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Investigation of conceptual change about double-slit interference in secondary school physics

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In this study, whether or not constructivist teaching of double-slit interference of light has a positive effect on the secondary school students' conceptual change is examined. An achievement test, a conceptual understanding test and semi-structured interviews were used as data collection tools in this mixed methods research. Experimental group was taught with constructivist approach while control group was taught with traditional method in which teacher was the only authority in defining the course of teaching. It has been identified that experimental group students show high level conceptual understandings after teaching. Superiorities of experimental group, which involve the construction of cause and effect relationships, the transfer and configuration of knowledge, have been identified with the interviews conducted. It was concluded that teaching in the experiment group was more successful than teaching in the control group in terms of the construction of the meaning of interference, path difference, fringe width concepts and understanding the formation of bright and dark fringes.

Keywords: conceptual change, conceptual understanding, constructivist approach, double-slit interference, physics education

Introduction

Constructivist approach underlines that students are in interaction with the physical world in learning process. As a result of such interactions, students come to class equipped with certain ideas and notions about the physical world. Most of these notions are quite different from the physical world that has so far been constructed by scientists. Such student ideas are resistant to change and create a sound barrier before instruction. Constructivist approach considers such ideas as useful opportunities for teachers to meaningfully restructure notions (Tytler, 2002).

Numerous researchers have referred to the concepts held by students under different names. These student concepts were termed by Driver and Easly (1978) as 'alternative conceptions', by Gilbert, Watts and Osborne (1982) as 'children's science', and by Novak and Gowin (1984) as 'misconceptions'. A great deal of research on students' misconceptions in science has emphasized that misconceptions are embedded in students' prior ideas that hinder seriously understanding certain concepts. Therefore, Miller and Brewer (2010) consider misconceptions as more systematic, consistent across situations and more difficult to remedy than errors arising from lack of knowledge.

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The term 'misconception' will be used in this paper to denote any ideas held by students that are in conflict with the scientific view. Yip (1998) finds not only the identification of misconceptions important initial step for better teaching and learning of science but also monitoring the development of such informal views essential for constructing effective teaching strategies that aim to remedy misconceptions. Yip (1998) categorizes students' misconceptions in science after teaching according to the nature and sources of origin into three broad groups. The first group involves informal ideas that are generated through students' life experiences which students bring with them to the classroom. Misconceptions of the second type are developed by students during teaching and defined by Yip (1998) as 'incomplete or improper views' due to lack of the prerequisite knowledge needed for the construction of a new concept in the cognitive structure. Another source of misconception originates from teachers as well as from textbooks. Less competent teachers are thought to propagate incomplete or erroneous concepts to their students through inaccurate teaching or inattentive use of textbooks. Kousathana, Demerouti and Tsaparlis (2005) termed this category of misconceptions as instructional misconceptions and they suggest the inclusion of history of science in instruction to prepare teachers to anticipate students' misconceptions and to motivate student learning.

As suggested by Tytler (2002), when students are explained the scientific view that is different from the concepts they previously held and to which they were adhered strictly, students may accept the scientific view, abandoning their previous opinion; however, in some cases, they may also continue to cling to their previous ideas, combine the scientific view with their own ideas to develop a hybrid concept, or reject the scientific view and continue to adopt their ideas. According to Hamza and Wickman (2008), science learning is described by the nature of misconceptions and meaningful learning can be achieved by supplanting misconceptions with scientific conceptions. Based on Ausubel's (1968; p.18) idea that "the most important single *factor influencing learning is what the learner already knows*", the constructivist theory of learning underlines the fact that a student reconstructs a new piece of information by comparing it to his/her previous knowledge and thus, assigns meaning to the world around him/her. Thus, a teacher cannot possibly communicate a model in his/her mind to his/her students with all its aspects and every individual mentally filter and reconstruct information in different ways (Hand & Treagust, 1991; Kearney, 2004). In other words, learning science is considered to construct, interpret and modify students' own ideas about reality based on their own experiences.

Constructivist learning approach has developed in three different ways: cognitive, radical, and social. All three approaches are grounded in the same idea; yet, social constructivism is predominant in science classes. Social constructivism emphasizes that learning is a social activity in which knowledge construction takes place in both personal and social planes through discussions and negotiations with peers and teacher. Lemke (2001) referred to this as sociocultural learning. The constructivist learning environment guided by a sociocultural perspective draws on social settings where students are encouraged to identify and articulate their prior ideas, to exchange views by explaining their ideas to one another and by discussing disagreements and to cooperate in complex problems by reflecting on those of other students. Hence, students can reorganize their views by linking new ideas with personal experience and existing knowledge and negotiate shared meanings while teachers act as a facilitator of this type of activity (McRobbie & Tobin, 1997; Frailich, Kesner, & Hofstein, 2009).

In social constructivist approach, the focus is on language and society and a social constructivist teacher should be interested in the constructs in the minds of the entire class (Tytler, 2002). Social interaction between students is the principal factor in the formation of knowledge and Vygotsky (1987) argues that an individual cannot be isolated from his/her environment and the effect of environment on knowledge construction is undeniable. The development of understanding by writing and discussion of ideas is an essential element in learning from a social constructivist perspective. Furthermore, as communication is promoted in the science classroom, Marin, Benarroch and Gomez (2000) argue that correct use of language is crucial during knowledge construction. Leach and Scott (2002) also argue that firstly language and other semiotics (e.g. symbols, diagrams, etc.) provide the way of discussing and sharing ideas on the social plane. Following the process of internalization, language and other semiotic mechanisms provide the means for students' thinking, testing their understandings with meaningful peer and teacher discussions and making sense of the ideas of other students. Thus, talk and thought are firmly associated dimensions of a social constructivism.

Various strategies, which are usually grouped under three categories as discrepant events, conflict between ideas, and development of ideas, have been suggested for the use in science education of the constructivist theory of learning. In the strategy of discrepant events, students are introduced with a discrepant event. The aim is to make them recognize their own and their peers' conceptual constructs through discussions in groups and to promote conceptual conflicts by explaining the discrepant event. Students are guided towards cognitive accommodation and assisted in constructing the conceptual models adopted by the scientific view (Nussbaum & Novick, 1982).

Cosgrove and Osborne (1985), Champagne, Gunstone and Klopfer (1985), and Rowell and Dowson (1985) have introduced conceptual accommodation approaches based on conflict between ideas. Among them, Cosgrove and Osborne (1985) suggested a learning strategy they called '*generative learning model of teaching*', according to which teacher provides a synthesis of the scientific view, students' views, and his/her own view. Students present their own views and test the content of their own conceptions. They discuss the positive and negative aspects of their views and the teacher introduces the scientific view and provides opportunities for students to apply the new idea in different situations. In Champagne et al.'s strategy termed as '*ideational confrontation*', students make guesses about a physical phenomenon together and each student presents his/her own guess. Students debate on the accuracy of their views and try to convince each other. Then, the teacher explains the physical phenomenon using scientific concepts and provides opportunities for students to compare their views with the new concept. On the other hand, Rowell and Dowson (1985) argue that students must first be introduced with the scientific view. Furthermore, students' own theories should only be replaced with a better theory and the new aspects of the better theory should be immediately compared with the old theory to ensure knowledge construction.

Adopting the strategy of development of ideas, Brown and Clement (1989) maintain in their '*analogical teaching strategy*' that the aim should be to increase intuitional beliefs close to the scientific view and to reduce inaccurate beliefs. This strategy claims that conceptual change is possible if students are provided with opportunities to establish an intuitional and qualitative understanding of physical phenomenon, rather than its numerical relations. Students can more easily have access to the scientific view through the bridging strategy presented to them following the supportive example and thus, development of ideas can take place.

Whichever the selected strategy is, social constructivist approach underlines an active environment and endorses the conceptual change, which is described as the process of harmonizing the impressions made by universal phenomena on students' minds with scientific views. Posner, Strike, Hewson and Gertzog (1982) argue that a conflicting situation with the existing concept must be present for conceptual change to take place. Students will most probably reject the existing concept that lacks the capacity to solve a problem introduced in classroom and adopt the newly introduced and rational concept with the capacity to solve the problem. Therefore, they should be convinced by instruction that they cannot solve the problem by the existing concept, make them recognize the abnormality of the situation and feel discomfort about the existing concept.

Problem

The quite low correct response rates to the questions about sciences in the university admission examinations particularly in Turkey clearly demonstrates the shortcomings in science education of the behaviorist approach, which had been adopted and applied until recently. The university entrance examinations contained questions concerning subjects included in the curricula of primary and only the ninth grade of secondary education until the academic year 2005-2006. This approach adversely affected the teaching of tenth- and eleventh-grade physics subjects at schools. Particularly some subjects forming the basis of university education for the quantitative group students (for instance, for physics course: spring waves, water waves, wave and particle models of light, atomic theories, movement of charged particles in electric fields) were either left untreated or taught superficially.

In the academic year 2005-2006, through a decision of the Student Selection and Placement Center (OSYM), all the subjects in the secondary curricula were included in the scope of the examination. This decision raised the attention on subjects such as light theories and atomic theories to their peak. Particularly science students had to learn and internalize abstract subjects like wave and particle models of light, along with concrete ones such as force and Newton’s laws of motion. Furthermore, evidently, the examination system that was applied until the academic year 2005-2006 and included the primary science and the ninth grade of secondary science curricula also affected the subjects investigated by the researchers of science education.

The literature contains much research, whether international or national, on the constructivist approach and discusses its effects on conceptual change, student attitudes, and student achievement. These studies mostly focused on the subjects of physics course such as heat and temperature, electrostatic, electrical current, Newton’s laws of motion, force and pressure. There are numerous studies in the literature on the abovementioned subjects. Nevertheless, there are almost no international or national studies on the wave model of light with secondary school students and most of the existing studies were conducted with university students. In this sense, it is thought that the findings obtained from this study will contribute to the literature.

Accordingly, a question is raised on the effects of the constructivist approach on the learning of a subject like the wave model of light, which has grown in prominence in secondary education since the academic year 2005-2006. It is a subject of inquiry to what extent the constructive approach that aims to train inquisitive and questioning individuals affects the learning of the wave model of light, a subject that is rarely investigated in the literature but is critically important for secondary and university education. Consequently, the problem of the present study is whether the designed teaching which is based on the constructivist approach is effective on the conceptual changes of secondary students about the wave model of light.

Aim of the Study

The aim of this study is to explore the effect of socio-constructivist approach based teaching on double-slit interference, which is the subtopic of Wave Model of Light unit, on grade 11 students’ conceptual change. The following questions are therefore set out as research questions.

Research Questions

1. What are the conceptual understanding levels of experimental and control group students before embarking a teaching on the topic of double-slit interference?
2. Are there any difference between the conceptual understanding levels of experimental and control group students after teaching completed?
3. What are the prominent conceptual difficulties or learning barriers involved in coming to an understanding of double-slit interference of light after teaching?

Literature Review

In the previous section of the study, comments were made on the scarcity of the studies which were conducted on the subject of double-slit interference of light and encountered in the literature. In a study on the subject in question, Wosilait, Heron, Shaffer, and McDermott (1999) worked on groups of graduate students and undergraduate freshmen. The study reports that both student groups had had studied the wave model for light but did not have an accurate conceptual understanding of the subject. The study adopted a research-based teaching approach to ensure conceptual changes in students. In the study in which pretest and posttests were administered, Wosailait et al. started instruction with interference in water waves. Figure 1 presents a pretest problem used by Wosailait et al. (1999). Students were required to calculate the distance by $d\sin\theta$ by drawing the line in Figure 1.(b) and to decide whether constructive or destructive interference would take place at points A, B, and C. The results showed that only 10% of 1200 students in the introductory group accurately answered the question. Even among 95 graduate students, only 55% responded correctly.

In the light of the results obtained from the preliminary study, the researchers designed an instruction for the development of the concept of wave model of light in students. Instruction started with the interference of two sets of concentric circles that represent the water waves due to two point sources in the ripple tank. With this experiment in the ripple tank, the students recognized that some points vibrated at maximum displacement, while some others did not. They discovered that superpositions at these points result in the formation of nodes and antinodes.
At the subsequent stage, the same experiment was conducted with two narrow slits instead of two point sources rising and falling in water in the ripple tank. The students were shown that waves diffracting in the two narrow slits interfered in each other, forming nodal and antinodal lines.

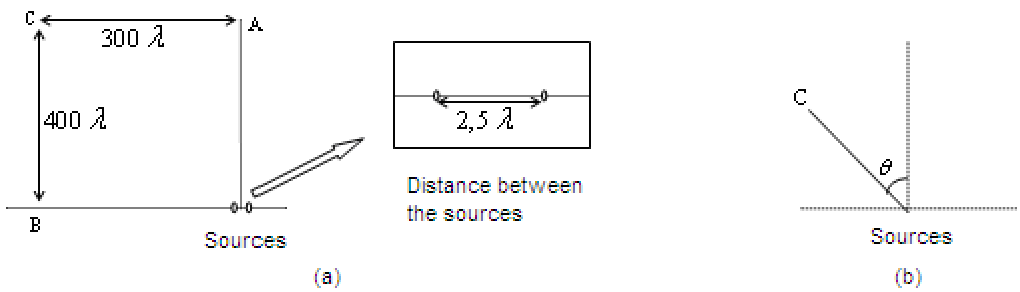

Figure 1(a). Pretest question about interference in water waves used by Wosailait, Heron, Shaffer and McDermott (1999) before instruction, (b) procedure to be followed by students during the solution of the question

Here, the aim was to make a connection between water waves experiment and double-slit interference of light.

In the later part of the study, the students were given a double-slit interference pattern and were asked what would happen when the left slit was covered. Of 50 graduate students, 55% provided an accurate answer to the question, while only 25% of the students indicated in their responses that a single-slit interference pattern would be obtained. The results of the study demonstrated that some students formed a hybrid conception by combining geometrical and physical optics and explain bright areas by geometrical optics and dark areas with physical optics.

Colin and Viennot (2001) found in their investigation that 120 sophomore and tertiary students, who were taught on geometrical and wave models in optics, had difficulty understanding the use of those two models. In one of the problems involving an illuminated two diffracting holes, students were asked to explain what can be observed on a screen when a converging lens was located between the screen and the holes. None of the students were reported to give a complete answer involving the two models to propose that fringes of interference were enlarged with a lens.

Furthermore, in another study conducted with 46 university students taking the introductory and modern physics courses, Ambrose, Shaffer, Steinberg and McDermott (1999) found that although they had been taught the subject previously, some students believed that when one of the slits was covered, a part on the covered source area of the interference pattern on the screen would disappear. Therefore, Ambrose et al. recommend starting with teaching double slits and to continue with multi-slit teaching.

In Ambrose et al.'s (1999) study, the students were supposed to extend the wave model developed on double-slit interference to n number (more than two) of slits. The researchers aimed in their study to make a shift from multi-slits to a single-slit and to introduce Huygens' Principle, which is required for the teaching of the single-slit interference. Consequently, the study revealed that although most students had been taught the wave model of light before the instruction, they could not develop a rational model to be used to explain the phenomena of interference and diffraction and had difficulty in explaining these phenomena. The results of the study demonstrate that if students are encouraged to make step-by-step inferences about a situation containing the applications of a new concept, they can easily grasp even a difficult piece of information. In this respect, research-based teaching approach helped students make physics more meaningful and developed rational models even in abstract and complex subjects such as interference and diffraction.

Method

Aiming to define students' conceptual understanding about double-slit interference in the unit The Wave Model of Light and to reveal their conceptual changes by two different instructional methods that adopt social constructivist and traditional approaches, the present study has a quasi-experimental design with pretest and posttest control groups. In accordance with the aim of the study, the effect of the constructivist approach on conceptual change was examined by the integrated use of quantitative and qualitative research methods (Tashakkori & Teddlie, 1998). The research questions were attempted to be answered by the achievement test, the conceptual understanding test, and semi-structured interviews as primary data sources. Notebooks of the experiment group students, the diaries they kept during the instruction period, the worksheets used in the class, and instructional video recordings were also collected as additional data sources; however, they were not analyzed to categorize the types of students' conceptual understanding. Nevertheless, these secondary data sources provided effective feedback on the formal evaluation of students' learning (Black & Wiliam, 1998) and served an ancillary role in revealing the students' conceptual difficulties at the beginning of the following class or during interviews and the inconsistencies between their verbal and written representations, when necessary.

Sample

The sample of the study group consisted of a total of 41 students who were enrolled in two different eleventh-grade (age 17) classes in Edremit Anatolian High School of the district of Edremit in the province of Balıkesir, Turkey in the academic year 2006-2007 and were selected by purposive sampling, a nonrandom sampling method. The selected school was the institution of the second author who was teaching physics for four years. Students are considered average students in the eleventh-grade based on the results of Secondary School Institutions Examination (OKS) organized by the Ministry of National Education once a year.

Data Collection

Below is an explanation of the three data collection instruments used in the study; achievement test (AT), conceptual understanding test (CUT), and semi-structured interviews.

Achievement test

AT was developed to examine whether there was a significant difference between the cognitive levels of the experiment and control groups. In Edremit Anatolian High School selected for the study, there are two eleventh-grade science classes taught by a teacher contacted by the researcher to conduct the study. These two classes were administered the AT, which had been developed previously and subjected to trials.

Originally consisting of 28 multiple choice questions, this test was administered to a total of 197 eleventh-grade students enrolled in secondary schools in the central district of Balıkesir. Four questions were removed from the test as a result of item analysis and the Coefficient Alpha (or KR-20) of the test was calculated to be .82. The test covers all the subjects in the eleventh-grade curriculum until the unit on the wave model of light (geometrical optics, spring and water waves). Containing 24 questions, the final version of the AT was simultaneously administered to the two eleventh-grade science classes four weeks before the instruction.

Conceptual understanding test

The second data collection instrument, *CUT*, was developed to reveal the students' ideas prior to the instruction about the subjects covered under the unit The Wave Model of Light as a pretest and the post-instructional change in students' ideas as a posttest. *CUT* was developed by writing down eight open-ended questions in accordance with the concept map based on the eleventh-grade physics curriculum. This version of the *CUT* was administered for trial purposes to a group of 30 eleventh-grade students studying in the Private Bahçeşehir Körfez College. After pilot test, on the basis of experts' opinions, one question was removed from the *CUT* and the questions were subjected to some formal modifications. Figure 2 shows the phenomenologically framed (Driver & Erickson, 1983) question in the *CUT* about double-slit interference.

Semi-structured interviews

Employed as the third data collection instrument, semi-structured interviews were conducted to describe in-depth students' pre- and post-instructional ideas, the changes in these ideas, and the

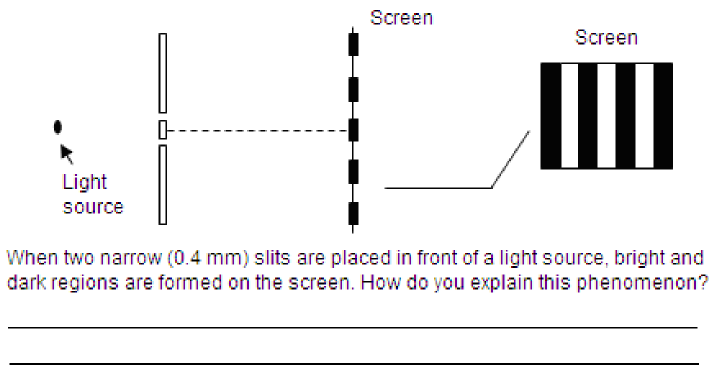

Figure 2. Question about double-slit interference in the conceptual understanding test

factors affecting these changes. The interviews were performed with five students from each of the experiment and control groups. Preliminary interviews were conducted two weeks before the instruction, while the final interviews were done one week following the instruction.

Data Analysis

Meeting the desired reliability level (α=.82), the 24-item AT was then administered to two eleventh-grade classes. The mean equivalence of the two groups on the pretest AT was supported by a non-significant t-test for independent groups. Therefore, class 11 Science D was randomly selected as the experiment group, while class 11 Science A was assigned as the control group. Class 11 Science D consisted of 12 male and 9 female students, while class 11 Science A had 11 male and 9 female students.

The method of content analysis was used to reveal the concepts and relationships that can explain the data obtained from the *CUT*. As the first step of this analysis, an answer key was formed for each question, revealing the full responses as a result of a synthesis of opinions of experts in physics education area and the researchers' opinions. Thereafter, the students' responses to the questions in the pretest and posttest were analyzed on the basis of the main and sub-categorization system used by Kocakulah (1999) for each question. First of all, student responses were grouped under four broad categories: 'Scientifically acceptable responses', 'Scientifically unacceptable responses', 'uncodeable responses' and 'no response'. Two sub-categories were formed under the main category of scientifically acceptable answers: exactly accurate answers were termed as 'full response', while scientifically correct but incomplete answers were called 'partially correct responses'.

The answers that are incompatible with scientific facts and contain inaccurate conceptions were grouped under the main category of 'Scientifically unacceptable responses'. Answers under this category were divided in three sub-categories: 'responses involving wave model of light ideas', 'responses involving the explanation of double-slit interference with geometrical optics' and 'intuitive responses' which indicate the naïve student expressions.

The answers that are ambiguous and irrelevant to the concepts contained in the questions or those containing the exact repetition of the question were put under the category of 'Uncodeable answers', while the answers left unanswered or containing expressions such as 'I do not know' were grouped under the category of 'No response'.

In order to examine the students' individual development, development charts were drawn for each student that represents the changes in the answers from the pretest to the posttest. Furthermore, apart from the researcher's coding for each question in the pre- and post-tests, to determine the reliability of the coding of student answers, an experienced physics teacher employed in a private training center for five years was first familiarized with the coding scheme and then asked to encode all the student answers. The consistency percentages calculated through coding of the experiment and control groups' answers by the researcher and the second coder assumed quite high values (p>90%) in the pre- and post-tests. This result demonstrates that there is a certain consistency between two independent coders (Gazit, Yair, & Chen, 2006).

Experiment Group Instruction Design

In the instruction of The Wave Model of Light for the experiment group, the social constructivist approach was adopted and one of the researchers performed the instruction. Learning was taken as a social activity and it was aimed that the students would construct a common meaning through discussions in a social environment and observations. When presenting their own ideas, the students were provided with opportunities to recognize their fellow students' ideas, the differences between their and other students' ideas, as well as their positive and negative aspects. Thus, the students were given the chance to reorganize or completely change their ideas.

In experiment group instruction, '*Generative Learning Model of Teaching*', which was introduced by Cosgrove and Osborne (1985), was adopted as a teaching strategy. Therefore, the instructor first attempted to reveal the students' ideas and then to provide them with opportunities to recognize or validate their ideas. In the following stage, the instructor introduced the scientific view to students and oriented them towards other application areas with the newly acquired information. Table 1 presents the sub-headings in the eleventh-grade curriculum for double-slit interference and the teaching durations allowed for these headings in the experiment group instruction.

Table 1. Themes and durations of teaching episodes

Section	**Lesson**	**Duration (min)**	**Conceptual Themes Covered**
1	1	40	Explanation of double-slit interference
	2	15	Path difference
		25	Fringe width and the relationship between fringe width and wavelength
2	3	10	Illumination of double slit with white light and the concept of in phase sources
		10	Phase difference

Application of Experiment Group Instruction

Lesson 1

Teaching of double-slit interference started with a presentation of the historical development of ideas about light and information about the scientists who introduced these ideas. As it was deemed inappropriate to provide students with information about the scientists who adopted the idea of '*the wave model of light*', the presentation of the historical development of ideas about light ended with Newton's views.

At the next stage, the students were asked to look at the light sources through the double-slit setups existed in front of them and to write down what they see on a piece of paper. At the end of the process, the instructor asked the students to show and draw their drawings on the board. After showing them the scientific image on the computer, the instructor asked the four groups to find an explanation through discussions among them. Some of the answers provided by the groups are summarized below.

> *Group 2: Since light is dispersed in the form of waves, interference pattern is formed. Where a wave crest meets another crest, it becomes bright while troughs compose dark.*
>
> *Group 3: View 1. Light interferes by coming out of the slits and comes in an uncontinuous form to our eyes. Light does not reach to dark regions, but it reaches to bright regions. Light disperses. Certain regions do not receive light. They appear as discontinuous from now on. View 2. It may be the case that slits cause brights while the ink composes darks.*
>
> *Group 4: View 1. Light arrives at certain regions but it does not arrive at some other certain regions. View 2. It is due to thin property of the slits. Light disperses.*

The instructor drew on the board an image with two large slits and a light source behind them. The students were asked about the image formed on the screen and they collectively answered that '*two bright patches will be formed*'. The instructor asked what the students expect if the distance between two gaps is reduced enough until it is equalized to the thickness of a razor blade. The intention was to stress that geometrical optics model is inadequate to explain the situation considered.

Furthermore, as the idea of scattering of light (scattering of photons bouncing off the slit) had been previously mentioned in the literature, the researcher prepared a material about it prior to the lecture. He made an analogy between the light coming through the slit and '*pellets scattering around from a fired shell*' and stated that no such shapely dark and light fringes could be formed under such circumstances.

The instructor asked a question of '*Can we explain this pattern you see in double-slit setup by an analogy with water waves?*' and make other students participate in the discussions to remind them water waves. The students were active in this part of the lecture and the instructor only created a cognitive conflict with an attempt to reveal students' ideas. Subsequently, he introduced the scientific view and underlined that the double-slit interference pattern can be explained by an analogy with water waves and thus, light assumes the character of a wave. Using an analogy with water waves, he emphasized that light waves cancel each other on certain points on the screen, while they reinforce each other on other points. At this point, the instructor turned to former subjects, reviewing students' ideas and asked the groups who thought that the dark areas would not receive light whether they still maintained the same idea.

After students' answer that K_1P and K_2P lines are equal, as seen in Figure 3.a, the instructor stated that if the crest of the light from source K_1 reaches point P, then the crest of the light from source K_2 will reach it and there will be reinforcement at this point, which will, therefore, look bright. The students stated that in Figure 3.b where the path difference is assumed to be half-wavelength long, point R on the screen will be reached by the crest of the light from a light source and the trough of a light from another light source. Thereafter, the instructor asked the students, '*What kind of a generalization can we make?*', and the significant dialogs between some groups and the instructor are presented below.

> *Group 2: We decided that if the distance of the point to the light sources is a whole number of wavelenght λ it becomes bright, if it does not it becomes dark.*
> *I: Which distance do you mean? There are two distances between the point and the sources; one of them is K_1 and the other is K_2.*
>
> *Group 2: (Another student in the group intervenes) Ooh. Path difference. Difference in two lengths.*
>
> *Group 4: When the point is in equal distance to the slits, light waves reinforce each other and that point is seen as bright. When the point is not in equal distance to the slits, they cancel each other and the point is seen as dark.*
> *I: (The researcher selected a bright fringe on the slide and made connections between this fringe and slits) Do you think that these lines are in equal length?*
>
> *Group 4: No, they aren't.*
> *I: But a bright fringe is formed. It must be a dark one according to what you have said.*
> *Grup4: ...Yes, but... We perhaps made a mistake.*

First traces of misconceptions about path difference were observed in this lesson. Generalizations followed discussions and it was underlined that darkness forms when path difference is equal to a half number of wavelengths, and brightness forms when path difference is equal to a whole number of wavelengths.

Lesson 2

An examination of the student responses to the question about path difference in the previous lesson reveals that Group 2 and Group 4 had some misconceptions about path difference. Since this was predicted on the basis of literature review on the subject, it was concluded that there was a need for an activity on path difference.

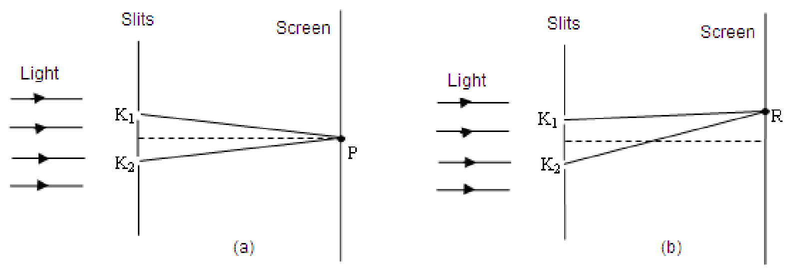

Figure 3. A drawing used by the teacher during the explanation of double-slit interference

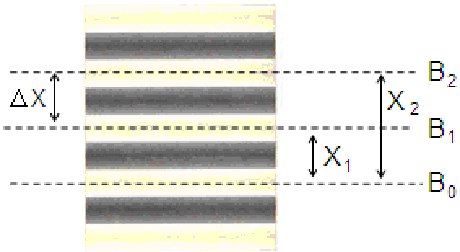

Figure 4. A figure used when students were asked to explore the equation for fringe width

During the second lecture, worksheets were handed out to the students, each of whom was asked to answer the questions about *path difference* on this worksheet and discuss their opinions with other students in their group for five minutes. Group opinions were discussed in the classroom and the following 25 minutes of the lesson concerned the concept of fringe width. The instructor asked the students to look at the light source through the double-slit setup using the blue and red filters on the tables.

During the experiment, some students complained of not being able to see any difference. This problem was solved by maintaining the viewer in his/her place and having another student change the filter for him/her. Meanwhile, student E3 found out a practical and productive solution for that particular problem by covering half of the light source with a blue filter and the other half of it with a red filter and looked through the double-slit setup at this source.

The instructor asked the students to find X_1 and X_2 distances in Figure 4 using the path difference-wavelength relationship and calculate the difference between them; thus, to arrive at the fringe width Δx. Subsequently, the students were directed to the questions about *fringe width* in the worksheet provided.

Lesson 3

In this lecture, illumination of double-slit setup with white light and the effects of phase difference on double-slit interference pattern were examined. The students were asked to look at the light source through the double-slit setup without using any filters and to note down and explain what they see. For this activity, two groups' explanations are presented below.

> *Group 1: It resembles to the double-slit interference but different colours were observed due to use of white light.*
> *I: Why does it resemble to the double-slit interference?*
>
> *Group 1: There is not a single colour namely a single wavelength here. Light exists in the form of many wavelengths. Different colours are formed in different places.*
> *I: What can be the reason of the formation of different colours in different places?*
>
> *Group 1: They might be formed relating to their wavelengths.* (The idea referring to path difference has not been proposed yet.)

Group 2: Wavelength is important since we use white light. We observe the coloured pattern due to the existence of light in different wavelengths. Darks also exist. They are formed with the interference of a crest and a trough of a wave.
I: What is responsible for the formation of green or red at your eye (i.e. on the screen)?

Group 2: Path difference. As the path difference is changed it sometimes corresponds to the wavelengths of different light colours. (Group 2 arrives at the scientific view.)

The instructor stated that there were darks in the pattern, as mentioned by Group 2. Meanwhile, the instructor asked the other groups who did not see the dark areas in the pattern to look at the white light again using the double-slit setup. Reminding them of the idea of Group 2 when explaining these dark areas, the instructor asked other groups about their opinions to initiate a discussion. The instructor then asked, '*why do we see a configuration of different colors*?' Using the questions-and-answers technique, he directed the students towards the idea that wavelength-path difference relationship should be used to explain the observed pattern. Subsequently, he introduced the scientific view by underlining that the colors in the white light have different wavelengths and thus, as path difference changes, it will correspond to a whole number of wavelengths of a light with a different color each time. Thus, it was stated that different colors on the screen (eye) will be situated on different points.

The concept of phase difference was finally examined in this lesson and with an attempt to introduce the effect of phase difference on double-slit interference pattern, the students were asked about how the interference pattern in water waves was affected by phase difference. As student E15 in Group 1 stated that in water waves, phase difference would move the wave trains and nodal lines in the interference pattern towards the delayed source and no other answers were provided to the question about any other ideas, the scientific view was introduced. Subsequently, the students were directed to the questions on phase difference in the worksheets and found the opportunity for new applications.

Control Group Instruction

As in the experiment group, the researcher also assumed the role of an instructor in control group instruction. There was no difference between the control group and experiment group instruction in terms of the conceptual themes covered. However, there were differences in terms of the duration of activities. In the control group instruction, teacher-based teaching techniques were used instead of student-centered activities in line with the constructivist approach. The concepts were presented by the instructor by using an inductive approach. Yet, each experiment performed in the experiment group was also performed in the control groups. The instructor carried out each experiment, the students looked at the experiment setup one by one, and the instructor immediately began to explain the physical fact in the experiment. Furthermore, the worksheets used in the experiment group were handed to the control group as assignments and at times they were used as supplementary materials for solving problems by the instructor. In brief, the students in the control group watched the experiments and tried to comprehend instructor's explanations and problem solving.

Findings

This section of the study contains the results obtained from the CUT, which was administered as a pre- and post-test, and the preliminary and final interviews.

Pre-Instructional Findings

Table 2 was formed by categorizing the responses to the question on double-slit interference (Figure 2) contained in *CUT*. For the answers to be scientifically accurate, the students need to mention the wave characteristic of light, interference of light, constructive (trough–trough and crest–crest) and destructive interference (trough–crest). None of the students in the experiment and control groups provided a full response to the pretest question. There are no students in the experiment group who provided partially correct responses, while 6 control group students (30%) gave partially correct responses. Of these students in the control group, C1's interview with the researcher is given below.

> *R: How do you think we obtain bright-dark regions with two slits here?*
>
> *C1: We have a barrier with two slits and light rays do wave motion. They compose crests and troughs. Also, crest-crests compose bright region as they come together.*
>
> *R: You wrote 'trough-troughs compose dark' in your response to the test question. What are those crests and troughs? Where do they emerge from?*
>
> *C1: There were crests and troughs of light.*
>
> *R: Does light have crests or troughs?*
>
> *C1: What I remember is that there have been crests and troughs like that. Like a wave. Light shows wave properties. It also has crests and troughs.*
>
> *R: You wrote that 'when a crest and another crest come across, brights were formed'. Can you tell me more about how this happens?*
>
> *C1: For instance, when a crest comes across with a trough they cancel each other. Dark is formed. A crest and a crest do not cancel themselves it becomes bright.*

In the preliminary interview with student C1, it was stated that light was analogized to wave and crests and troughs must exist. C1 emphasizes that there is brightness when there are two crests together; however, he is confused about the formation of darkness. C1 wrote in his response to the CUT that darkness forms when there are two troughs together. The researcher suspected of one of his answers during the interview that '*crest and trough form darkness*' and asked him about the reason for this discrepancy. C1 was confused by this question. When asked again about how the bright-dark fringes are formed, student C1 cannot provide any additional explanation. Furthermore, student C1 mentions *'coming together'*, instead of *'interference'*. Interviews with student C1 and other control group students who provided partially correct responses revealed that the students recalled some concepts, but did not have an accurate conceptual understanding.

In the pretest, about 10% of the experiment group and 30% of the control group students provided answers that contained the scientifically unacceptable idea of the wave model of light. Moreover, about 5% of the experiment group students and 15% of the control group students attempted to explain the phenomenon with geometrical optics. Below is a part of the interviews with students E3 and C4 who provided answers in this category.

> *E3: When light comes to the slit, it is refracted in those edges of the slit. I thought that light is refracted as it passes through the air in the slits around the edges.*
>
> *R: Two sides of the slit are in the medium of air. How the light is refracted?*

Table 2. Types of students' responses given to double-slit interference question

Types of Responses	**Experiment Group**		**Control Group**	
A. Scientifically Acceptable Responses	Pretest	Posttest	Pretest	Posttest
A1. Full Response	n (%)	n (%)	n (%)	n (%)
Double-slit interference pattern is formed as a result of interference of light waves emanated from two slits. The points, where light waves reinforce each other (T+T or C+C), become bright while the points in which light waves cancel themselves (T+C) become dark.	0	8 (38.01)	0	2 (10.00)
A2. Partially Correct Responses				
➢ It is a double-slit interference. Due to the wave nature of light, C+C and T+T form bright while T+C forms dark. ➢ Light composes an interference pattern on the screen by passing through the double slits.	0	11 (52.38)	6 (30.00)	14 (70.00)
Subtotal 1	0	19 (90.47)	6 (30.00)	16 (80.00)
B. Scientifically Unacceptable Responses				
B1. Responses Involving Wave Model of Light Ideas				
➢ Interference in double slits occurs. If bright phases of light come out from two slits, it becomes bright. When a bright phase comes out from one source and a dark phase comes out from another source, that dark fringe appears. ➢ C+C become bright, T+T and C+T becomes dark. ➢ Diffraction and interference occur. ➢ Formation of bright and dark regions depends upon the width of a slit and upon the number of slits placed in front of the light source.	2 (9.52)	1 (4.76)	6 (30.00)	2 (10.00)
B2. Responses Involving the Explanation of Double-slit Interference with Geometrical Optics				
➢ Light touches on some places but it does not touch on some other places due to double-slit. Therefore, bright and dark fringes are formed. ➢ As the gap is reduced less light crosses over to the screen. Bright reduces while darkness increases. ➢ Light is refracted from two different points. Darkness is formed in the points where rays coincide.	1 (4.76)	1 (4.76)	3 (15.00)	0
B3. Intuitive Responses				
This happens because light does not reach some regions on the screen. Light first comes to a very narrow slit and huddles over there. Then, it disperses. This phenomenon takes place twice when there are two slits.	1 (4.76)	0	1 (5.00)	0
Subtotal 2	4 (19.04)	2 (9.52)	10 (50.00)	2 (10.00)
C. Uncodeable Responses	1 (4.76)	0	1 (5.00)	2 (10.00)
D. No Response	16 (76.19)	0	3 (15.00)	0
Total	21 (100)	21 (100)	20 (100)	20 (100)

* T denotes a trough of a light wave while C denotes a crest of a light wave

E3: I think that it may be refracted since the slit is a very narrow gap.

R: All right. How do we explain the formation of bright-dark fringes?

E3: Light rays go through the gap and are refracted. The points of which become bright when light rays overlap. Divergences occur. Certain points do not receive light. Diverged rays meet in some places while some places do not receive light.

Student E3 states that light will be refracted in the air in a very narrow slit and these rays will focus on certain areas to form brightness, while the remaining areas will remain dark. Obviously, the ideas of E3 are incompatible with the scientific view.

R: In the pre test, you replied that 'as the area of the slit is decreased, the area of bright region becomes narrow. Because middle part of the interference pattern contacts with light source uninterruptedly, this part is bright, namely light is focused'. Could you please explain the idea of focusing light further?

C4: As the light source is placed directly to that opposite part of the screen, much light touches on that part. It is seen as bright.

Student C4 provided an answer to the question using his notions about geometrical optics. Student C4 tried to explain the central bright fringe with the idea of focusing and when the researcher asked him about how to explain other bright fringes, student C4 did not provide any answers. In some part of the interview, student C4 said *'I guess they form as light is wave'* while trying to explain the bright–dark fringes. Clearly, C4 lacks an accurate conceptual understanding about the wave model of light.

In general, in the pretest, about 19% of the experiment group and 50% of the control group provided scientifically unacceptable answers. About 70% of the experiment group and 15% of the control group students left the question unanswered.

Post-Instructional Findings

An examination of the posttest responses reveal that 90% of the experiment group and 80% of the control group students provided scientifically acceptable answers. Nevertheless, the full response was provided by about 38% of the experiment and 10% of the control group students and this is where the difference is first revealed. Below are the explanations in the post-instructional interview of student E5, who did not answer the double-slit interference question in the pretest but provided a scientifically correct and full response in the posttest.

R: In the post test, you mentioned crests and troughs from sources and the occurrence of double-slit interference pattern. Firstly, what are these crests and troughs?

E5: We associated light with waves. It had crests and troughs. When a crest or a trough coincides with another crest or trough of light rays emanated from slits, it becomes bright. If a crest coincides with a trough, it becomes dark. In this way, bright-dark fringes are formed on the screen.

R: How do we know whether a bright or dark fringe is formed at a point on the screen?

E5: If path difference is a whole number of wavelength, it becomes bright. When it is an odd number of half wavelengths it becomes dark.

R: What is path difference?

E5: The difference of lengths of those two lines drawn between a point on the screen and the sources.

R: How do we explain the placement of bright-dark fringes on the screen?

E5: It is related to the change in path difference. We find different path difference values for a chosen point on the screen. That's why; some points are seen as bright while some are dark.

Student *E*5 exhibited a high level of understanding of the subject by underlining the need for path difference to know whether brightness or darkness will form on the screen and explaining successfully path difference. Furthermore, he attributed the configuration of bright–dark fringes on the screen to the change in the path difference. The same is true for the other experiment group students who provided the full responses to the question in the CUT.

In the posttest, about 52% of the experiment group students and 70% of the control group students provided scientifically partially correct answers. Student E1, one of the interviewed experiment group students in this category, and C4, a control group student, had the following dialogues with the researcher.

R: Your response to the post test is 'Light rays emanating from the source pass through a barrier and behave as a wave. Different rays passing through two slits compose an interference pattern on the screen'. Can you explain this more, please?

E1: Rays passing through those two slits interfere. They cancel each other in some points while they reinforce themselves in some other points. Bright-dark fringes appear on the screen.

R: Why bright-dark fringes are arranged in order on the screen?

E1: They are arranged due to the change in path difference. As different points are selected path difference is changed and has different values.

R: What is path difference?

*E1: We choose a point on the screen. We connect this point with the sources (slits). Difference here (*draws a line at right angle from the slit above to lower line drawn between the point on the screen and the slit below*) is called path difference.*

Final interviews with the experiment group students demonstrate that these students had in fact fully accurate ideas although they provided scientifically partially correct answers with weak explanations in the posttest. Student E1 successfully explained double-slit interference pattern and the configuration of bright–dark fringes on the screen. What is more, the student's ideas about the concept of path difference are fully correct in scientific terms.

Below follows a presentation of the state of the control group by the interviews.

R: In somewhere in the posttest you reasoned that 'crest-crest coincidence occurs when path difference is equal'. Can you explain this part further?

C4: If path difference is equal, a crest and another crest coincide.

R: What is path difference?

C4: If we take a point and connect that point to the sources, difference between those two lines is called path difference.

R: You wrote that 'when path difference is equal'. What makes it to be equalized?

C4: When those two lines are equal then path difference is equal. Bright is formed.

R: Aren't there some situations in which those lines are unequal? What happens in the situations of lines which are unequal in length?

C4: Darks are formed in unequal length situations.

While providing the scientifically partially correct response in the conceptual understanding test after instruction, student C4 had misconceptions about path difference and he was unable to provide a scientifically acceptable explanation about it during the interview. When asked about path difference to C4, who implied that there was brightness when the lines from the point to the sources were equal, and there was darkness when they were not equal, he connected the sources to the point and took the difference. Yet, he has the idea of that difference will be equal.

Similar to C4, student C1, who stated that '*In a double-slit, there will be bright bands at a whole number of λ'*, was confused and could not provide any answers when asked about which quantity will be equal to a whole number of λ. Interestingly, the student could not mention '*path difference*' for this question. He was also asked about why bright–dark fringes were arranged on the screen and he could not provide any answers too. This result shows that C1 did not have an accurate conceptual understanding about the concept of path difference.

Student E10, an experiment group student who mentioned the idea of the wave model of light in the posttest in a scientifically unacceptable manner, replied that '*there is double-slit interference; if a bright phase comes through a slit and a bright phase comes through another, that area will be bright; however, the area will be a dark fringe if a dark phase comes through one slit and bright phase comes through the other*'. Thus, E10 provided a distinctive comment on constructive and destructive interference.

Attempting to explain the double-slit interference by the principles of geometrical optics, E19 answered that '*as it is a double slit, light will reach some areas but will not reach others, so brightness-darkness is formed*'. Consequently, 10% of the students in both groups provided scientifically unacceptable answers to the post test question.

Discussion

In this study that examined the change in student ideas before and after instruction on double-slit interference, each student's process of conceptual change was further examined and the individual development diagram was produced as can be seen in Figure 5. In Figure 5, green lines indicate positive changes in student ideas, red lines indicate negative changes, and blue lines indicate no change. The numbers on arrows indicate the number of people experiencing such change or steadiness, while the codes in brackets (C1, E3, etc.) show the concerned students in experiment or control groups.

An examination of Figure 5 reveals that all students in the experiment group experienced positive changes in their ideas; of 16 students (76.16%) who left the question unanswered in the pretest, 15 (71.43%) provided scientifically acceptable answers after the instruction; and 6 (28.57%) students in the same group provided full responses. On the other hand, 10 (47.62%) students in the control group experienced positive changes after the instruction, participating in

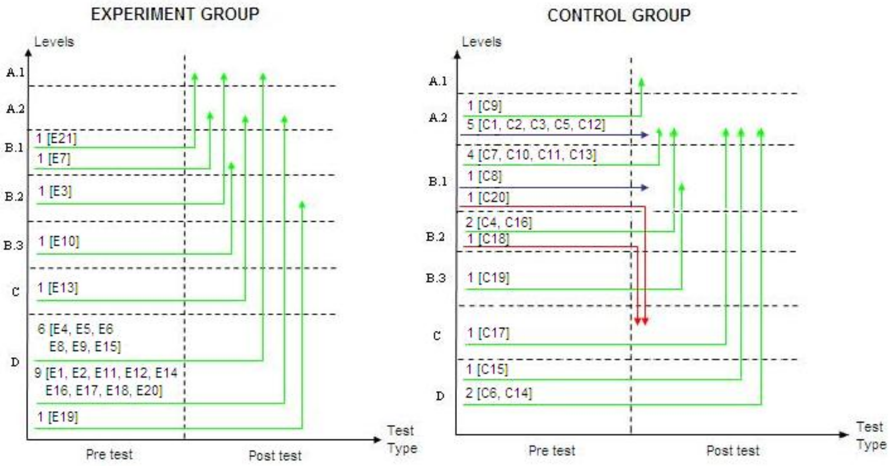

Figure 5. Monitoring ideas of experimental and control group students about double-slit interference question

the student group who provided partially correct responses. Another striking finding is that in contrast to the experiment group, 6 (28.57%) students in the control group experienced no change in their ideas after the instruction and 2 (9.52%) students in this group experienced negative changes.

Prior to the instruction, 30% of the control group provided partially correct responses and interviews with the students who provided partially correct responses revealed that these students lacked an accurate conceptual understanding about double-slit interference. The students used statements like '*crest–crest will be bright*' to explain the formation of bright–dark fringes, but could not provide an accurate explanation. In particular, students C1 and C3 stated that '*crest–crest will be bright, and trough-trough will be dark'*. Scientifically, trough-trough interference leads to brightness. It is assumed that this misconception in students resulted from the fact that trough is the opposite of crest. In students' understanding, crest was associated with brightness, while trough was associated with darkness.

Attempting to explain double-slit interference by the concepts of geometrical optics, the students mostly had the idea that '*light is refracted in the slit air*'. It was stated that refracted rays focused on certain areas to form bright parts, while the remaining areas will be dark. The students answering in this category tried to explain the central bright fringe using the idea of focusing. During the interviews, the researcher asked how other bright-dark areas are formed, a question which was left unanswered. Some statements in the pretest, such as '*the light does not reach certain areas*' and '*the light is caught in a very narrow slit and then scatters*' demonstrate the way the students intuitively interpret the phenomenon without the scientific view.

The final interviews with the experiment group students who provided partially correct responses in the posttest revealed that these students provided answers with weak explanatory power in the Conceptual Understanding Test (CUT), but in fact, they had completely accurate ideas. Indeed, the students were successful in explaining the formation of bright-dark fringes, the configuration of these fringes on the screen, and path difference. However, this was not the case with the control group students. For instance, when interviewed student C1, said, '*In a double-slit, there will be bright bands at a whole number of λ and dark bands at a whole number of $\lambda/2$*'. When asked about which quantity will be equal to a whole number of λ or whole numbers of

$\lambda/2$, the student experienced confusion and interestingly, could not answer this question using the concept of '*path difference*'. Student C1 seemed to focus on the information about the whole numbers of λ for bright and dark bands to help him in solving multiple-choice questions, but did not know which quantity will be equal to a whole number of λ or whole numbers of $\lambda/2$. This was also revealed by his inability to provide any answers to the question about why bright–dark fringes were arranged in a line on the screen. In brief, the control group students did not comprehend the meaning and effect of path difference and their statements did not go beyond memorized information.

Student C3, one of the students who provided partially correct responses in the posttest, stated in the final interview that the relationship between path difference and wavelength determines the arrangement of the bright-dark fringes on the screen. The student also managed to explain scientifically the formation of bright-dark fringes. Yet, in the following part of the interview, C3 was detected to have a misconception about the concept of path difference. When asked, '*where is the path difference?*', student C3 described path difference as the distance between a point on the screen and the light source. Such misconceptions were commonly identified particularly among the control group students, which clearly points out to the importance of understanding the concept of path difference during teaching of the subject.

A general examination of the analysis results for the responses to the conceptual understanding test reveals a slight difference of 10% between the students in the experiment and control groups in favor of the experiment group in terms of scientifically acceptable responses; however, discrimination of these responses as fully correct and partially correct showed both qualitative and quantitative differences. Furthermore, interviews with the students after the instruction demonstrated that this difference was in fact greater in favor of the experiment group. The students whose responses in the posttest were coded as partially correct provided fully correct answers in the interviews and control group students, who gave partially correct responses in the post test, showed that they had misconceptions when their responses were further probed. Thus, it could be argued that the gap between experiment and control group students expands in terms of the levels of development in students' understanding.

Even some authors (Kirschner, Sweller & Clark, 2006; Tobias, 2009) question the efficacy of constructivism as an instructional tool. It was reported earlier in this study that constructivist teaching strategies introduce innovative ways to enhance classroom teaching by eliciting students' prior conceptions, providing experiences that contrasted or conflicted with misconceptions, discussing the scientific viewpoint and applying it to new situations with feedback. Baviskar, Hartle and Whitney (2009) suggest the application of these four essential criteria to implement or evaluate constructivist teaching methods.

It can be argued that research concerning constructivist methods has not generally been transferred into science classrooms (Duit & Treagust, 2003) and research should focus on informing classroom practice. Baviskar et al. (2009) attribute probable misunderstandings on constructivism by teachers and researchers to little emphasis on practical application of the studies reported in the literature and evaluate that a lesson should not necessarily follow a specific formula to be constructivist. Palmer (2005) concludes that the recent models of constructivist teaching are broadly similar to the earlier models. The principle idea is that strategies should be integrated with teaching techniques that can reduce the status of students' misconceptions and increase the status of scientific concepts. Therefore, teachers or researchers should select the best strategy according to development level of their students, their pedagogical content knowledge and facilities (i.e hands-on activities, experimental devices, technological tools, etc.) provided to be able to motivate students, internalize scientific ideas and apply newly learnt concepts to new situations or real life.

Palmer (2005) adds the dimension of motivation to teaching to initially arouse students to participate in learning but also to complete knowledge construction. He points out a particular phase that was intended to arouse motivation with relating content to everyday life in generative learning model of Cosgrove and Osborne (1985). Indeed, it was observed throughout teaching in experimental group of this study that students' motivation aroused by orienting them towards other application areas with the newly acquired information. For instance, students were able to explain successfully path difference, configuration of bright and dark fringes and change in fringe widths on the screen when they looked at the light source using the blue or red filters or when double-slit setup was illuminated with white light. In addition to Palmer's (2005) view, the focus phase of the teaching model implemented in this study, in which the students' attention was focused on a phenomenon and their ideas about phenomenon, was also found to provide students motivating experiences.

Finally, sample of this study consists of middle achievers and they displayed a high level of engagement in activities and understanding of the subject by providing accurate explanations as opposed to low socio cognitive engagement in the mental-model-building task on the nature of matter unit with low and middle achieving eighth graders in the study of Hogan (1999). Bischoff and Anderson (2001), Tsai and Huang (2001) also explored the difference between low and high achievers in science learning and they revealed that high achievers always displayed more integrated cognitive structures and better usage of information processing strategies than low achievers.

The effects of long-term constructivist-oriented science instruction on the development of different science achievers' cognitive structures were also investigated in the study of Wu and Tsai (2005) and both the high and low achievers in the constructivist-oriented instruction group obtained more concepts or ideas and displayed better usage of higher order information processing strategies (i.e., making inferences or explanations) than their counterparts in the traditional teaching group did. This was also evident in this study that experimental group students were able to respond with high levels of explanations about the phenomenon of double-slit interference. It is clear from such results that both high and low achievers benefited from the constructivist-oriented science teaching more than those traditionally taught.

Conclusion and Suggestions

Arguably, the teaching strategy adopted in this study and also by Çalık (2008) is successful in convincing students about scientific ideas. Nevertheless, the most significant result of the study is that instead of relying on written tests to determine the change in students' conceptual understanding, there is a need for in-depth interviews for questioning of students' ideas. As presented in the results section, the experiment group students who provided partially correct answers in the posttest successfully explained in the final interviews the formation of bright-dark fringes and the configuration of these fringes on the screen and proved that their ideas about the concept of path difference were in full agreement with the scientific view. However, the control group students coded in the same category as these experiment group students in the posttest had difficulty in explaining phenomena such as path difference, why path difference is calculated, and why bright–dark fringes are orderly arranged on the screen.

Another result of the study is that control group students still had misconceptions about the concept of path difference and method of calculating path difference following the instruction. This result was obtained in four of the five control group students, with whom interviews were made after the instruction. Misconceptions about path difference were revealed by the statement of '*when the path differences are equal*'. When asked how the path differences can be equal,

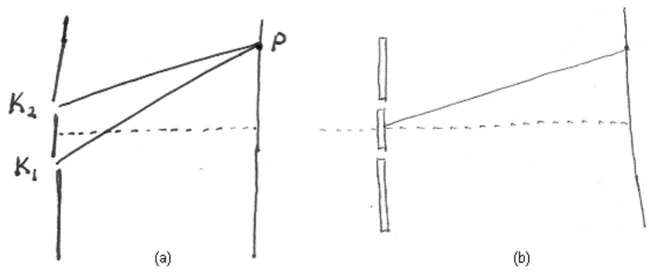

Figure 6. Drawings done by a) student C4 and b) student C3 to explain path difference

student C4 replied, '*path differences are equal when these lines (Figure 6.a) are equal*'. According to the definition of path difference by C4, if K_1P and K_2P lines are equal, path difference will be equal to zero and thus, this shows that C4 expressed his ideas without internalizing them. These results of the study are consistent with the results of Ambrose et al. (1999).

When asked about the concept of path difference, C3, a control group student drew the figure given in Figure 6b. This drawing reveals the confusion experienced when constructing the concept of path difference by the control group students who were only provided with concept definitions and solving problems about the wave model of light. This demonstrates that the concept of path difference is an important point of attention in planning teaching. Therefore, there is a need to reveal students' understandings about the concept of path difference prior to the instruction and to establish the relationship between path difference and wavelength in order to make these understandings comply with the scientific view. A suggested activity could focus on *'an analogy between light and water waves'* during instruction and in-class discussions since the experiment group students were not shown to have any misconceptions about path difference.

As demonstrated by the results of this study, the first subject which presents learning deficiencies is explaining the orderly alignment of bright–dark fringes on the screen. The control group students had difficulty in explaining the formation of bright-dark fringes by establishing the relationship between path difference and wavelength. This learning deficiency in students and insufficient understanding about the concept of path difference is demonstrated by the fact that the students did not have any idea about the need for calculating path difference. Similarly to a study by Wosailait et al. (1999), another learning deficiency was detected as the students' difficulty in explaining the concept of '*interference*' and their inability to apply this concept in explaining double-slit pattern. Students' inability to explain the configuration of bright-dark fringes shows that they did not have the opportunity to mentally filter and construct their ideas in a non-sharing learning environment in which their ideas are not taken into consideration.

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Ortaöğretim öğrencilerinin çift yarıkta girişim üzerine kavramsal değişimlerinin incelenmesi

Yapılandırmacı yaklaşım temel alınarak tasarlanan bu araştırmada, Işığın Çift Yarıkta Girişimi konusuna ait öğretimin öğrencilerin kavramsal değişimleri üzerinde olumlu bir etkisinin olup olmadığı belirlenmeye çalışılmıştır. Karma yöntemin kullanıldığı bu araştırmada veri toplama aracı olarak; hazır bulunuşluk testi, kavramsal anlama testi ve yarı yapılandırılmış görüşmeler seçilmiştir. Deney grubuna yapılandırmacı yaklaşım, kontrol grubuna ise öğretmenin aktif olduğu geleneksel yaklaşım benimsenerek öğretim yapılmıştır. Öğretim sonrasında yapılandırmacı yaklaşımın benimsendiği deney grubundaki öğrencilerin kavramsal anlamalarının daha üst düzeyde gerçekleştiği belirlenmiştir. Neden sonuç ilişkileri kurma, bilgiyi transfer edebilme ve yapılandırma noktalarında deney grubunun üstünlükleri yapılan görüşmeler ile açığa çıkarılmıştır. Bu araştırmada, yapılandırmacı yaklaşım temelinde tasarlanan Işığın Çift Yarıkta Girişimi öğretiminin, geleneksel öğretime göre girişim, yol farkı ve saçak aralığı kavramlarının anlamlarının yapılandırılmasında ve aydınlık-karanlık saçakların oluşumunun anlaşılmasında daha başarılı olduğu sonucuna ulaşılmıştır.

Anahtar Sözcükler: kavramsal değişim, kavramsal anlama, yapılandırmacı yaklaşım, çift yarıkta girişim, fizik eğitimi