and journal writing for student reflection and critiques.

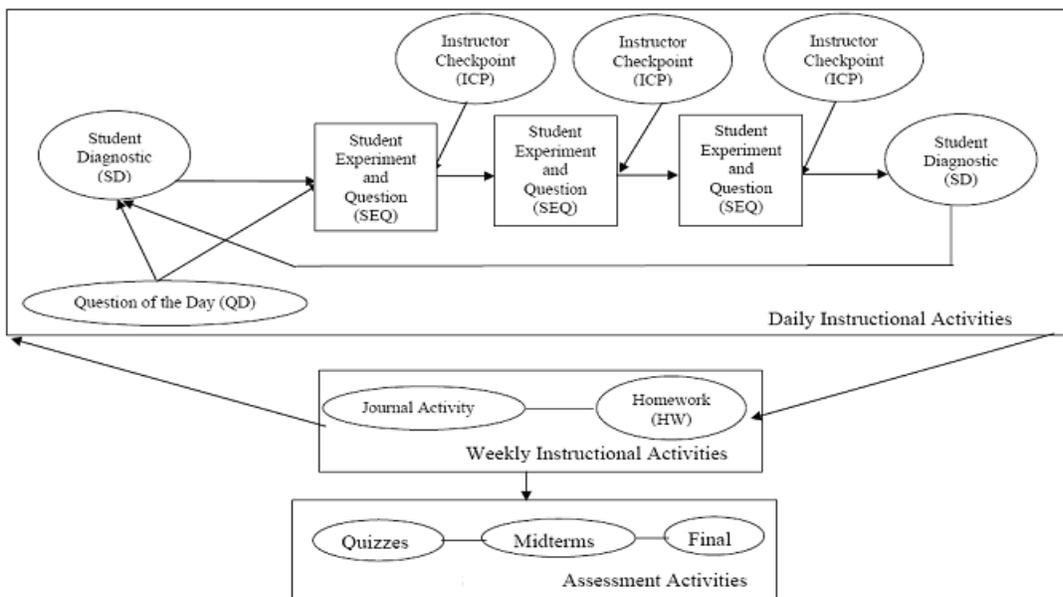


Figure 1: Sequence of the instructional activities.

Daily instructional activities consisted of the question of the day (QD), student diagnostic (SD), student experiment and question (SEQ), and instructor check point (ICP). QD and SD activities consisted of open-ended questions requiring written responses and took 10 minutes to complete each. Each QD activity was conducted at the beginning of the class every day as a review and reflection of the topics studied in the previous class. SD questions were about topics of upcoming activities and administered as a pre-post question helping students to observe the changes in their optics conceptions. Students had opportunity to share ideas with group members on QD activities and worked SDs individually. The instructors evaluated the student responses to QD and SD activities and provided feedback. Students kept QD and SD paperwork reminders of optics concepts studied in the course. The student experiments and questions (SEQ) and instructor checkpoints (ICP) took almost 2-hours in each session. SEQ activities were conducted with a lab manual designed for guided inquiry teaching of physics, *Inquiry Physics* (McDermott et al., 1996). The authors advocated in the book that learning physics concepts can only be achieved by active mental participation in the process of knowledge construction rather than the conventional roles such as reader, listener or problems solver accustomed for the students.

Pinhole activities in SEQ were conducted so the students would experience the changes in the size, shape, and sharpness of the pinhole images and so does the plane mirror activities, the students would experience the reflection of light, image observation, image formation, effects of multiple mirrors, and formation and observation of multiple images. SEQ activities completed with an examination process with one of the available instructors, called instructor checkpoint (ICP). At a checkpoint reminded to the student groups by the manual book, the instructors asked questions about the conducted experiments. The questions dealt with student explanations for the situation and concepts underlying the experiment. Upon completing each checkpoint, the group was given permission to start a new experiment set.

Data Collection

The students participated in this study were allowed 10 minutes to answer three pinhole and five plane mirror multiple choice questions. A physics professor with 20 years experience selected the questions from a collection of optics questions and made the needed modifications. The questions dealt with the concepts given in Table 1 and were administered to the class at the first and last days of the class. Student response to each question is scored as 1 for the correct and 0 for the wrong responses. Kuder-Richardson-20 coefficients of reliability for pinhole and plane

mirror questions were revealed as .73 and .65 respectively. While the value for pinhole items is moderate, the plane mirror value is low. Outputting a set of items measuring the student knowledge of plane mirror in a consistent trend might be challenged with the varying nature of student difficulties with plane mirrors. In addition, the limited number of participants in the study might have obstructed a moderate reliability level.

Table 1: The concepts each question is designed to assess.

1-Predicting the formation of an inverted image with pinholes.
2-Predicting any change in a pinhole image with a small opening on the mask.
3-Predicting any change in a pinhole image with a big opening on the mask.
4- Predicting number of images of a nail with a two-mirror system.
5- Predicting the image place in a plane mirror.
6- Comparing the field of view of a plane mirror for different observers.
7- Comparing the visibility region of a mirror in different positions.
8- Distinguishing image observation from image formation with multiple images

Students were also asked on the test whether or not they were taught pinholes, plane mirrors prior to this class. Percentages of the students who did not have any learning experience with pinholes and plane mirrors were % 80 and % 65 respectively.

Data Analyses and Findings

The mean scores for each question are given in Table 2. Student pretest responses to first pinhole question, which asked for the fact that the basic property of a pinhole system is to create an inverse image, revealed that one in every ten students had this knowledge. For question 2 before the instruction, one in every four students made correct predictions about the changes in pinhole images with a small opening on the mask while one in every two students provided correct responses to the third pinhole question when the opening on the mask was larger.

Table 2: Student mean scores for pinhole and plane mirror questions

Items	M	
	Pre	Post
1	.08	.63
2	.25	.58
3	.54	.75
4	.58	.67
5	.08	.29
6	.17	.30
7	.29	.42
8	.21	.29

The majority of student responses to plane mirror questions were incorrect when compared with the pinhole questions at the pre-instruction level. The situation changed for the student pinhole knowledge at post-instruction level. However the plane mirror responses were still mostly incorrect even with observed increases in the correct responses. The majority of student responses to image formation in parallel mirrors (question 4) were correct. The responses to other plane-mirror questions before the instructions revealed the extent of student difficulties with determining the relationship between an observer and an image (question 5), differentiating image observation from image formation (question 6), predicting and comparing the visibility region of a mirror (question 7) and distinguishing formation and observation of multiple images (question 8). The responses to plane-mirror items showed that students' pre-instruction plane-mirror conceptions were mostly naïve when an observer was included in the context of the question.

At the posttest level, student responses to the pinhole questions improved well and majority of them provided correct responses for each question. Student plane mirror responses at the posttest level showed increases, however many students still kept on informal ideas found in the pretest level. Univariate analyses of variance with repeated measures were conducted to identify significant mean differences in the scores of each question before and after the instruction. There were statistically significant differences for pinhole question 1 ($F = 20.34, p = .000$) and question 2 ($F = 5.38, p = .003$). The assumption of normality for F-test is hardly holding for small sample size of this study, however any inference could be drawn from the results is valuable for the further analysis. Hays (1964) left an open door for such instances and

stated that larger sample size is always a way to apply F-test safely but it can be applied even with small samples when it is a must.

A further analysis was conducted to detail in that whether or not the changes given above are actually noticeable when these changes for each instrument were combined as one. Univariate analysis of variance with repeated measures was conducted to investigate significant differences between the pretest and the posttest mean scores of the each pinhole question and the each plane mirror question. Table 3 shows that when the increases in student responses to questions compounded according to the instruments, the changes in pinhole as well as in plane mirror responses are significant.

Table 3: Univariate analysis of variance with repeated measures of the change in the student pinhole and plane-mirror responses.

Effect	M Diff	F	Error df	P
Pinhole Items	.36	14.13**	23	.001
Plane-Mirror Items	.13	5.44*	23	.029

Note. $n = 24$. * $p < .05$, ** $p < .01$.

An additional analysis was conducted to reveal whether or not significant changes could be observed when student responses to questions are considered individually in each instrument group. For this purpose multivariate analysis of variance with repeated measures was conducted to investigate significant differences between the pretest and posttest pinhole and plane-mirror individual items. The combined mean differences is only significant across pinhole items ($F = 6.60, p = .003$) and not for the plane mirror questions.

Conclusions

The study aimed at investigating the changes in student pinhole and plane-mirror knowledge after a guided-inquiry instruction. Informal nature of student knowledge at the pre-instruction level was observed for both instruments but mostly in cases of plane mirrors. Student correct responses to plane mirror questions increased at the post-test but still the majority of the responses were actually wrong. It can be concluded that student plane mirror knowledge was still informal at the post-instruction level though the weight of the correct responses was increased in student predictions.

Significant changes observed in student pinhole responses when both the increases in the scores of each question compounded as one or considered individually within the group. However, only significant change in student plane mirror knowledge observed when the effects of the increases in the scores of each question unified. It can be concluded from the results that pinhole activities appeared to have improved student scientific knowledge and understanding of the pinhole systems and helped students in connecting experiences with pinholes into substantive knowledge of it. Plane mirror activities did not help students in achieving such a connection and justified with students in advancing to the plane-mirror systems.

For the student pinhole knowledge, the responses were changed systematically suggesting a trend toward an organized nature. However, for the plane mirror knowledge, student responses were progressed without any combined bearing toward a concord. Student pinhole responses tend to converge more toward coherence than the ones produced for plane mirror questions. This might be caused by the differences in the formation of pinhole and plane mirror images. Especially, this could be argued on the fact that responses to plane mirror questions require implicit or explicit existence of an observer since the human eye is an inseparable component of explanations for plane mirror questions.

Guided inquiry designed and practiced by the instructors with the help of the manual book, *Physics by Inquiry*, presented reorganization in the physics classroom and substantiated changes in the roles of the students, the teachers and written materials. The activities SDs, QDs, and SEQs were utilized as sources of knowledge and played a major role in articulating formal understanding of the instrument. Therefore the guided inquiry instruction fulfilled the purpose of that the student constructs their own knowledge through explanation and justification transforming the hands-on experiences to the substantive content knowledge.

Implications for Instruction

Optics instruction must take the role played by the observer in image formation not only in the plane mirror systems but also in other optics instruments into consideration. Intervention activities should provide students the instances to compare whether or not the observer can actually affect and change the image formed in the instrument or image can form without the help of observer's eye.

There are many experiments conducted with optics instruments so that the students are in need of guidance for how to record, organize and manage the results from each activity into organized and coherent schemes in a systematic way. Moreover, the guidance by instructors can take students toward a model construction to explain the questions encountered. Optics instruction should not take the organization and differentiation of optics knowledge by students for granted but motivates students toward a systematic data analysis and synthesis as a method for studying optics phenomena. Simply involving students in a set of experimental activities may not incidentally lead to a formal understanding of optics.

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