DEVELOPMENT OF A SCIENCE LEARNING UNIT TO ENHANCE HIGH SCHOOL STUDENTS' UNDERSTANDING OF RAINBOW BASED ON PREDICT-OBSERVE-EXPLAIN APPROACH

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Thesis
entitled

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Sonam Choegyal

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ABSTRACT

Students find the subject of Physics tough and uninteresting due to abstract and complex content. Consequently, students' interest in and attitude towards physics is deteriorating all over the world, which is also blamed on the unacceptable quality of teaching. In order to address the aforementioned problems, this study says that the introduction of interesting topics in physics raises the interest and curiosity of the students thereby motivating students to continue studying physics. In addition, hands-on activities, along with a suitable learning cycle, help students to learn the concepts better. Therefore, in this study, the Predict-Observe-Explain (POE) learning cycle was used along with models for hands-on learning on interesting optical phenomena related to rainbow formation. This study was aimed at investigating students' conceptual understanding about the optical phenomenon of rainbow formation and investigating students' opinions on the developed learning unit. A conceptual understanding test along with a learning unit opinion survey questionnaire (LUOSQ) was used to investigate students' understanding of the concepts. The opinion of the students towards the learning unit was investigated using the LUOSQ items and students' interview responses. The participants of this study were 120 grade 11 science students from one district in Bhutan. The study found that the average score increased from 23.3% in the pre-test to 82.7% in the post-test with an overall gain of 59%. Moreover, the average mean of LUOSQ items was 4.71. These results indicate that there was significant improvement of the students' conceptual understanding of rainbow formation and the opinion of the students showed strong approval of the learning unit.

KEY WORDS: POE/ RAINBOW/PHYSICS EDUCATION/INDOOR RAINBOW MODEL/HANDS-ON LEARNING

132 pages

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LIST OF ABBREVIATIONS

AAPT	American Association of Physics Teachers
ASPEN	Asian Physics Education Network
CD	Compact Disc
cm(s)	centimeter(s)
CUT	Conceptual Understanding Test
DRCD	Department of Curriculum and Research Department
et al.	et all and others
EUPEN	European Physics Education Network
IOP	Institute of Physics
K–12	Kindergarten through 12th Grade
LED	Light Emitting Diode
LUOSQ	Learning Unit Opinion Survey Questionnaire
m/s	meter per second
mm	millimeter
NAPE	New Approach to Primary Education
nm	nanometer
PER	Physics Education Research
PhET	Physics Education Technology
POE	Predict-Observe-Explain
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
THz	Terahertz
UNESCO	United Nations Educational, Scientific and Cultural Organization

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CHAPTER I
INTRODUCTION

Overview

This chapter provides an overview of the research study including the significance, research objectives, research questions, framework of the study, scope of the study, expected outcomes of the research, definition of terms and summary of organization of the thesis.

1.1 Significance of Research Study

The content knowledge in science is abstract and complex (Ruby, 2001). Examination and manipulation of things make abstract science knowledge more clearer and concrete because it require students to learn through hands-on and eyes-on, thereby giving opportunity to the students to see and experience the real illustrations of the science knowledge. Furthermore, Ruby (2001) found that in science education, student achievement was improved through hands-on learning. It was also found that rather than just through hearing and seeing alone, a combination of hearing, seeing and hands-on are much better for humans to learn (Alcorn, 2003). However, even after all these findings, the majority of instructions were still through lecture in many countries, so it was pointed out that students are not prepared by science education in all educational level to live and work in the twenty-first century, the science and technology rich environment. Moreover, study indicated that in many developed countries students' interest in and attitude toward science was deteriorating, and this failing was also blamed on undesirable quality of teaching (BouJaoude, 2011).

According to international researches, many students are not in favor of physics throughout the world for its toughness and challenging in nature. In order to develop students' interest towards the subject it was suggested that finding some interesting topics that stirred enough curiosity in students was very important. Dömény

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(2010) proposed that it could be appropriate if the topics are selected from the field of atmospheric physics and to be more precise, he mentioned that perhaps the best possible choice would be if the topics are chosen from atmospheric optics.

The topics on atmospheric optic have abundance of literatures including rainbow formation. Almost all the literatures about rainbow are based on theoretical and mathematical aspects, such as, the literature on 'the mathematical physics of rainbows and glories' by Adam (2002), 'Mie theory, Airy theory, and the natural rainbow' by Lee (1998), 'rainbows, coronas and glories' by Laven (2012), 'rainbows and fogbows' by Lynch & Schwartz (1991), 'the theory of the rainbow' by Nussenzveig (1977). On contrary, there are very few literatures in education context to teach this phenomenon to children through observation and experiment (Kikas, 2010). For example, the literatures on 'atmospheric phenomena in physics teaching' by Dömény (2010), 'Children Explain the Rainbow: Using Young Children's Ideas to Guide Science Curricula' by Siri & Kremer (2011). Study found that rainbows are popular amongst children. The beautiful colors of the rainbow fascinate children and even inspire them to various artworks but since the refraction and reflection of light cannot be seen, children are unaware of all these details.

As stated in the Science Curriculum Framework PP - XII (2013), students in Bhutan study science as a subject right from pre-primary (PP). From pre-primary to grade III, science is studied as environmental studies (EVS), from grade IV to VI it is studied as science and from grade VII to VIII it is studied as integrated science. The segregation of science into three disciplines (Physics, Chemistry and Biology) begins from class IX. From so many topics in science, students learn about the topics on light and optics in all the grades stage-wise (from simpler to complex concepts). The topic on rainbow is learnt only in grade XII physics through ray diagrams and lecture method was used to teach this topic. Through researcher's teaching experience, it was found that as a result of lecture method used in teaching this topic, students could not answer correctly in the exam to the questions related to rainbow formation. Researcher concerned that if students fail to understand well about this interesting and simple topic then it is obvious that students would face difficulty in learning other physics topics that are least interesting and complex.

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It was suggested that attention of children could be captured by creating rainbow through demonstration (Planinšič et al., 2008). In addition Durbin, Pickett, and Powell (2011) said that formation of explanations and development of understanding in children about the world and characteristics of objects begins only after physically encountering it.

Furthermore, Ruby (2001) found that learning achievements in science content can be improved through hands-on. Hands-on activities provide practical opportunity to the students to apply knowledge as well as opportunity to exchange the knowledge acquired (Ates & Eryılmaz, 2011). According to Millar (2010) he specified that, if seen from students' practical activity perspective then science cannot be learnt by the students through doing only. In good science education, hands-on activities are necessary but they are not enough (Brown & Abell, 2013). An approach should also be included along with activities to make learners think critically in a more inquiry-led approach. As a consequence, the approach encourages children to think and pose their questions regarding the physical world. Moreover, through their own effort be able to seek answers to them, in so doing, makes them more independent and self-reliant (Science Curriculum Framework PP-XII, 2013; Hassard & Dias, 2008). Therefore, researcher hoped that students would be shifted from mindless memorization to comprehension and appreciation on the rainbow topic through the use of active learning method and model for hands-on learning, thereby enhancing students' conceptual understanding on this topic and motivating students to learn physics in long run.

Every teacher knows well that all children do not learn any particular subject in the same way. Students in a class differ in their learning ability. So, it is important for a teacher to use variety of teaching methods in order to reach all the students effectively. Using a variety of teaching methods keeps children from being bored, and helps them encounter the information in new and exciting ways. A variety of teaching strategies, knowledge of student levels, and an implementation of which strategies are best for particular students can help teachers to know which teaching methods will be most effective for the class (Nsamenang, & Tchombe, 2012).

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There are several teaching methods developed based on inquiry learning such as 5E learning cycle, POE learning cycle and so on. According to Budprom,

Suksringam & Singsriwo (2010); Trundle, Atwood, Christopher & Sackes (2010) they say that 5E learning cycle is derived from constructivism and helps in promoting conceptual change. It was also reported that this instructional model showed gains in learning achievement of the students as well as critical thinking and basic science process skills. The five phases of 5E learning cycle are as given in Table 1.1 that includes: Engagement, Exploration, Explanation, Elaboration and Evaluation (Bybee, Buchwald, Crissman, Heil, Kuerbis, Matsumoto, & McInerney, 1990). As in any cycle, there is really no end to the process. After elaboration ends, the engagement of the next learning cycle begins. Evaluation is not the last step. Evaluation occurs in all four parts of the learning cycle.

Table 1.1 The five phases of 5E learning cycle

Engagement	Object, events or question used to engage students. Connections facilitated between what students know and can do.
Exploration	Objects and phenomena are explored. Hands-on activities, with guidance.
Explanation	Students explain their understanding of concepts and processes. New concepts and skills are introduced as conceptual clarity and cohesion are sought.
Elaboration	Activities allow students to apply concepts in contexts, and build on or extend understanding and skill.
Evaluation	Students assess their knowledge, skills and abilities. Activities permit evaluation of student development and lesson effectiveness.

Adapted from Bybee et al. (1990)

For students to learn more quickly and engaged in the lesson it is important for a teacher to find the best teaching method for a particular group of students. This can be done if a teacher have teaching experience with a particular group of students for some time, enabling teacher to easily identify a method that is suitable with students' interests, ability levels, and learning styles. The effectiveness of the use of learning method also depends on the age of the children, provided that children are able to write answer or explain the answer. Hsu, Tsai, and Liang (2011);

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Coştu, Ayas, and Niaz (2011); Ayvacı (2013) presented the effectiveness of one approach named Predict-Observe-Explain (POE) learning cycle with hands-on activities. They suggested that that POE learning cycle was suitable for the topics that are "hands-on". This learning cycle has been found to probe students understanding through prediction, observation and explanation. It was also found to expose learners' prior knowledge of the concepts (Tlala, 2011; Wu & Tsai, 2005), achieve better conceptual understanding and enhanced retention of new concepts in long-term memory (Coştu et al., 2011). Therefore, predict-observe-explain (POE) learning cycle was used in this research study mainly because it was suitable with the topic, as it had to be taught through hands-on. There are also several other reasons for using POE learning cycle in this study. They are, the method was simple to follow by the students, large amounts of material could be covered in a short period of time, it was extremely student-centered and students could work together in small groups. Students were not grouped by ability, but put in a group with children at a variety of levels. The students are then given tasks to accomplish together. Teachers monitored these groups carefully, to make sure they are staying on task and that all students are participating.

Therefore, a learning unit was developed by combining Predict-Observe-Explain (POE) learning cycle with model for hands-on learning to enhance students' conceptual understanding on rainbow formation. Researcher thus designed and implemented the conceptual understanding test (CUT). The six concepts that are covered in CUT are;

1) Spectrum formation by rain drop
2) Conditions for rainbow formation
3) Rainbow shape
4) Color sequence
5) Ray diagrams
6) Locating rainbow

Students' response to learning unit opinion survey questionnaire (LUOSQ) was used to find out the opinion of the students about the developed learning unit categorized under six themes.

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1) Topic and lesson
2) Teacher

3) Class activities
4) The learning cycle
5) The developed model
6) Overall learning unit

Moreover, the information from the response of the interview question was used to justify and support the realness of the concept learnt and justify the effectiveness of the developed learning unit used to learn the concept. The information collected from ten students in semi-structure interview questions were analyzed by categorizing under the theme concept, topic, method, model, teacher and overall view on learning unit.

1.2 Research Objectives

The objectives of this research study are as follow:

1) To investigate students' conceptual understanding about optical phenomenon on rainbow formation.
2) To investigate students' opinion on the developed learning unit.

1.3 Research Questions

This research study aims to investigate the following research questions:

1) What extent has the learning unit enhanced students' understanding on the concept about rainbow formation in nature?
2) What are the students opinion on the developed learning unit used in the lesson?

1.4 Framework of the Study

The framework of this study is shown in Figure 1.1. The focus of this study was to enhance the Bhutanese students understanding on the concept about rainbow formation in nature and investigate their opinion towards learning unit. The POE learning cycle was used as a guideline to design activities for learning about

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rainbow using models. To investigate students' conceptual understanding about the related concepts, the CUT was developed and implemented as pre-test and post-test to the students. To investigate Bhutanese students' opinion towards the learning unit, LUOSQ were developed and implemented after the post test.

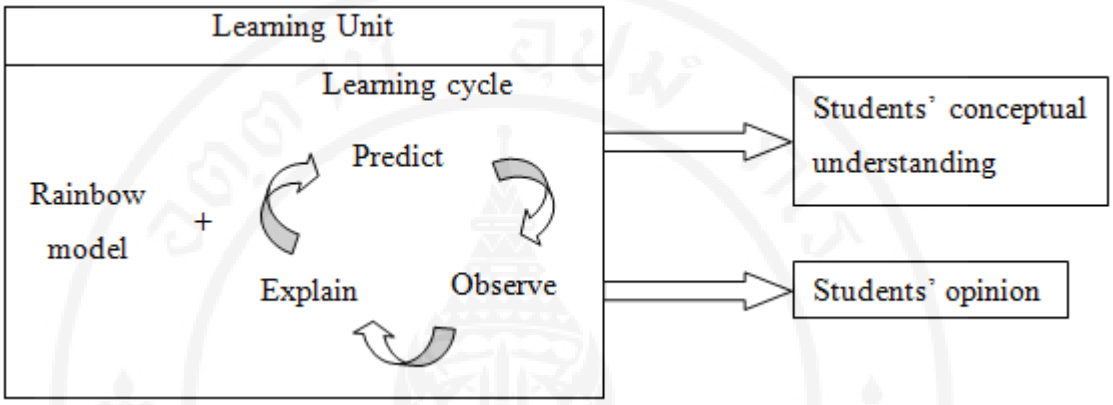

Figure 1.1 Framework of the study

1.5 Scope of the Study

This study focused on enhancing students' conceptual understanding about the natural phenomena on rainbow formation through the use of learning unit. The participants of this study were 120 Bhutanese students of grade XI science from one district in the academic year 2013. The activities were developed based on predict-observe-explain (POE) learning cycle.

1.6 Expected Outcomes

The expected outcomes of this research study are as follows:

1) The implementation of the developed learning unit is expected to help in enhancing students' understanding about rainbow formation. The result can be derived by analyzing the conceptual understanding test (CUT) items supported by the opinion of the students from learning unit opinion survey questionnaire (LUOSQ) items.

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2) The opinion of students can exhibit strong agreement with the items given in the learning unit opinion survey questionnaire (LUOSQ). The result can be derived from the analysis of the items in learning unit opinion survey questionnaire (LUOSQ) supported by the students' responses in the interview.

1.7 Definition of Terms

Conceptual understanding is what learners know and understand about a concept, that is; the generalizations learners can develop about the nature or properties of that concept. D'Avanzo, (2008); Godino (1996) define conceptual understanding as "the ability to describe the relationship among the concepts, to elaborate knowledge and recognize the applications of the learned scientific concepts and phenomena in everyday life situations".

Hands-on science is defined as "any instructional approach involving activity and direct experience with natural phenomena or any educational experience that actively involves students in manipulating objects to gain knowledge or understanding" (Haury & Rillero, 1994).

Constructivist teaching and learning: is teaching and learning approach that considers the learners as actively making meaning and constructing new knowledge based on existing knowledge within an individual, either individually or socially (Gray, 1997)

Social constructivism emphasizes the importance of culture and context in understanding what occurs in society and constructing knowledge based on this understanding (Andrews, 2012; Kim, 2001).

Predict-Observe-Explain (POE) learning cycle method is a teaching-learning strategy proposed by White and Gunstone (1992), which includes three stages: Prediction, Observation, and Explanation. First, students predict and justify their prediction. Second, they observe what they see happen and third they reconcile any discrepancy between their prediction and observation.

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Science learning unit is a science learning lesson made from elements that has at least one learning outcome. Learning outcomes are statements of what a learner knows, understands and is able to do on completion of a learning process. Learning

outcomes are defined in terms of knowledge, skills and competence. A learning unit provides a short or a long-term conceptual model depending on the content. The advantage of the learning unit is to give teachers the opportunity to advance plan, to think holistically about the content and its delivery. It makes lesson planning more efficient and effective. Learning unit in this study was created using POE learning cycle and model for hands-on learning on the topic of rainbow formation.

Conceptual understanding test (CUT) is two-tier multiple choice questions to investigate students' understanding of the concepts on rainbow formation. Literal understanding is not desired or expected to accomplish in this study. Literal understanding means the person is fixated on the meaning of words and does not perceive the ideas or intentions behind the communication very well. Instead real communication and learning (understanding the concepts) is desired. Having achieved conceptual understanding, the student will have achieved the ability to evaluate and judge data from his own point of view. To make such a high level of communication possible it is equally important that the student understands the words or symbols used. Each word used should be understood by the student to a point where the student not only knows the definition but is able to understand the word itself conceptually.

Learning unit opinion survey questionnaire (LUOSQ) is opinion survey questionnaires that ask students about statements regarding learning unit they may or may not agree with.

A rainbow is an optical and meteorological phenomenon that is caused by both reflection and refraction of light in water droplets in earth's atmosphere, resulting in a spectrum of light appearing in the sky.

Reflection is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated. It is also defined as a phenomenon of light travel where by light rays or beams are redirected to a different path when they encounter a shiny surface.

Refraction is the bending of the path of a light wave as it passes across the boundary separating two media. Refraction is caused by the change in speed experienced by a wave when it changes medium.

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The normal line is the line drawn perpendicular to the reflective surface of any object, or the boundary where refraction occurs at the point of incidence of a light ray.

The incident ray is a ray (drawn perpendicular to the wave fronts) that shows the direction that light travels as it approaches the boundary.

The refracted ray is a ray (drawn perpendicular to the wave fronts) that shows the direction that light travels after it has crossed over the boundary.

The angle that the incident ray makes with the normal line is referred to as the angler of incidence (i).

The angle that the refracted ray makes with the normal line is referred to as the angle of refraction (r).

The angle of deflection (θ) is the angle between the original direction of the light ray and its direction after striking the rain drop.

1.8 Summary of Organization of the Thesis

The aims of this study was to investigate to what extent students' conceptual understanding about optical phenomena on rainbow formation in nature was enhanced through the use of learning unit and to investigate opinion of the students about the learning unit used in this study.

This thesis is organized into six chapters as follows:

Chapter one provides the significance of the research study. This part includes research objectives, research questions, definition of terms relevant to this research study, framework of the study, scope of the study, expected outcomes and summary of organization of the thesis.

Chapter two provides literature reviews related to the scope of this study. The review involving teaching physics around the world, teaching physics in Bhutan, Bhutanese physics curriculum and studies about rainbow are described. This chapter also describes about hands-on activities and elaborates on the social constructivism theory and POE learning cycle.

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Chapter three covers the description about the construction and working of model used in this study. It also describes the methodology and methods employed in

the studies including research design, participants, instruments, data collection and data analysis.

Chapter four describes about the results and discussions of this research study.

Chapter five presents the conclusion of this research study. This chapter also provides the limitation of this study and recommendations for future studies and development.

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CHAPTER II
LITERATURE REVIEW

Overview

There are seven main sections in this chapter. The first section starts with teaching and learning physics around the world followed by teaching and learning physics in Bhutan in the second section. The third section provides the study about rainbow in Bhutanese curriculum. The forth section explains about rainbow studies. The learning theory is presented in the fifth section followed by POE learning cycle in the sixth section and finally the hands-on learning is described in the seventh section.

2.1 Teaching and Learning Physics Around the World

McDermott noted that science in elementary high school till late 1950s and 1960s were mostly of reading and rote learning. In order to help new science teachers identify concepts that affected with learning, she set up physics education group in the physics department at the University of Washington, Seattle, which became her major work. After the formation of physics education group it was hoped that student can be shifted from mindless memorization to comprehension and appreciation using the tools of physics in teaching (Wieman & Perkins, 2005).

The emphasis of Physics education research (PER) was on student understanding of the science content (Lillian, Christie & McDermott, 2001). It originated from two professions, pedagogy in general and physics instruction in particular. The purpose of PER was to improve existing techniques and to innovate methods of teaching physics.

Many physicists enrolled in this emerging field of physics education and now small research groups active in this field exist in several physics departments (Beichner, Hake, Redish, & Risley, 1995). Many organizations were also established

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to deal with the development of physics since 1997 (Sharma, Swan, Pollard, Mendez, & Byrne, 2009). The details of the projects are as follow:

In 1981, UNESCO established a co-operative network of physics academics in the Asia-Pacific region. The group, with representatives from 10 member countries, was named ASPEN: the Asian Physics Education Network. The main goal of ASPEN was to promote the development and improvement of university physics education in the Asian region, especially in developing countries (Alarcon et al., 2005).

Steenstrup, dalle Rose, Jones, Tugulea, and van Steenwijk (2002) conducted a comparative study in the year 1997 and 1998 with many universities across Europe to look at the differences and similarities between physics studies under the project name the European Physics Education Network (EUPEN).

In 1997 and 1998 academic year to obtain a good functional understanding of fundamental concepts in physics and mechanics in particular a project was started with support from the Council for Renewal of Undergraduate Education especially to develop experimentally based physics instruction using hands-on experiments and computers (Bernhard, 2005).

In 2000 and 2001 the Institute of Physics (IOP) carried out inquiry into Undergraduate Physics in the United Kingdom.

In 2001 and 2002 the American Association of Physics Teachers (AAPT) established the National Task Force on Undergraduate Physics (Sharma et al., 2009).

Besides establishment of the projects mentioned above following are some of the physics education researches carried out related to teaching and learning physics.

The Physics Education Group at the University of Washington was deeply involved in preparing K–12 teachers to teach physics and physical science by inquiry (Lillian C. McDermott, Shaffer, & Constantinou, 2000).

In the paper “Computational Physics: A Better Model for Physics Education?” findings claims that on comparing computational physics major with traditional physics major, the former provides a broader, balanced, and flexible education than the later. Moreover, in teaching physics, presenting it within a

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scientific problem solving paradigm was found to be more effective and efficient way than the traditional approach (Landau, 2006).

Similarly in introductory college physics, to compare the use of traditional educational resources in lecture and laboratory with simulation, a project called "High-Tech Tools for Teaching Physics: the Physics Education Technology (PhET)" was set up. This project introduced new suite of computer simulations, identified features of these educational tools and demonstrated their utility (Finkelstein, Adams, Keller, Perkins, & Wieman, 2006).

Williams, Stanisstreet, Spall, Boyes, and Dickson (2003) in their study discovered that the general reasons for finding physics uninteresting by the students was physics for most of them was seen as difficult and irrelevant. They also stated the cause for losing interest in physics and the ways to enhance students' interest in physics.

According to Ornek, Robinson, and Haugan (2008) the reason for finding physics difficult by the students was to the students physics was new. To address this issue they suggested that first, the faculty members must understand the way students think about physics courses and approach physics. Second, curriculum should be designed in a way that can assist students to learn physics concepts and improve physics problem solving. Third, even if the students find physics difficult the faculty members should know how to reach to students and make physics concepts be understood by them. Furthermore, as suggested by (Dömény, 2010) finding an interesting topic that stirs enough the curiosity in students would motivate students to learn physics better.

Since the formation of physics education group by McDermott, several groups and organizations were established to deal with the improvement and development of physics. These groups also carried out researches related to teaching and learning physics. They found that physics for most of the students were uninteresting as it was difficult and irrelevant. Physics was seen as difficult subject because it was new to the students. Therefore, teacher has to connect students' existing knowledge with the concept to be taught so as to make physics concept more familiar and be understood by the students.

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2.2 Teaching and Learning Physics in Bhutan.

Science education in Bhutan started with the introduction of modern education in 1960s. In 1986, 'New Approach to Primary Education' (NAPE) was launched to make primary science curriculum for grade IV to VI into Bhutanese context so that science can be taught based on Bhutan's natural and social setting.

Having implemented for fourteen years, general public criticized that primary science textbooks, manuals and teaching guides were lacking content. So, in 2001, to add content and make learning activities more relevant, textbooks were revised. Moreover, to include more and better quality scientific information, teaching manuals were also revised simultaneously (Johnson, Childs, Ramachandran, & Tenzin, 2007).

The students in Bhutan learn science right from pre-primary (PP) as environmental studies (EVS) in Dzongkha (national language of Bhutan) as a medium of instruction. From grade IV onwards to till grade VIII it is studied as Science. In grade IX and X students studies advanced courses in science through three disciplines: Physics, Chemistry and Biology. While, at grade XI and XII, science studies is offered with Physics and Chemistry as elective subjects and Biology as an optional. The curriculum at this level offers specific subject syllabi designed to meet the needs of students as they prepare for university studies, training and employment.

The students of Bhutan learns same subject till grade X and after that they take up different streams namely Arts, Commerce and Science. Those students who opt for science in grade XI and XII, similar topics in science are continued as learnt in lower grades but in advanced level. In next section the details of the physics curriculum in Bhutan for grade X and XII are presented.

2.3 Study about Rainbow in Bhutanese Curriculum.

The Physics curriculum of Bhutan are arranged into different key stages based on the developmental stages of children underpinning the principle of how children learn and the learning standards they are expected to achieve (Science Curriculum Framework PP-XII, 2013). Hence, many topics in physics are studied part by part in different grade levels depending on the difficultness of the concepts and

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learning standard expected to achieve as can be noticed from the physics curriculum of grade X and XII mentioned below;

2.3.1 Middle secondary school level

In Science Curriculum Framework PP-XII (2013), the physics content Bhutanese grade X students have to learn in physics are given and the names of fifteen chapters are as follows:

Chapter 1	Force
Chapter 2	Work, Power and Energy
Chapter 3	Machines
Chapter 4	Pressure in Fluids
Chapter 5	Archimedes' principle
Chapter 6	Refraction of Light
Chapter 7	Lenses
Chapter 8	Photographic camera and the Human Eye
Chapter 9	Spectrum and colors
Chapter 10	Sound
Chapter 11	Current Electricity
Chapter 12	Electrical Energy, Electrical Power and Household Circuits
Chapter 13	Magnetic Effect of Current
Chapter 14	Calorimetry
Chapter 15	Modern Physics

From the chapters given above it can be understood that grade X students in Bhutan do not learn about rainbow, but they certainly learn about some basic properties of light. These concepts are required as pre-requisite knowledge in students to learn about rainbow formation. The requirement corresponds to the chapter six about refraction of light and chapter nine about spectrum and colors

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2.3.2 Higher secondary school level

There are twelve chapters in Grade XII physics text books and the names of each chapter are as follow:

Chapter 1	Electrostatics
Chapter 2	Current Electricity
Chapter 3	Magnetism
Chapter 4	Electromagnetism
Chapter 5	Electromagnetic Induction and A.C. circuits
Chapter 6	Wave Optics
Chapter 7	Ray Optics and Optical Instruments
Chapter 8	Electrons and Photons
Chapter 9	Atoms
Chapter 10	Nuclei
Chapter 11	Nuclear Energy
Chapter 12	Semiconductor Devices

The topic on rainbow formation is studied under "chapter seven: Ray Optics and Optical Instruments" under the sub topic "Dispersion" (The syllabus for Classes XI and XII, 2009).

2.4 Rainbow Studies

2.4.1 Brief history on the studies of Rainbow

Humans have always been fascinated by rainbows for its beautiful color (see Figure 2.1). It is evident from ancient literature of these phenomena given as mythology, cultural beliefs or religious interpretations. In Greek mythology, rainbows were assumed as the ladder for Iris, the messenger of gods (Blake, 2005). In Norse mythology, rainbows were assumed as Bifröst bridge connecting the homes of the gods and humans (Sarapik, 1998). Irish leprechauns were said to hide their gold at the end of a rainbow. According to the Mohave of Arizona rainbow is assumed to be a toy or charm used by the Creator to stop rainstorms. Tribes in northern California warn their children not to count a rainbow's colors otherwise their fingers will become crooked and fall off. They also believe that if a medicine person who walks through a rainbow, healing power is bestowed upon that person (Bastian & Mitchell, 2004).

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After Greeks began to speculate scientifically in the 6th century BC, the physical theories about rainbows and other meteorological phenomena came into vogue, starting with Anaximenes' doctrine about the rarefaction of air into fire and its condensation into clouds and then water (Stothers, 2009).

It was Aristotle who first attempted to explain about the formation of the rainbows. He said that the rainbows are formed by the reflection of sunlight from clouds. He could explained the circular shape of bow stating that light is reflected at a fixed angle giving rise to a circular cone of rainbow rays.

Figure 2.1 A picture of a rainbow (photograph taken by researcher few days before data collection. The red color is outside the bow and distinct violet color inside)

In 1266 Roger Bacon measured the angle formed and he found the angle to be about 42 degrees and the secondary bow from his measurement was found to be 50 degrees in the sky. These days the angles are measured from opposite direction, so as to measure the total change in the direction of the sun's rays. Therefore, the angle of the primary bow is 138 degrees and known as the rainbow angle.

In 1304 a German monk Theodoric of Freiberg did an experiment with a spherical flask filled with water. In doing so he could traced the path followed by the light rays that make up the rainbow and concluded saying that every single drop is capable of producing a rainbow. Hence, Aristotle's hypothesis about rainbow formation as collective reflection of light rays from raindrops in a cloud was rejected.

In 1637, Rene Descartes explained the paths taken by light rays through the raindrop (Sarapik, 1998). He employed the same method as Theodoric but independently rediscovering that to form primary rainbow the light rays is reflected once at the back of the drop. The secondary rainbow is formed by two internal reflections. He also gave the reason for fainter secondary bow as losing of some light during reflection (Khaparde & Pradhan, 2009).

Theodoric and Descartes during experimentation with spherical flask filled with water observed that only one color at a time could be seen. When the eye was moved to a new position other colors appeared one by one. Thus they concluded that different colors in the rainbow come to the eye from a different set of water droplets.

In 1600 Isaac Newton demonstrated that white light is composed of different color light with the help of a prism. When a thin beam of light rays was made to fall on the prism he observed the formation of spectrum. This phenomenon of forming spectrum is called dispersion of light. Newton explained that wavelength dependence of the refractive index of the raindrop produces the colors of the rainbow (Davies, Wannell, & Inglesfield, 2006).

The study on rainbow was then followed by Young, Airy and Mie subsequently. With Young's interference, it was able to explain the supernumerary bows based on a wave theory of light. In the beginning of the 19th century Airy showed that the wave front emerging from a water droplet is well approximated by a cubic law near the ray of minimum deviation. The exact solution of the rainbow problem shows only minor deviations from Airy's results with the observed features of

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the rainbow for droplet diameters larger than a few tenths of a millimeter (Konnen & Boer, 1979). Finally, with the coming up of Lorentz-Mie theory, the exact solution for the scattering of a monochromatic electromagnetic plane wave by a spherical particle in the form of an infinite series of partial wave contributions could be solved (James A. Lock, 2011).

Nowadays, based on theories and calculations, scientists and physicist have come up with the photographic evidence of higher order rainbows such as tertiary and quaternary rainbows adding many literatures about rainbows but surprisingly very limited papers are available on educational aspects about teaching this phenomenon to the children. Therefore, models were developed based on physical and geometrical facts associated with this phenomenon to be used in teaching about rainbow formation to the children. To understand more about physical and geometrical facts that take place during rainbow formation, it is discussed in the following two sections as conditions necessary for rainbow formation and theoretical aspects of rainbow formation consecutively.

2.4.2 Conditions necessary for rainbow formation

A rainbow is seen when raindrops scatter the sunlight back to an observer's eyes with separated colors. If the clouds are darker behind the rain, the rainbow will be more intense and prominent. The higher an observer is and the lower the sun as in sunrise or sunset, higher will be the position of the bow. Likewise, in an aircraft a complete circle rainbow could be seen (Maunder, 2007).

Beeson & Mayer, (2008) said that "since the sun was behind and the rain in the front, the sunlight must have been bouncing off the raindrops and reflecting into observer's eyes". From this statement it is understood that to form a rainbow there has to be sun as well as raindrops. The relative positions of sun and raindrops with respect to the observer must be at back and in the front respectively. The sun has to be above and behind and the raindrops somewhere in the front, if not falling onto the observer at the time. The beautiful color exhibited by nature in the form of rainbow is because of raindrop, sunlight and some angles to which it is directed to an observer eyes. Therefore, brief properties of sunlight and shape of raindrops are discussed below and rays' path is discussed in the section under theoretical aspects of rainbow formation.

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The sunlight is an electromagnetic (EM) wave composed of many different frequency components and usually appears white in day time. These different frequency components correspond to different colors. Human eyes detect electromagnetic waves ranging from 360 nm (violet color) to 750 nm (red color). It is called visible spectrum. From red to violet, the frequency increases from about 450 THz to 750 THz (Zerihun, 2007).

The speed of electromagnetic waves in vacuum, $c = 2{,}99792458 \times 10^8$ m/s, is one of the most important constants in physics. When light travel through a medium the speed changes and it is always smaller than the speed of light in vacuum. All materials are characterized by their ability to slow down the light waves, known as optical refractive index (μ) (Harizanova & Nedev, 2012).

The index of refraction of water changes for EM waves with different frequencies. A raindrop has variant indices of refraction for EM waves with different wavelengths or frequencies as shown in Table 2.1.

Table 2.1 Indices of refraction of water for different color lights

Color	Red	Orange	Yellow	Green	Blue	Indigo	Violet
Refractive index	1.33257	1.33393	1.33472	1.33659	1.33903	1.34055	1.34451

Source: http://www-ee.eng.hawaii.edu/~zqyun/caevpython/buildarainbow.pdf

It is known that a range of forces exerts on a raindrop, including those due to fluid flow (both inside and outside the drop), hydrostatic forces, and electrostatic forces. In the absence of forces other than surface tension, a raindrop will attain a perfectly spherical shape. Study also found that a falling raindrop deviate its shape from spherical to become a flattened oblate spheroid (Jones, Saylor, & Testik, 2010). Parker (2012) said that oblate spheroid or hamburger-shaped raindrops creates twin rainbows having two rainbows arcs that split from a single base rainbow, which is a rare phenomenon.

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Many assumes shape of a raindrop to be tear-shaped but studies have found that tear-shaped raindrops cannot be normal feature in rain cloud because of high surface tension of the water pulls them into spheres in very short order (Maunder,

2007). According to Lim (2006), he explains that if a drop falls from a surface it first assumes the shape of a tear but gradually it would take somewhat spherical form, and then distort to a shape like a hamburger shape. This is mainly because of the drag force on the falling drop causing it to be flattened.

Nussenzveig (1977); Lim (2006); Maunder (2007) assumes that the raindrops has to perfectly spherical for a bow to be seen. According to Maunder (2007) if the rain storm is heavier it is better to form perfectly spherical shape because the drops will be larger, well separated from its neighbor (unlike a mist) and in free-fall. These larger spherical drops produce the narrow but intense colored rainbow.

This is why shape of raindrops is one determining factor to see a rainbow. Even small departures from sphericity destroy a rainbow or possibly cause some odd effects such as twin rainbow. Hence to see a rainbow the rain drops has to be perfectly spherical. Again rainbows are not always seen even if the conditions are perfect like spherical raindrops in the front of the observer and sun behind. Another condition to see a rainbow depends on the angles to which lights are directed to an observer eyes. To understand this, knowing about light's path in rain drop is essential and it is discussed in the following section.

2.4.3 Theoretical aspects of rainbow formation

2.4.3.1 The path of light in a rain drop

The light rays follow countless paths in a rain drop. Each path is characterized by this bending towards and away from the normal. The path that is of great importance in rainbow formation is the one which refracts into, internally reflects, and then refracts out of the rain drop.

Figure 2.2 shows that light rays from sun at P incident on the rain drop at Q. They are refracted as they enter the drop at Q and are then reflected inside the drop at the air-water interface at R. The rays are refracted a second time as they leave the rain drop at S to the observer at T. This is how the light rays take the path in the rain drop to form intense primary rainbow due to one reflection. The weaker secondary rainbow is formed by reflecting twice inside the drop (Davies, Wannell, & Inglesfield, 2006).

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2.4.3.2 The angle of deviation (θ) of light rays through a drop

In Figure 2.2 the dashed lines N_1, N_2, and N_3 are normal drawn perpendicular to the surface of the sphere at points Q, R, and S from the center O. Consider a ray of light entering at point P and refracted into the drop at point Q. The ray hits the back of the drop at point R and is reflected to point S. There, it is refracted out of the drop and leaves at point T. The ray is now emerging at angle theta (θ) which is the rays' total deflection/deviation. First, notice that the triangles OQR and OSR are congruent isosceles triangles as the angles OQR and OSR are the same (r incident = r reflected), and because line segments OS, OQ and OR are all the same length. This means that angles ORQ, OQR, OSR, and ORS are all the same.

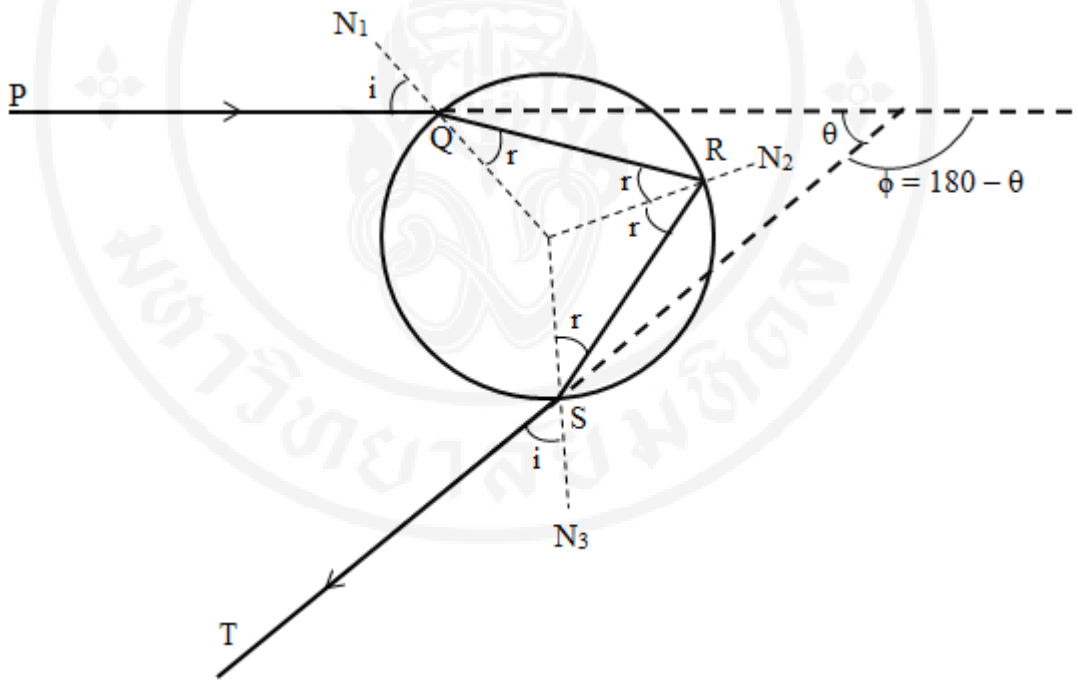

Figure 2.2 The light's path and angle of deviation (θ) by light ray in a rain drop.

Therefore, $\theta = 180° - \phi$

$\theta = 180° - (180° + 2i - 4r)$

$\theta = 4r - 2i$ (1)

Based on experiment and calculation it was found that the angle of deviation for red light in water drop was approximately 42 degrees and that of violet light was 40 degrees (Maunder, 2007; Laven, 2012).

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2.4.3.3 The incident angle on a drop

Consider a beam of sun ray incident on a spherical drop and let the angle of incidence be i (see also Figure 2.2). Part of the incident ray is reflected from the surface and part is refracted into the drop. Let r be the angle of refraction. The refracted ray will meet the water-air surface where it will again be partially refracted into the air and partially reflected back into the interior of the drop. The ray will continue to undergo multiple reflections inside the drop, losing intensity at each encounter with the water-air surface.

From Figure 2.2 the exit angle θ can be calculated by adding the deviations of the ray each time it meets the water-air interface. The deviation of the incident ray when it refracts into the drop is i – r. It also experiences the same deviation i – r when it comes out from the drop into the air. The ray that emerges from the drop after two refractions has a deviation of 2(i – r). The deviation for a reflected ray is 180 – 2r. Thus the total deviation in first order rainbow with one reflection inside the drop is

$$\Phi = 2(i - r) + (180 - 2r) \quad (2)$$

The exit angle for a ray that undergoes k reflections inside the drop before being refracted into the air is

$$\Phi_k = 2(i - r) + k\,(180 - 2r)$$

We can write; $\Phi_k = 2i + k\,(180) - 2r\,(k + 1)$ (3)

Since the angle r is a function of i and μ, the exit angle is a function of i, k and μ. Light reflected once inside the drop, k = 1, is customary referred to as “light of first order”; “light of second order”, k = 2, is reflected twice inside the drop. Each order has a minimum exit angle; customary called the Cartesian angle θCk. In order to find the incident angle that produces the Cartesian angle, the angle r must be eliminated from Eq. (3) using Snell’s law. The corresponding incident angle i; Ck is given by;

$$\theta i;\ Ck = \arccos\sqrt{\frac{\mu^2 - 1}{k(k+2)}} \quad (4)$$

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Thus for k = 1, $i = \arccos\sqrt{\frac{\mu^2 - 1}{3}}$

$$k = 2,\ i = \arccos\sqrt{\frac{\mu^2 - 1}{8}}$$

$$k = 5,\ i = \arccos\sqrt{\frac{\mu^2 - 1}{35}}$$

2.4.3.4 The angle refracted in a drop

The angle of refraction can be found out using Snell's law;

$$\mu = \frac{Sin(i)}{Sin(r)}$$

Therefore; $r = \text{Sin}^{-1}\left(\frac{Sin(i)}{\mu}\right)$ (5)

Putting the values obtained from Eq. (4) and Eq. (5) in Eq. (1) the rainbow angle in a drop can be calculated.

In this study, students used Eq. (1) and Eq. (5) for calculating θ for violet and red light for glass sphere and compared with the findings obtained through observing from the model. Finally the knowledge student gained from the model was used for learning and understanding about rainbow formation. But to have meaningful learning in students it is very important to know how learners learn. Therefore, the following section describes about learning theory.

2.5 Learning Theories

Learning theory is defined as conceptual framework that describes how information is received, processed, and retained during learning. The definition of learning depends on the orientation of the definer. Behaviorist defines learning as the alteration of behavior due to experience. The way the informations are perceived, retained, explained and retrieved is learning according to cognitive psychologist. Humanistic psychologists hold that learning takes place with personal growth and development, while constructivists reason that learning is concerned with how people develop different conceptions and constructions of reality (Brown, 2004). Historically, science education has moved between the three broad theoretical

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frameworks of learning: behaviorism, cognitive constructivism and social constructivism.

Ivan Pavlov (1849-1936), Edward Lee Thorndike (1874-1949) and Burrhus Skinner (1904-1990) are behaviorists and they hold that experience brings behavioral change and according to them they consider that scientific learning is a behavioral change induced through appropriate stimuli.

Jean Piaget's works are mostly based on cognitive constructivism. According to him humans cannot immediately understand and use informations provided to them, instead they must construct their own knowledge (Piaget, 1952). Similarly relating his theory in scientific learning would mean that to construct scientific concept children must put logical thought to the results of interaction with objects and phenomena.

The works of Lev Semenovich Vygotsky (1896-1934) are based on sociocultural theory. Theory if applied to science learning would mean that specific social and cultural context of the child bounds the learning of science. It presumes that learning takes place between people first and then in the individual. Murphy (2012) argued that repeated experiences do not form scientific concepts instead it is formed by combining the experiences with intellectual operations guided by language.

Since this study focus on students' conceptual understanding, the study is grounded on the theoretical perspectives of learning and understanding. Learning and understanding results from knowledge being formed from bits of information that are arranged into sections for the creation of personalized meaning. Therefore, it is important for teachers to identify the prior knowledge the learners bring into the classroom and the concept the teachers wanted to teach so that learners can assimilate the ideas easily (Vygotsky, 1978). Since social constructivism views the origin of knowledge construction as being the social intersection of people, interactions that involve sharing, comparing and debating among learners and mentors which accentuates the supportive guidance of mentors as they enable the apprentice learner to achieve successively more complex skill, understanding, and ultimately independent competence. It is also important for teacher to understand the mentoring component for learners to refine their own meanings and help others find meaning. In this way

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knowledge is mutually built. This view is a direct reflection of Vygotsky's (1978) sociocultural theory of learning as explained in the next section.

2.5.1 Vygotsky's model of social constructivism

Vygotsky (1978) explained three main concepts in his model of social constructivism. They are;

1) The zone of actual development (where the child actually and currently is developing mentally)

2) The zone of potential development (where the child potentially should or could be developing under the guidance of adult or together with more capable peers) and

3) The zone of proximal development (for a child to move from zone of actual development to zone of potential development certain amount of assistance is required, this amount of support is the zone proximal development).

Veresov (1935) said that understanding the zone of proximal development means really understanding what Vygotsky meant by development in general, so to elaborate the zone of proximal development "is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978). It is for this reason that learning in a social constructivist model has a strong mentoring component.

Vygotsky (1978) further elaborates that through social interaction humans acquire knowledge first and then it is internalized within an individual mind thereby converting the social knowledge into personal as quoted here, "at the beginning of each age period, there develops a completely original, exclusive, single, and unique relation, specific to the given age, between the child and reality, mainly the social reality that surrounds him. The social situation of development represents the initial moment for all dynamic changes that occur in development during the given period. It determines wholly and completes the forms and the path along which the social becomes individual" (Vygotsky, 1978).

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Vygotsky asserted that any given social situation cannot be considered as the social situation of development. For a social situation to be considered as social

situation of development there has to be specific relation. To understand this specific relation he explained that if a child is provided with a certain set of very new demands, tasks, and challenges by the social surrounding, and if the child does not have enough ways and techniques to follow the demands, resolve the tasks and face the challenges then there is a conflict (contradiction or dramatic collision) between the level of development of a child and the demands of the social surroundings. The contradiction is present in the relations between child and the child's social surrounding and its demands. "Drama" is the keyword used for this and it is a form of relation that exists between the child and the social surrounding (social situation of development). This relation represents the initial moment for all dynamic changes that occur in development during the given period and it defines wholly and completes the path along which the socially acquired knowledge becomes individual. Therefore, without this specific relation, the social situation is not the social situation of development as given, "The basic principle of the operation of the higher psychological functions (personality) is a social interaction… They can be accomplished to the full extent in the form of drama" (Vygotsky, 1978).

2.5.2 Social constructivism in education.

Through Vygotsky's work it can be understood that he was more interested in understanding about human learning with respect to the social and cultural conditions. Thus, social constructivism is considered to be closer to the concerns of educators. Vygotsky maintained that children are small adults as their minds work like adults but in a different way from those of adults. So teacher should always be challenging the children as Vygotsky contended that learning actually leads to development.

Form Vygotsky's point of view it can be understood that in learning science, using skills-based and hands-on will not help children to develop concepts unless the lessons are contextualized within an appropriate conceptual framework. Then only children can make out meaning from their experience. They can keep on integrating new and similar experiences into their conceptual framework, as it becomes more familiar and concrete with each subsequent related experience (Murphy, 2012). Therefore, social constructivist learning theory holds that students'

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existing understanding should be considered when developing a program for teaching and learning as it can be easy for learners to assimilate the ideas the teachers brings to the learners and learner's prior knowledge as the ideas are near.

Given here are some of the roles of teacher and students should consider in this study in accordance with social constructivist theory; Teacher should consider the knowledge and experiences students bring to class as they begin their study with pre-conceived notions. Students should construct their knowledge through a process of active enquiry through use of a method. "Discovery' should be facilitated by providing the necessary resources like model for hands-on learning. Students should be provided assistance with assimilation of new and old knowledge because they have to accommodate and assimilate new information with their current understanding. A learning environment should be created where the students feel safe questioning and reflecting on their own processes. Students should support collaboration in constructing knowledge and not competition. Teacher must provide scaffolding at the right time and the right level. Knowledge should be actively constructed in groups as a process of active discovery as students need guidance through the zone of proximal development because in social constructivism tutors and peers play a vital role in learning therefore, students should also be provided with opportunities for more expert and less expert participants to learn from each other.

Hence, in social constructivism there are four central characteristics believed to influence all learning: 1) learners construct their own learning; 2) the dependence of new learning on students' existing understanding; 3) the critical role of social interaction and; 4) the necessity of authentic learning tasks for meaningful learning (Bruning, Royce, & Dennison, 1995; Pressley, Harris, & Marks, 1992).

The learner always tries to construct meaning or make sense of the new experiences by actively striving in it. To do this learner has to connect to what they already know about a topic. It is through active construction process that the learners develop knowledge; passive reception of information will not help in developing knowledge. In other words, every individual learner constructs their own understanding. In the process of constructing knowledge, the way the information is presented and the way learner is supported is very important. The pre-existing knowledge the learners has on particular topic is also essential because learners with

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the current understandings on the topic can provide the immediate context for interpreting any new learning on the particular topic.

In this research study there were 120 grade XI science students in total. The students comprised of heterogeneous mix, which vary widely in their knowledge and intellectual abilities. For the sake of convenience to carryout classes in small size, 120 students were randomly grouped into 3 groups of 40 students each. Based on the academic result of the students in grade X, the students in the class was then divided into ten groups of four students each. It was assured that each group comprised of heterogeneous mix of students, having high, medium and low achiever. The students were made to sit in groups in neat rows in front of the board. It was made sure that teacher conducts the lesson while standing at the front of the classroom. In this manner teacher and capable peer in group can provide necessary help and guidance.

In social constructivism context, the reason for forming group was, dialogue is believed to be the catalyst for knowledge acquisition. Understanding is facilitated by exchanges that occur through social interaction, questioning, explaining, and offering timely support and feedback. The use of cooperative learning and peer tutoring are extensively used by constructivists, believing that students will learn more readily from having dialogue with each other on given topics. Therefore, the groups were formed in this study to let students learn, by helping and supporting one another through respectful listening, discussion and encouragement.

Regarding students pre-requisite knowledge required for learning about rainbow formation, students should have to have some basic knowledge about reflection of light, refraction of light, critical angle, total internal reflection, angle of incidence, angle of reflection and angle of refraction. These concepts and terms they have already learnt in lower class. Moreover, these concepts were briefly discussed after pre-test for about 20 minutes, hoping that students can easily assimilate the new concept on rainbow formation with the concept and terms they already know during real intervention of the learning unit because students' can easily interpret any new learning through their prior understandings on the concept.

The method that was consistent with social constructivism theory that highlights the importance of prior knowledge, strong mentoring component, and

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construction of meaningful learning was found to be Predict-Observe-Explain (POE) discussed in the following section.

2.6 The Predict-Observe-Explain (POE) Learning Cycle

White and Gunstone (1992) proposed this learning cycle to probe students' understanding. It is called Predict-Observe-Explain (POE) learning cycle. In POE learning cycle students perform three tasks. First, they predict the outcome of some event or situation and provide reasons for their prediction. Crouch, Fagen, Callan, and Mazur (2004) said if students are provided some time to predict the outcome and record their predictions it helps students understand the concepts better. Second, they observe what they see happen. Finally, they reconcile any discrepancy between prediction and observation. White and Gunstone (1992) also said that the sequence of this learning cycle should not be changed or components not to be missed as they have meaningful connection with each other.

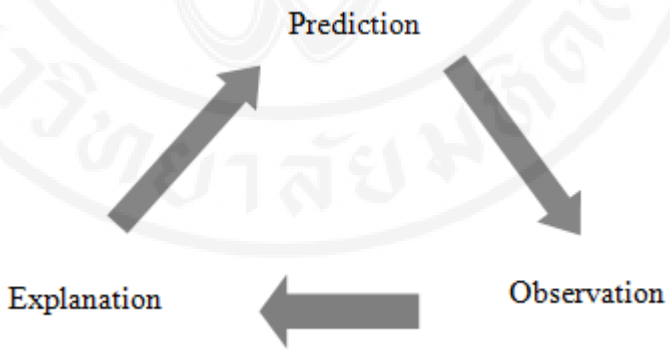

Figure 2.3 Diagram of POE learning cycle

Figure 2.3 shows the diagram of POE learning cycle that start with prediction. In this study to let students understand the concepts on rainbow formation better, researcher used the POE learning cycle with models for hands-on learning. Students got opportunity to explain their ideas and experience in their prediction phase and in observation phase they clarified and justified their own pre-conceptions in this study. In final phase, students got chance to explain their findings. Students also got

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opportunity to learn hands-on in groups with the model which offered more opportunities to share and negotiate their own personal interpretations.

Following are some of the advantages of using POE learning cycle. It can be used for finding out students' initial ideas (Tlala, 2011; Wu & Tsai 2005). Wu and Tsai (2005) added that this method provide opportunity to the students to interpret their new observations of the world around them, and then to share and negotiate their own personal interpretations. The findings also suggests that the use of this learning cycle helps students to understand the concepts better and retain new concepts in their long term memory (Coştu, Ayas, & Niaz, 2011). The study also found that use of POE learning cycle in the science classroom has are positive developments (Kearney, Treagust, Yeo, & Zadnik, 2001).

The POE method was used in this study for the following reasons; it encourages learner-centered lesson, focus is made on the outcomes of the learning process, critical thinking and reasoning skills of the students is stimulated, it also allow educators to act as facilitators rather than 'sage on the stage' or information transmitter. POE method was found to expose learners' pre-existing knowledge, provide opportunity to the students to observe new physical phenomenon, interpret and then share and negotiate their own personal interpretations. Study says that students' understandings of the concepts are mainly investigated using the POE method (Kearney et al., 2001; Palmer, 1995). It was also found that POE method is suitable in science lesson and it is the best teaching methods to use in both secondary and tertiary schools (Palmer, 1995). Any approach that emphasize on learner-centered approach is encouraged by Bhutanese education system and one such approach is POE method.

Here is a brief description of how the POE learning cycle was used in this study. Before class lessons, students were given individual activity sheet to write down their prediction and share their ideas to the class. Then, each group in the class was provided with a model, activity sheets and instruction sheets. The directions are given in the instruction sheet about how to carry out the activity using the model. Students write down their observation in activity sheet, discuss within their groups and then share the group's idea to whole class. Finally, students reconcile any discrepancy the groups have in their prediction and observation phase as well as discrepancy

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amongst groups. In general, students play an active role and accept more responsibility for their own learning.

The role of teacher in this class was, teacher introduced the lesson and provided direct instruction for about 5-10 minutes. After the direct instruction is finished, students work together in groups to solve the problems provided to them. At this point, the teacher becomes part of the social group, facilitating and encouraging students to work with one another. Wandering around the room, from group to group, the teacher guides the conversation while also getting an idea about how students are struggling. Teacher mediate and structure the class in such a way that peer interaction take place through collaborative learning. In general, teacher does not take the role of the "sage on the stage". Instead, teacher act as "guide on the side" providing students with opportunities to test the adequacy of their current understandings.

The only demerit of this learning cycle is, since it requires writing and explaining the answers, it is difficult to use with younger primary school students as they will face difficulty in communicating their ideas well. Study also pointed out that POE learning cycle was suitable with the topics that are "hands-on" (Hsu, Tsai, & Liang, 2011). The following section describes the meaning of hands-on learning and their advantages.

2.7 Hands-on Learning

Haury and Rillero (1994) define hands-on learning as learning by doing. With hands-on learning, learners actually "do" things to truly learn the concept. In science classes, hands-on learning is important as science is a process and if students are not actively engaged in the process, they are not doing science they are just learning the vocabulary of science and nothing else. Gupta (2011) said no other knowledge is profound than learning by experience. The children will be engaged in meaningful experience physically, intellectually and emotionally thereby learning best by imprinting the concepts deeply in their memory.

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The following are some of the benefits of hands-on learning; it motivates students to learn more and more, as a result improve their reading skills. Ruby (2001); Hussain and Akhtar (2013) found that learning and achievements in science content

increased through hands-on learning. Research also indicates that hands-on science improves students' attitudes toward science, as students in a hands-on science program remember the material better and feel a sense of accomplishment thus developing positive attitude towards science (Foley & McPhee, 2008). Hands-on activities were also found to increase skill ability in processes of science such as laboratory skills, drawing skills, graphing skills etc. Furthermore, hands-on science makes learning fun for both students and teacher although it requires more preparation time to develop a system for hands-on activity.

Brown and Abell (2013) said hands-on activity is necessary but not sufficient to help students to learn science. So, as pointed out by Hassard and Dias (2008); Science curriculum framework PP-XII (2013) hands-on activities should involve an approach to let learners think and be critical as a consequence will encourage them to become more independent and self-reliant. Ogan-Bekiroglu (2007) further advocated that when instruction is designed to actively engage students in activities, students develop more scientifically sophisticated understanding of natural phenomena.

Therefore, to let students learn about rainbow formation through hands-on, two models were developed and incorporated with POE learning cycle. The following chapter discusses about construction, components and workings of the two models.

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CHAPTER III
METHODOLOGY

Overview

This chapter describes about the construction, components and workings of the two models used for hands-on learning about rainbow formation. Moreover, this chapter also provides an overview of the description of research methodology including research design, participants, instruments, data collection and data analysis.

3.1 Model Development

3.1.1 The first model: indoor rainbow model

3.1.1.1 Construction of the indoor rainbow model

In the first indoor rainbow model the main body was made from black polypropylene (PP) corrugated board, also known as future board. The dimension of the main body was 30 x 40 x 10 centimeters. A 23W compact fluorescent light bulb (CFL) was used as light source. A glass sphere of diameter 10 centimeters was used as water drop. A rubber sucker and string was used to hold and suspend the glass at required height. A slider box attached to the main body by a slider which can be moved vertically up and down.

The important parts that can be seen on the slider box were protractor, a pointer and a telescope modified from binocular lens. The protractor was attached on the side of the slider box. Inside the slider box was fitted with a telescope and on the axil of the telescope a pointer was attached to make the reading of the angles on the protractor when the telescope was rotated partially.

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This model was constructed mainly to let students see the spectrum formed by a glass sphere, the position of different color in the spectrum, measure the angle at which different color lights are deviated and finally to help them

connect this idea with the formation of spectrum by water droplet. Figure 3.1 shows the picture of the first rainbow model.

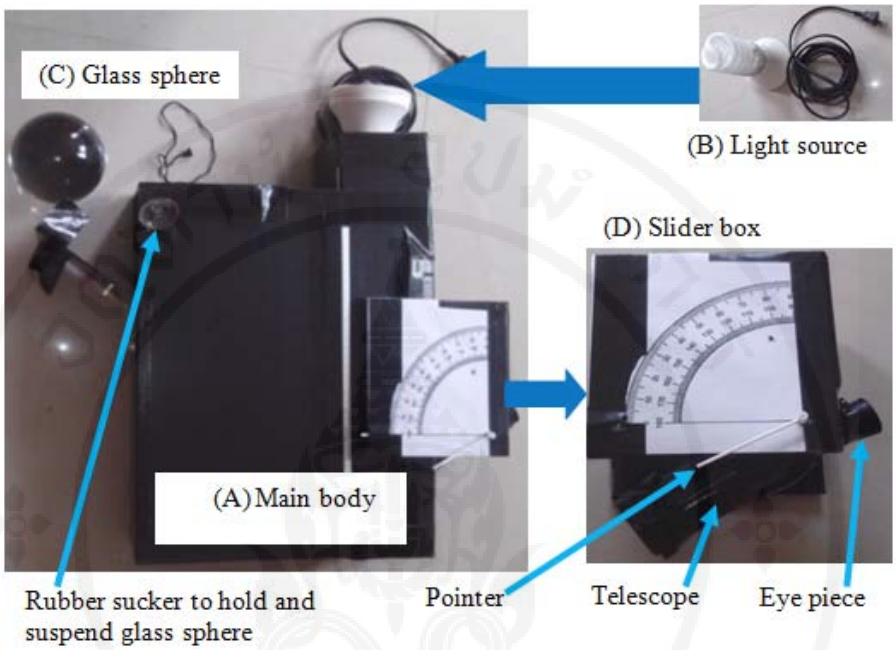

Figure 3.1 Four components of the first indoor rainbow model. (A) Main body, (B) a light bulb, (C) a glass sphere with rubber sucker, and (D) a slider box

Having constructed the model, it was piloted with one high school in Samut Sakon province in Thailand with 15 grade XI science students to find out its effectiveness in enhancing students' understanding about spectrum formation in rain drop. For this purpose eight two-tier questions were developed and used as pre-test and post-test and opinion survey questionnaire for investigating students' opinion which is discussed detailly in the section about development of research tools. The picture of students piloting with first model is shown in Figure 3.2.

After the intervention of lesson on spectrum formation with the model, students were asked to share their views and suggestion about the model for further improvement. It was found that students were very frank and they said "the activity was very interesting and we enjoyed the class but the time for doing the activity was short" All the 15 students agreed that they felt happy and satisfied with the model, when they were asked, How did you feel learning with the model?

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Figure 3.2 Students carrying out experiment with first indoor rainbow model

During experimentation of model with 15 students it was found that in using the model for long time the fluorescent light bulb got heated up and became hot which was unsafe for the user. The telescope was not required as it magnified the color light thereby giving inaccurate reading of the angle by the pointer. The glass sphere was big and expensive (US$ 30 per piece) and to do experiment with two glass spheres the main body was found to be slightly small.

The problems found with the first model were rectified as follow; the fluorescent light bulb was replaced with the Eveready LED easy light as it did not get heated up, portable, safe to handle as batteries were used to give light and it also formed desirable spectrum with the glass sphere.

The lenses of the telescope were removed and instead straw was connected with the eye piece so that only desired color light of the spectrum could be seen and not the whole spectrum as a result got the correct readings of the angles for different color lights from the protractor.

The big glass sphere was replaced by small glass sphere of 5 centimeters in diameter as it was found that even smaller spheres produces same effect moreover it was cheaper (US$ 6 per piece).

The length and height the model was increased to 72 x 50 centimeters to see color lights from two glass spheres but the thickness was reduced to 7.5 centimeters as the size of the glass sphere was reduced.

The improvised model was then piloted with 50 students of grade XI in one school in Bangkok, Thailand as shown in Figure 3.3. Students also responded to post-test items and opinion survey questionnaire. The post-test consisted

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of 14 two tier multiple choice items discussed detailly in the section about development of research tools.

Figure 3.3 Students carrying out experiment with second indoor rainbow model

With the increase in length and height of the model it was noticed that when glass sphere was hanged inside, the model would easily deviate its shape as it was not so firm and would not stand upright. So, to overcome this problem the final model was constructed with thin plywood. The construction and picture of final model is given in Figure 3.4.

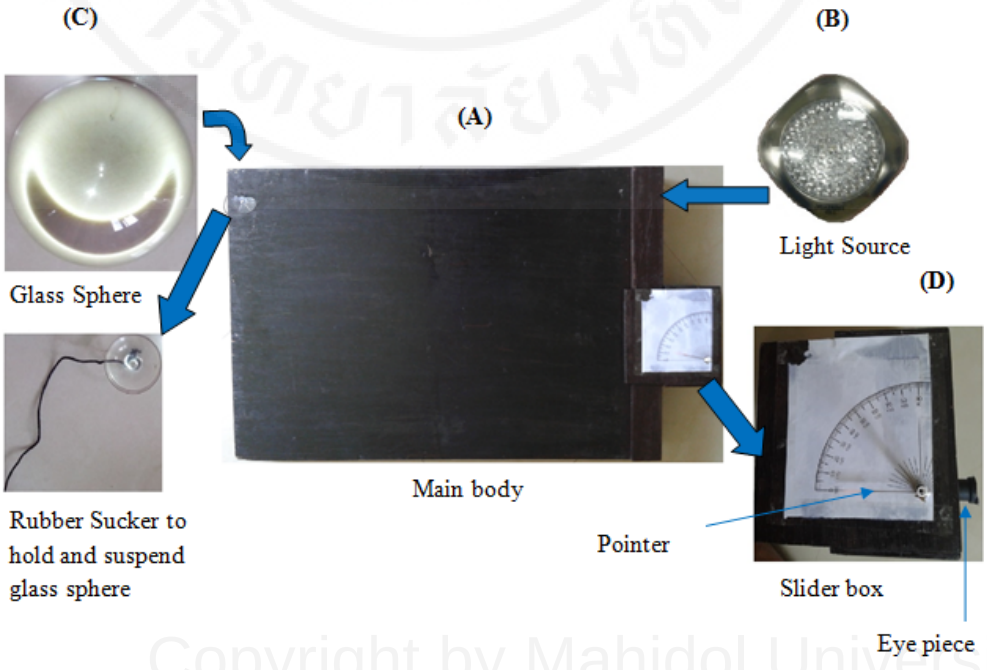

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Figure 3.4 The indoor rainbow model. It has four components (A) Main body (B) a light bulb (C) a glass sphere with rubber sucker and (D) a slider box

The model has four main components as shown in Figure 3.4. The first component (A) is the main body. It is a rectangular box made up of plywood with approximate dimensions: 72 x 50 x 7.5 centimeters. The plywood was selected because it is light, cheap and easily available. The interior part of the box was painted black to absorb light and avoid internal reflection of lights inside the model so that observer can see clear spectrum formed by the glass sphere during experimentation.

The second component (B) is eveready LED easy light used as light source placed at the top one side of the main body in the model.

The third component (C) in the model is a glass sphere of radius about 2.5 centimeters suspended at top opposite to the light source with the help of a string and rubber sucker. The material of the glass sphere was crown glass having refractive index 1.52.

The forth component (D) in the model is a slider box that can be seen below the light source. It can be moved vertically up and down by the observer to adjust and look at each color of the spectrum through eye piece attached to the slider box (see also Figure 3.4 D). The other things that can be seen on the slider box are protractor and a pointer.

The advantages of this model are; portable, inexpensive, safe, can be operated even in well illuminated room and user friendly as it very simple to use and learn from the model.

3.1.1.2 Description on the use of indoor rainbow model

In this study the indoor rainbow model was used for two purposes as follow;

To observe spectrum and measure the angle of different color lights deviated from one glass sphere

Firstly, suspend a glass sphere inside one corner of the main body of the indoor rainbow model and place light source on the opposite corner of the main body. When the light is put on, light refracts into the glass sphere, internally reflects, and then refracts out of the glass sphere. The deviated color lights are seen by eyepiece placed inside the slider box by rotating it partially. The slider box is placed at the bottom of the light source and it can be moved vertically up and down. As the eyepiece is rotated partially, the pointer, attached to the axil of the eye piece, points to

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the calibrations on the protractor thus measuring the angles at which different color lights are seen (also refer Figure 3.5).

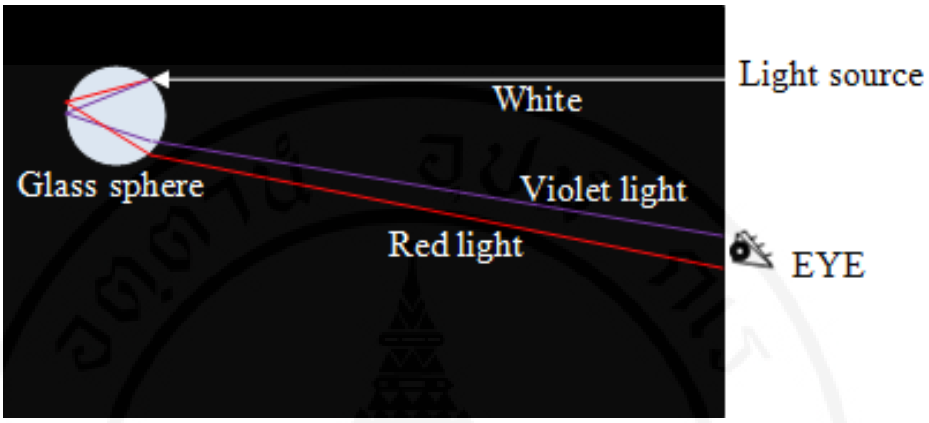

Figure 3.5 The color light as seen from the single glass sphere

To observe two different color lights (red and violet color) from two glass spheres.

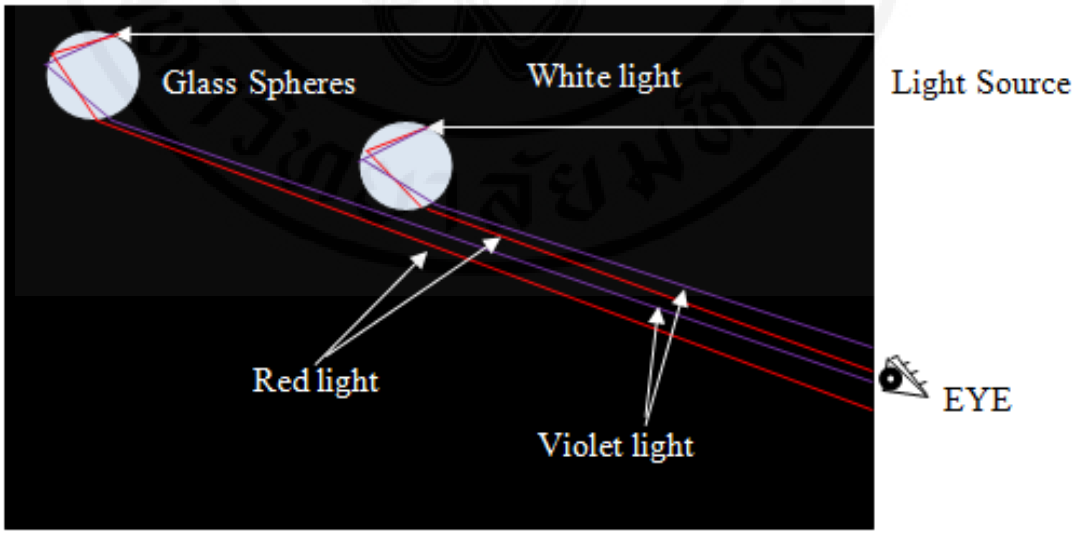

Figure 3.6 Two colors as seen from two glass spheres

To observe two different colors from two glass spheres the arrangement was done as shown in Figure 3.6. The arrangement of these two glass spheres was set-up in this position for the following reasons;

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The light from the source reaches to both the spheres but if the spheres are kept at horizontal position the glass sphere in front blocks the light and casts shadow on the sphere at back thereby affecting the effect.

As observer looks from the position labelled as 'EYE', the glass sphere at the back could be seen slightly lower than the glass sphere placed in the front thereby, allowing the observer to see two different colors from the two glass spheres simultaneously but at different angles.

In the literatures on rainbow by Rudd, (1988); Davies et al., (2006); Beeson and Mayer, (2008); Radi and Rasmussen, (2013); the explanation on different color formation in rainbow are done by using pictures showing two raindrops drawn vertically to each other and red and violet lights being seen at different angles. In order to show in this way with the model, the length of the model has to be increased to meet the two color lights exactly at observer eye from two large glass spheres. Therefore, aforementioned arrangement was followed with two glass spheres.

3.1.2 The second model: Glass beads and the rainbow

3.1.2.1 Construction and components

Sakurada & Nakamura (2002) demonstrated rainbow by projecting sunlight on glass beads. Similarly, the researcher constructed a model using 100 x 100 centimeters black cloth, glass beads and black paint. The size of glass beads used to construct this model was 180-300 μm.

The construction procedures of this model are as follow; first, a layer of black paint was applied evenly in the black cloth about 50 x 50 centimeters in dimension. Next, before the paint gets dried up, a layer of glass beads were spread evenly over the paint on the cloth. Then carefully, it was taken under the sun to dry the paint.

The glass beads were used in this model to represent raindrops and the black cloth represents dark clouds or dark atmosphere behind the rainbow. The picture of a rainbow observed from the second model is shown in Figure 3.7.

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3.1.2.2 Description on use of glass beads rainbow model

This model was used for letting the students to understand about the shape of rainbow and to understand the relative position sun, raindrops and observer during rainbow formation.

The model can be hanged vertically to see rainbow colors by facing the side with glass beads to the sun in the morning and evening. If it is towards noon, it can be spread horizontally on the flat surface by facing the side with glass beads to the sun.

Figure 3.7 Rainbow by glass beads on a black cloth

3.2 Research Design

In this study single group pretest-posttest research design was used. However the conceptual understanding of the students was measured before and after the intervention by means of pre-test and post-test. Figure 4.1 shows the layout of one group pretest-posttest design.

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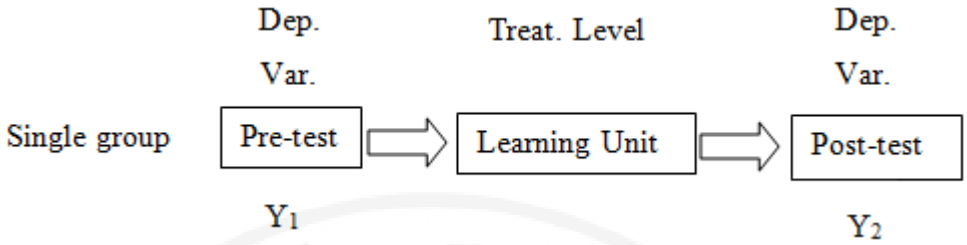

Figure 3.8 Layout for one-group pretest-posttest design. The dependent variable (Dep. Var.) for all the participants (120 students) is measured prior to the presentation of the treatment level and again after the treatment level (Treat. Level) has been presented. The means of pretest and posttest are denoted by Y_1 and Y_2 respectively

3.3 Participants

The purposive sampling method was employed to draw samples for this study. Whole population of grade XI science students from one district in Bhutan took part in this study. There were two higher secondary schools and in total there were 120 grade XI science students.

These 120 students were drawn as sample for this research study solely by considering the following criteria; they have learnt about basic properties of light in lower classes and they have not learnt on the topic about rainbow before. Regarding grade XII science students, they are not drawn as sample in this study because they have already learnt on this topic at the time of data collection.

3.4 Instrument

The instruments used in this study were instructional tools and research instruments. The instructional tools includes lesson plans, activity sheets and instruction sheets (see also Appendix A, B and C). The research instruments are conceptual understanding test (CUT), learning unit opinion survey questionnaire (LUOSQ) and interview questionnaires. Table 3.1 shows the overview of research instruments used to answer the research questions and research objectives.

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Table 3.1 Overview of research question, research objectives and research instruments

Research objective	Research question	Research Instrument
Investigate students' conceptual understanding about natural phenomenon on rainbow formation.	What extent has the learning unit enhanced students in understanding the concept about Rainbow formation in Nature?	The Conceptual Understanding Test (CUT) Learning Unit Opinion Survey Questionnaire (LUOSQ)
Investigate students' opinion on the developed learning unit.	What are the students opinion on the developed learning unit used in the lesson?	Learning Unit Opinion Survey Questionnaire (LUOSQ) Interview

3.4.1 The conceptual understanding test (CUT)

The instrument used for investigating students' conceptual understanding was pre-test and post-test items. These items were two-tier, multiple choice questions based on six objectives from lessons on rainbow formation. The six concepts and its corresponding items are as shown in Table 3.2.

Table 3.2 The six concepts and corresponding items of CUT

Items	Concepts
6, 8, 12, 15 and 17	Spectrum formation by raindrop
7 and 9	Condition necessary for rainbow formation
1, 2 and 3	Rainbow shape
4, 5, 16 and 18	Color sequence in a rainbow
13 and 14	Ray diagram
10 and 11	Locating rainbow

After having constructed the CUT items based on the six objectives of the two lesson plans about rainbow formation and other research instruments such as LUOSQ and interview questions, they were sent for content validation to two experts in Thailand from the field of education and physics education and three experts in Bhutan who had more than 5 year experience in teaching physics in higher secondary

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school. A table was constructed for each expert to use during the item validation (see also Appendix E). Each expert assessed the agreement of each item with the stated purpose for the item, and marked: agree (+1 point) if the item and its purpose correlated, not sure (0 point), or disagree (-1 point) if the item and its purpose did not correlate. The scores from all experts for one item were averaged and the criteria for accepting and rejecting items were based on the Index of the Item-Objective Congruence (IOC index) (Rovinelli & Hambleton, 1977). The IOC index can be computed by using the following equation;

$$IOC_k = \frac{\sum R}{N}$$

Where IOC_k is the index of the Item-Objective Congruence of the item k,

$\sum R$ is the total score of item k from the content experts, and

N is the number of content experts.

Therefore, the CUT items with Index of Item-Objective Congruence ≥ 0.80, equivalent to overall agreement that the item matched its stated objective, were selected for inclusion as CUT items. Some items were also modified based upon expert suggestions. All the CUT items were accepted since Index of Item-Objective Congruence was greater than or equal to 0.80.

After content validation by the five experts, the CUT items were sent to Bhutan and piloted with 40 grade XII science students who have already learnt about rainbow formation. The reliability coefficient (Cronbach's alpha) of the items was found to be 0.704. This shows that the items can be considered very good as indicated by Table 3.6. In order to check for the quality of CUT items, the difficulty and discrimination indices were found which is discussed in detail under the section instrument analysis.

Regarding CUT items, both the first and second tiers had only one correct answer. In the first-tier students were to choose whether the statement was true or false. In the second-tier there were four options presented as the possible reasons for the answer given in the first tier where students had to choose one appropriate reason out of four possible choices. The CUT items were used before and after the teaching process as pre-test and post-test.

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Responses to the items on the CUT were scored on the basis of the assessment criteria presented in Table 3.3 as used by Bayrak (2013). The distributions of scores for each question were entered into the SPSS 16 software package.

Table 3.3 The assessment criteria for two-tier multiple choice items

The degree of concept leaning	Assessment criteria
No answer (0 point)	Students answer wrong answer in both tier
Not mark answer (0 point)	Students misses to mark answer
One correct answer (1 point)	Student have only one correct answer
Two correct answer (2 points)	Students have both the answer correct

3.4.2 Learning unit opinion survey questionnaire (LUOSQ)

This questionnaire was used with the students only after finishing the instructional process. The questionnaire consisted of 28 items about assessing student's opinion on developed learning unit using a 5-point Likert scale, where 1 stands for "strongly disagree", 2 "disagree", 3 "neither agree nor disagree", 4 "agree", and 5 "strongly agree".

Initially, there were 33 items developed to investigate students' opinion on learning unit. Five items had to be discarded after validation by the experts as these five items had Index of Item-Objective Congruence less than 0.80, employing the same criteria as that of CUT for finding the Index of the Item-Objective Congruence (IOC index) by Rovinelli and Hambleton (1977).

The final version of LUOSQ items consisted of 28 items to check students' opinion on the six themes as can be seen from Table 3.4.

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Table 3.4 The six themes and corresponding items of LUOSQ

Items	Themes
1, 2, 3, 4 and 5	Topic and lesson
6, 7, 8 and 9	Teacher
10, 11, 12, 13 and 14	Class activities
15, 16, 17 and 18	Learning method
19, 20, 21, 22, 23 and 24	Indoor rainbow model
25, 26, 27 and 28	Overall learning unit

After validation LUOSQ items by five experts, they were piloted with 50 students of grade XII in one school in Bangkok, Thailand (see also Figure 3.9) and checked for its reliability. The reliability coefficient (Cronbach's alpha) of the items was found to be 0.87. This shows that the items can be considered very good as indicated by Table 3.6. The LUOSQ items could not be sent to same group of 40 students in Bhutan as checking the opinions for the item requires students to have direct experience with learning unit especially the indoor rainbow model. For example to check on the opinion regarding indoor rainbow model, students should have seen and used the indoor rainbow model, otherwise students would not check on the appropriate opinion that they feel in the opinion scale. Therefore, it was used with 50 students in Bangkok, Thailand.

Figure 3.9 Students responding to the learning unit opinion survey questionnaire (LUOSQ) items

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3.4.3 Semi-structured interview questions

Interview protocol was used to guide the researcher during the interview session with the participants. Interview protocol served as procedural guide for the researcher to maintain the focus of the interview.

The semi-structured interview questions were used in this study. Ten students were selected for the purpose of interview in this study. The selection of interviewees was based on the students' low score from post-test and disagreement to the items given in the learning unit opinion survey questionnaire (LUOSQ). All dialogs in the interviewing process were audio recorded.

To develop the semi-structured interview questions, a list of open-ended questions were developed. Interview questions were re-arranged, re-worded and some were removed with comments and discussion with the researcher's thesis advisors. Finally, the completed interview protocol was sent for content validation by the five experts. The final semi-structured interview protocol is shown in Table 3.5.

Table 3.5 Themes and corresponding semi-structured interview questions

Theme	Interview questions
Lesson and concept	1. What did you learn from this lesson? Prompt: Please, can you elaborate it further? 2. Which concept was easy/difficult for you to learn in this lesson? Prompt: Why do you think so? 3. Do you think the model has helped you to understand the concept on rainbow formation? Prompt: If yes, how?
Learning unit	1. What did you like/dislike about the learning unit used in the lesson? Prompt: what makes you feel this way? 2. Do you have any suggestions regarding learning unit used in this lesson? Prompt: If yes, how?
Overall view	3. What is your overall view towards the learning unit?

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3.5 Data Collection

In this study, both qualitative and quantitative data was collected. All the 120 students received the same procedure as described here;

On day one, forty minutes Pretest (CUT) was conducted. On the same day students and researcher recapitulated on the prerequisite concepts required for the lesson which students have already learnt in lower grades. The learning unit has been implemented to the students in day two and day three for sixty minutes each and for this purpose there were two lesson plans with six learning objectives (see also Appendix A). On day four, post-test (CUT) was conducted for forty minutes and another thirty minutes was used for answering questionnaire (LUOSQ) items.

The interviewing of ten selected students using semi structured interview protocol was carried out after school hours. The duration for interviewing each interviewee was about five minutes. All dialogs in the interviewing process were audio recorded. Figure 3.10 shows the overview of research process carried out in this study.

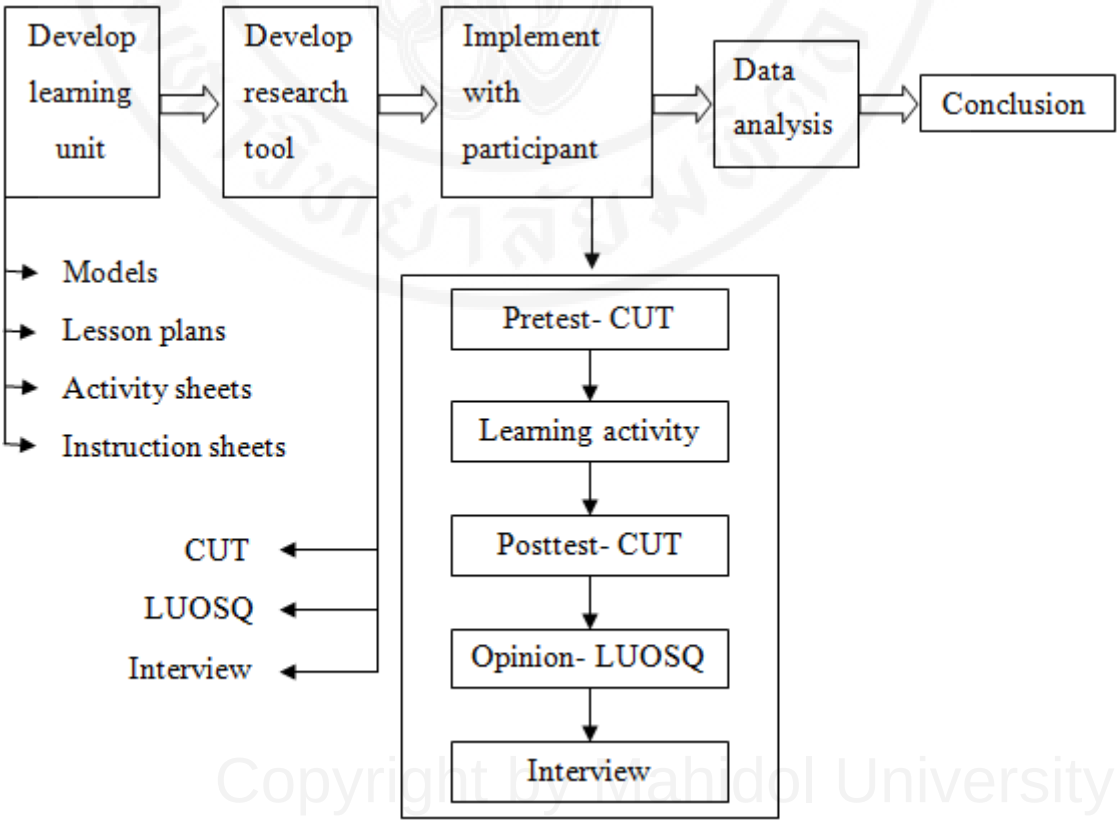

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Figure 3.10 Flow chart of the research study

3.6 Statistical Analysis

The statistical analyses of the instructional tools used in this study were done by categorizing into two headings; instrument analysis and data analysis.

After the construction of research instruments (CUT, LUOSQ, and interview) and instructional tools (lesson plans, activity sheets, and instruction sheets) they were sent for content validation by two experts from Thailand from the field of education and physics education and three experts from Bhutan who had more than 5 year experience in teaching physics in higher secondary school.

Finally, the CUT items were sent to Bhutan and used with 40 grade XII science students who have already learnt on the topic. The details of the findings from CUT items are given in the section of instrument analysis as follow.

3.6.1 Instrument analysis

The quality of CUT items was evaluated by finding reliability coefficient (Cronbah's alpha), item difficulty index and item discrimination index and the quality of LUOSQ was evaluated by finding reliability coefficient (Cronbah's alpha). The details are described in the following sections.

3.6.1.1 Reliability of CUT items

The reliability coefficient of the CUT was found to be 0.704 with 18 items. This shows that the items were acceptable as indicated by Table 3.6.

Table 3.6 Reliability Cronbach's alpha range

Cronbach's alpha	Internal Consistency
< 0.60	Unacceptable
0.60 to 0.65	Undesirable
0.65 to 0.70	Minimally acceptable
0.70 to 0.80	Respectable
0.80 to 0.90	Very good
>0.90	Should consider shortening the scale

Source: DeVellis (2003)

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3.6.1.2 Item Difficulty index (p) of CUT

It is normally determined to the percentage of the total number of correct responses to the test item. The formula is;

$p = R/T$

(or)

Facility = No. of correct response/ Total no. of students

Where R is the number of correct responses and T is the total number of respondents.

Hence, if the index value is high it indicates that the item is less difficult and vice-versa (Sim & Rasiah, 2006). The *p-value* ranges from 0.0 to 1.00. As cited by Sabri (2013) from Instructional Assessment Resources (IAR) acknowledged values of difficulty index and their evaluation as tabulated in Table 3.7.

Table 3.7 Evaluation of item difficulty index

Item Difficulty Index *(p)*	**Item Evaluation**
Above 0.90	Very easy item
0.62	Ideal value
Below 0.20	Very difficult items

Source: Instructional Assessment Resources (IAR 2011)

The item difficulty indexes of the CUT items are shown in Figure 3.11. Most questions in CUT reached to a preferred value of 0.62 and over. This means that 62% of the students or more are able to give a correct response indicating that these questions are suitable. However, the item no 2, 3, 14 and 17 have low difficult index meaning these items were quite difficult for students to answer. Therefore, these items were modified slightly by restructuring the sentence to make them more simple and easy to understand by the students.

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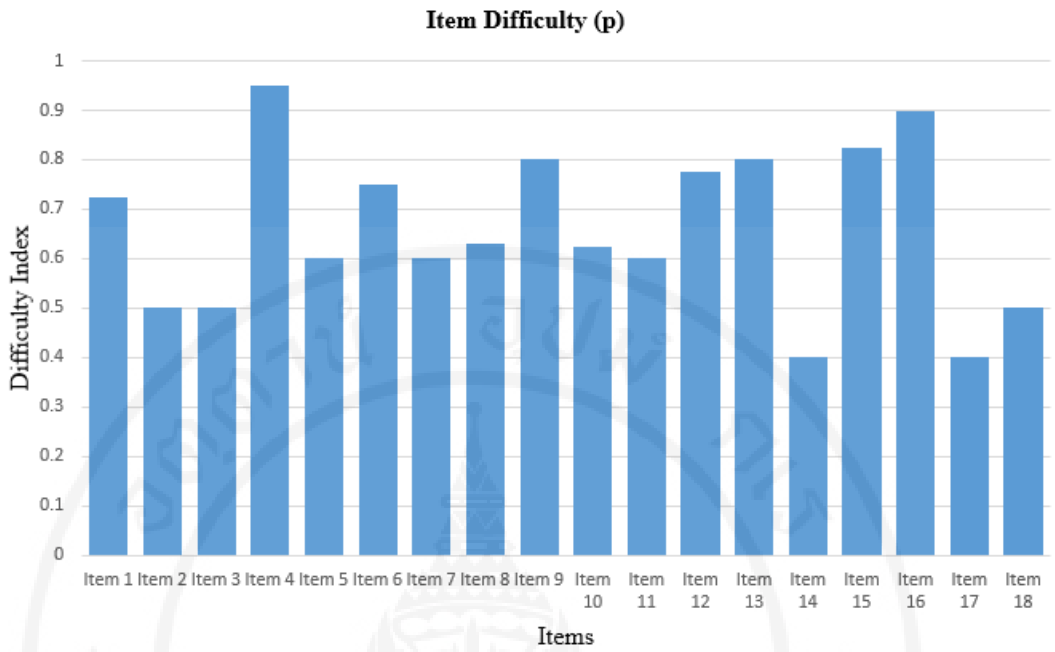

Figure 3.11 Item difficulty of CUT

3.6.1.3 Item discrimination index (D) of CUT

The item discrimination index *(D)* is a measure of item quality whenever the purpose of the test is to produce a spread of scores, reflecting differences in students' achievement, so that distinctions may be made among the performances of respondent (Hotiu, 2006).

It measures the difference between the percentage of students in the higher 27% group *(PU)* and the lower 27% group *(PU)* who obtained the correct response (Sim & Rasiah, 2006). Therefore the discrimination index was calculated by using this formula;

$$D = PU - PL$$

The higher the discriminating index, the better the item can determine, i.e., discriminate, between these students with high test scores and those with low ones.

Note that $-1 \leq D \leq +1$

When $D = 0$, *i.e.*, $PU = PL$, there is no discrimination

When $D = +1$. *i.e.*, $PU = 1$ *and* $PL = 0$. There is perfect discrimination, and when $D = -1$, there is inverse discrimination, which is most likely caused by a mis-keyed item (Sim & Rasiah, 2006).

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The value of discriminating index *(D)* is between *+1* and *–1* and the interpretation is listed in Table 3.8 shown by Sabri (2013) from Ebel's (1972) guidelines.

Table 3.8 Evaluation of item discrimination index

Index of Discrimination	**Item Evaluation**
0.40 and above	Very good items; accept
0.30 – 0.39	Reasonably good but subject to improvement
0.20 – 0.29	Marginal items usually need and subject to improvement
Below 0.19	Poor items to be rejected or improved by revision

Source: Ebel (1972)

The item discrimination of CUT is shown in Figure 3.12. Most questions are classified to be very good questions because their item discrimination index are over 0.4 which means these items discriminates between the students with high test scores with low ones. However, the discrimination index for item 4 and 16 are found to be 0.18 each. It means that the questions on item 4 and 16 are poor items. So the items was revised before data collection (see also Appendix D).

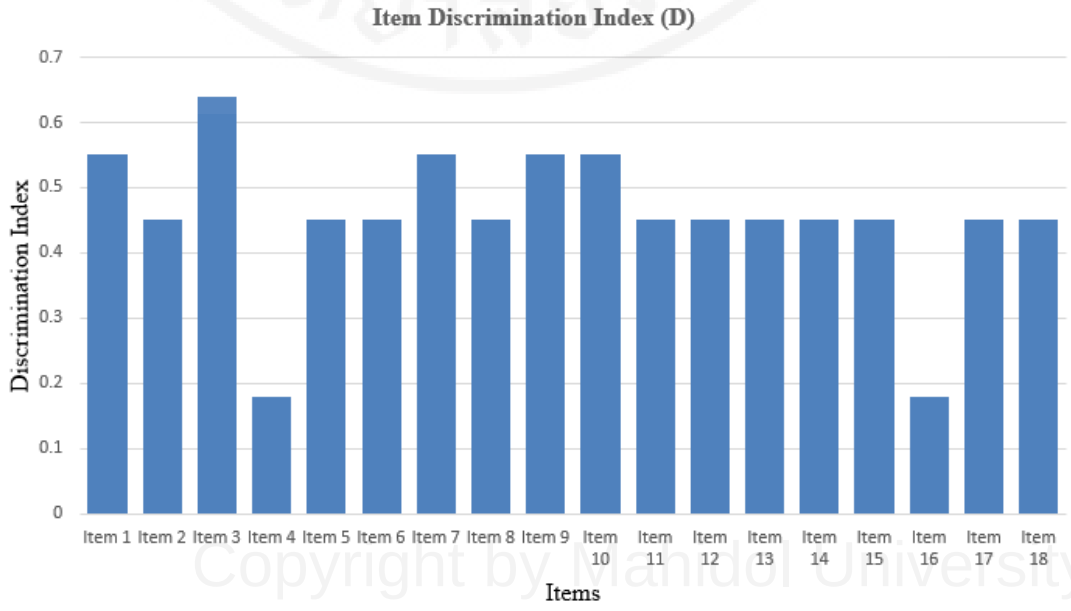

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Figure 3.12 Item discrimination of CUT

3.6.1.4 Reliability of LUOSQ items

Alpha was developed by Lee Cronbach in 1951 to provide a measure of the internal consistency of a test or scale; it is expressed as a number between 0 (if no variance is consistent) and 1 (if all variance is consistent). Internal consistency describes the extent to which all the items in a test measure the same concept or construct and hence it is connected to the inter-relatedness of the items within the test (Tavakol & Dennick, 2011). The Statistical Package for the Social Sciences (SPSS 16) was used for finding the reliability coefficient of LUOSQ items.

The reliability coefficient (Cronbach's alpha) for the 28 items of the LUOSQ items was found to be 0.87. This shows that the items are 87% reliable thus, has relatively high internal consistency and items can be considered very good as indicated by Table 3.6.

3.6.2 Data Analysis

The students' response to CUT items was analyzed by adapting a method as proposed by Abraham et al. (1994) through categorizing students' response into various level of understanding. Inferential t-statistics and percent gain were also used to analyze CUT items. The LUOSQ items were analyzed by finding mean. The analysis procedures of CUT, LUOSQ, and interview questions are discussed in detail in the following section.

3.6.2.1 Analysis of CUT items

3.6.2.1.1 Students' levels of understanding

To examine students' level of understanding, students' grade levels, cross-age and longitudinal studies are often used (Abraham et al, 1994). However, they have implied that a cross-age study is more applicable than a longitudinal study if there is limited time, and several researchers have carried out cross-age studies with satisfactory results (Blanco and Prieto, 1997; Krnel, Glažar and Watson, 2003; Westbrook and Marek, 1991). Therefore, in this study, a cross-age study has been undertaken.

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The method as used by Abraham et al. (1994); Calik and& Ayas (2005) have five levels of understanding as given in Table 3.9. The

criteria provided were used to classify students' responses and make comparisons about their level of understanding.

Table 3.9 The level of understanding and its criteria

The understanding level	The evaluation criteria
Sound understanding (SU)	Responses that included all components of the validated response.
Partial Understanding (PU)	Responses that included at least one of the components of validated response, but not all the components.
Partial understanding with specific alternative conception (PUSAC)	Responses that showed understanding of the concept, but also made a statement, which demonstrated a misunderstanding.
Specific alternative conceptions (SAC)	Responses that included illogical or incorrect information
No understanding (NU)	Repeated the question; contained irrelevant information or an unclear response; left the response blank.

The CUT items in this test included 18 two-tier multiple-choice questions. First tier was true or false question and second tier a multiple choice questions. Each tier had only one correct answer. The second tier had three distracters. These questions were prepared considering three categories, the similar categories as used by Abraham et al. (1992); Çalık (2005); Ünal et al. (2010). The categories are below in Table 3.9.

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Table 3.10 Evaluation criteria for levels of understanding

The understanding level	The evaluation criteria
Sound understanding (SU)	Scientifically complete response and correct explanations take part in this category.
Specific alternative conception (SAC)	This category includes scientifically complete response and unacceptable explanations. Completely scientifically unacceptable response and acceptable explanations.
No understanding (NU)	Completely scientifically unacceptable response and explanations that match this category

3.6.2.1.2 Test of normality

The test of normality was done for the scores obtained from the difference between post-test and pre-test of all items in CUT. Subsequently, paired sample t-test method was used which is given below.

3.6.2.1.3 Paired sample t-test

In this study a paired samples t-test was used to compare two related mean. It tests the null hypothesis that the difference between two related mean is zero. The SPSS output generates a column labeled as "Sig (2-tailed)" gives the two-tailed p value associated with the test. Decide if null hypothesis (Ho) can be rejected, If the p value was less or equal to the alpha level ($\alpha = 0.05$), then the null hypothesis (Ho) was rejected.

3.6.2.1.4 Mean scores and percent gain

The mean score in each concept was also analyzed by categorizing the CUT items under six concepts. The percent gain in the mean score of pre-test and post-test was found in six concepts as follow;

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1) Spectrum formation by rain drop

2) Conditions for rainbow formation

3) Rainbow shape

4) Color sequence

5) Ray diagrams

6) Locating rainbow

3.6.2.2 Analysis of LUOSQ

Analysis the learning unit opinion survey questionnaire (LUOSQ) items was done by finding the individual item mean, mean of each themes (i.e., topic and lesson, teacher, class activities, the learning cycle, the developed model, and overall learning unit) and also the overall mean of all items. In order to analyze the items of negative statement the values were reversely recoded and mean was obtained. In reverse recoding of a typical 1 - 5 scale, the formula given results in the same recoding (X_{new} value = 6 – X_{old} value).

The opinions of the students was rated into five levels as per Likert scale principles, 1 point for strongly disagree, 2 point for disagree, 3 point for neither agree nor disagree, 4 point for agree and 5 point for strongly agree. The average mean obtained from each item, theme and overall items were interpreted looking at the score range as shown in Table 3.11. The range was fixed by finding the average value $\bar{x}$ using the formula as given below;

$\bar{x}$ = Maximum point – Minimum point ÷ Total level in a scale

$\bar{x} = 5 - 1 \div 5$

$\bar{x} = 0.8$

Table 3.11 Opinion evaluation criteria

Score range	Degree of opinion
4.21-5.00	Strongly Agree
3.41-4.20	Agree
2.61-3.40	neither Agree nor Disagree
1.81-2.60	Disagree
1.00-1.80	Strongly Disagree

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3.6.2.3 Analysis of interview responses

Qualitative data in this study was interview. The interview data was collected to investigate students' opinion towards the learning unit and also to see the authenticity of the concepts understood by the students. The response given by students in the interviews was tape-recorded, transcribed, and analysed by categorising under the theme topic, method, model, teacher, and overall views.

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CHAPTER IV
RESULTS AND DISCUSSION

Overview

This chapter presents the results of the students' response to conceptual understanding test (CUT), learning unit opinion survey questionnaire (LUOSQ) and interview questions. This chapter also has discussion on CUT items and LUOSQ items. The data for CUT and LUOSQ were collected from 120 Bhutanese grade XI students and 10 students took part in the interview. Analysis of the CUT items were done by measuring levels of students' conceptual understanding, normality test, test of significance (paired sample t-test) and normalized gain. For LUOSQ items, mean of individual items, mean of each theme and overall all mean were found. The tape-recorded responses of 10 students in the interview questions was transcribed and analysed by coding techniques.

4.1 Analysis of CUT

The summaries of 120 Bhutanese students' responses to conceptual understanding Test (CUT) for pre-test and post-test are shown in Figure 4.1. From the response to pre-test questions researcher could make out that students who participated in this study had some basic knowledge about the rainbow formation even if the topic was not learnt before. This knowledge as said by them in response to interview derived from similar concepts learnt in lower classes like dispersion of light in prism and could relate those concepts with this new topic.

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Q. no	1st tier				2nd tier							
	Pre-test		Post-test		Pre-test				Post-test			
	T	F	T	F	a	b	c	d	a	b	c	d
1	81	39	120	0	18	30	14	58	5	13	95	7
2	38	82	108	12	20	11	50	39	8	15	33	64
3	64	56	94	26	0	53	42	25	111	5	0	4
4	112	8	120	0	60	17	43	0	120	0	0	0
5	43	77	0	120	45	26	40	9	17	73	20	10
6	91	29	50	70	38	7	60	15	0	3	117	0
7	34	86	119	1	55	7	36	32	2	5	28	85
8	59	61	13	107	45	25	10	40	5	22	7	86
9	32	88	13	107	32	27	48	13	0	0	119	1
10	78	42	116	4	65	14	24	17	4	84	23	9
11	37	83	11	109	38	34	26	22	13	107	0	0
12	39	81	111	9	32	30	29	29	114	6	0	0
13	71	49	40	80	23	35	29	33	11	89	14	6
14	86	34	100	20	37	32	44	7	88	24	5	3
15	88	32	74	46	39	34	28	19	10	5	102	3
16	91	29	120	0	46	43	0	31	0	0	0	120
17	46	74	96	24	30	34	20	36	72	11	14	23
18	20	100	120	0	36	47	10	27	72	13	15	20

* The shaded number indicates the correct answer

Figure 4.1 Summaries of students' response in pre-test and post-test items in 18 two tier questions (Q. no). The first tier require students to state True (T) or False (F) and the second tier to choose correct answer from four options a, b, c and d

4.1.1 Students' levels of understanding

The results obtained from the post-test are presented below by considering each item. The actual number of students' responses as well as the percentages obtained for each level of understandings is shown in Table 4.1. The correct answer for the first-tier is given in bracket and the correct answer to the second-tier is given in every first response from four possible choices.

If the response of students in both the tiers in particular item has been correct, then the level of understanding the students were regarded under sound understanding category. If the response of the students has been correct only in first tier or second tier then the level of understanding of the students were grouped under specific alternative conception category. If the response of the students has been not correct is both the tier then the level of understanding of the students were grouped under no understanding category as can be seen in Table 3.10.

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Table 4.1 The level of understanding in number and percentages for each item

Item	Concept level
1. Rainbows are normally seen as half circle. (True) Because; ▪ The earth gets in the way ▪ Water droplets displaces it at some degrees from the centerline ▪ The earth surface is curved ▪ The back part of the drop that reflects color is curved	SU (95) 79.2% SAC (25) 20.8%
2. If you point to a wall with your arm extended to make about 42º angle to the normal to the wall and rotate in a full circle while keeping the same angle, The finger sweeps out a circular shape on the wall. (True) Which statement best suits with by the above analogy? ▪ The rain drop reflects same color at a time from a fixed angle ▪ A drop reflects all the color light at any angle to an observer's eye ▪ The rain drops reflects same color light to an observer's eye ▪ The entire raindrops collective reflects light rays to form rainbow	SU (60) 50% SAC (52) 43.3% NU (5) 6.7%
3. When seen from an airplane, a rainbow sometimes forms a complete circle. (True) When this happens, where do you we expect to see the shadow of the plane with respect to rainbow? ▪ At the center because the center of a rainbow is in the straight line with plane and the sun ▪ Upper part of the rainbow because the plane at this particular instant is straight to the sun and upper part of rainbow ▪ No shadow is expected as the atmosphere will be dark. ▪ No shadow is expected as the dark clouds will prevent us from seeing it	SU (90) 75% SAC (25) 20.5% NU (5) 4.2%
4 In a rainbow, blue color is seen in the outer part of the bow. (False) Which option shows the correct order of rainbow color from inside? ▪ Violet, Indigo, Blue, Green, Yellow, Orange and Red ▪ Red, Orange, Yellow, Green, Blue, Indigo and Violet ▪ Red, Violet, Indigo, Yellow, Orange, Green and Blue ▪ Blue, Indigo, Violet, Yellow, Orange, Green, and Red	SU (120) 100%
5. The red color is seen at an angle of 40 degrees in a rainbow. (False) If you are looking at a rainbow from the ground floor of an apartment building and notice that the kite is hovering right in the green portion. If you were to go up to the second floor, where would you be likely to see the kite hovering in? ▪ The blue portion of the rainbows ▪ The red portion of the rainbow ▪ The yellow portion of the rainbow ▪ The green portion of the rainbow only	SU (73) 60.8% SAC (47) 39.2

SU = Sound Understanding SAC = Specific Alternative conception NU = No Understanding

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Table 4.1 The level of understanding in number and percentages for each item (cont.)

Item	Concept level
6. Reflection of light is responsible to let you see spectrum in a raindrop. (False) The correct process that light undergo in a drop to form spectrum is ▪ Refraction, reflection and refraction ▪ Reflection, refraction and reflection ▪ Refraction, reflection and reflection ▪ Reflection, refraction and refraction	SU (67) 55.8% SAC (53) 44.2%
7. Rainbows are seen in the direction opposite to the sun. (True) The reason is due to ▪ Reflection of light ▪ Interference of light ▪ Refraction of light ▪ None of them. These processes have nothing to do with the rainbow's position	SU (84) 70% SAC (36) 30%
8. The formation of color in a rainbow is mainly due to reflection. (False) Because ▪ The wavelength dependence of the refractive index of the raindrop produces the colors of the rainbow ▪ The reflection of light breaks the light into constituent color producing colors of rainbow ▪ Either wavelength or frequency of light alone produces colors of rainbow ▪ The refractive index of the raindrop alone produces the colors of the rainbow	SU (81) 67.5% SAC (31) 25.9% NU (8) 6.6%
9. To see a rainbow, relatively the sun must be between raindrop and the observers. (False) Then, where in the sky would you expect to see a rainbow in the evening? ▪ northern sky ▪ southern sky ▪ eastern sky ▪ western sky	SU (106) 88.3% SAC (14) 11.6%
10. Sometimes we can see a rainbow setting slowly below the horizon. (True) Because; ▪ As the sun rises from the east in the morning the top of the rainbow will set below the horizon ▪ As the sun sets in the west in the evening the top of the rainbow will rise above the horizon ▪ Even if the position of sun changes slowly the rainbow will remain stationary without changing its position ▪ When the raindrops fall down sequentially one after another the colors in the rainbow will also be pulled down slowly	SU (80) 66.7% SAC (40) 33.3%

SU = Sound Understanding SAC = Specific Alternative conception NU = No Understanding

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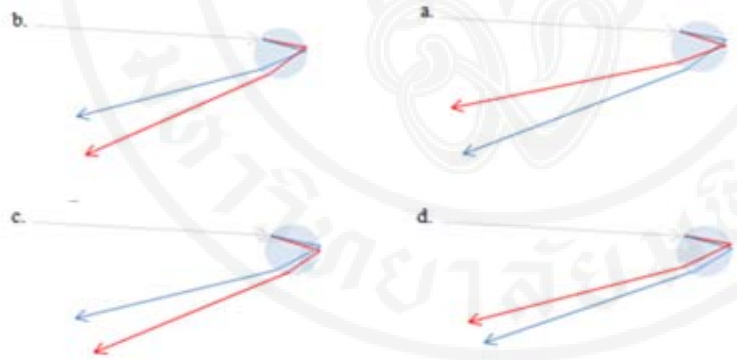
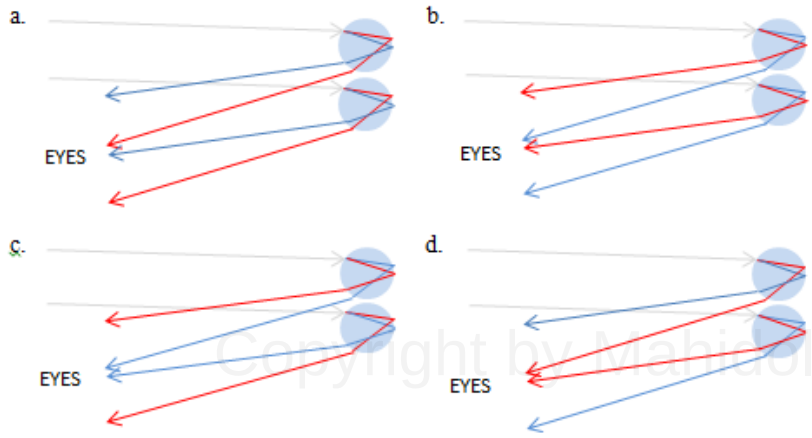
Table 4.1 The level of understanding in number and percentages for each item (cont.)

Item	Concept level
11. At around 5 PM you are in an airplane and if you saw a rainbow then you are flying towards western sky. (False) Because; ▪ The rainbow will be seen in the eastern sky ▪ The rainbow will be seen in the western sky ▪ The rainbow will be seen exactly above the plane ▪ The rainbow will be seen exactly below the plane	SU (96) 80% SAC (24) 20%
12. Every single rain drop is capable to produce a rainbow color. (True) Because; ▪ A spectrum of color can be seen in a drop illuminated by sunlight ▪ A single color is seen from a faraway drop ▪ A spectrum of color can be seen from a faraway drop ▪ A single color can be seen in a drop illuminated by sunlight	SU (105) 87.5% SAC (15) 12.5%
13. Red color light will be refracted more than violet color in a rain drop. (False) Which ray diagram correctly represents the formation of spectrum by single drop? 	SU (49) 40.8% SAC (71) 59.2%
14. Red color light will be deviated more than violet. (True) Which ray diagram correctly represents the rainbow formation by two drop? 	SU (72) 60% SAC (44) 36.6% NU (4) 3.4%

SU = Sound Understanding SAC = Specific Alternative conception NU = No Understanding

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Table 4.1 The level of understanding in number and percentages for each item (cont.)

Item	Concept level
15. The position of red light in the spectrum formed by water drop will be seen at bottom. (True) Because ▪ The smaller bending of red light at the first surface causes it to strike the back surface of the drop at a greater angle of incidence ▪ The greater bending of red light at the first surface causes it to strike the back surface of the drop at a greater angle of incidence ▪ The greater bending of red light at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence ▪ The smaller bending of red light at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence	SU (56) 46.7% SAC (64) 53.3%
16. The angle of deviation of violet light is more than red light. (False) b. Because ▪ The red rays exit from the drops at an angle of 42°degrees and violet light emerges at an angle of 40 degrees from the drops ▪ The violet rays exit from the drops at an angle of 41°degrees and red light emerges at an angle of 40 degrees from the drops ▪ The red rays exit from the drops at an angle of 40°degrees and violet light emerges at an angle of 41 degrees from the drops ▪ The violet rays exit from the drops at an angle of 42°degrees and red light emerges at an angle of 40 degrees from the drops	SU (120) 100%
17. The angle of refraction subtended inside the water drop will be equal to angle of incidence subtended inside the back of the water drop. (True) The geometry is ▪ The triangle drawn by two normal and refracted ray is isosceles triangle ▪ The triangle drawn by two normal and refracted ray is scalene triangle ▪ The triangle drawn by two normal and refracted ray is acute triangle ▪ None of them	SU (53) 44.2% SAC (62) 51.6% NU (5) 4.2%
18. We see the Violet color on the inner part of the arc in rainbow. (True) b. because ▪ We are looking along a same line of sight that has a smaller angle (40 degrees) for the violet ▪ We are looking along a different line of sight that has a greater angle (42 degrees) for the violet ▪ We are looking along a same line of sight that has a greater angle (42 degrees) for the violet ▪ We are looking along a different line of sight that has a smaller angle (40 degrees) for the violet	SU (72) 60% SAC (48) 40%

SU = Sound Understanding SAC = Specific Alternative conception NU = No Understanding

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As can be seen from Table 4.1, in item 1, 79.2 percent of the students showed “sound understanding” (SU). The proportion of students’ responses categorized under the “specific alternative conception” (SAC) is 18.3 percent while none in “no understanding” (NU) category.

In item 2, 50 percent show SU. The percentage of students’ responses categorized under SAC is 43.3 while 6.7 percent could not answer in either of the tier correctly so they fall in NU category.

SU in item 3 is 75 percent while the percentages of students’ responses classified under SAC is 20.8 and those in the NU category is 4.2 percent as they could not provide correct answer in both the tier in this item.

SU in item 4 shows 100 percent as all the students responded correctly in both the tiers.

In item 5, SU is 60.8 percent. The proportion of students’ responses categorized under the SAC is 39.2 percent while none in NU category.

For item 6, 55.8 percent of the students exhibited SU. The proportion of students’ responses categorized under the SAC category is 44.2 percent while none in NU category.

In item 7, SU is 70 percent while the percentages of students’ responses categorized under SAC is 30 while none in NU category.

SU in item 8 is 67.7 percent, while the percentages of students’ responses classified under SAC is 25.9 and in that of NU category is 6.7 percent.

For item 9, 88.3 percent of the students exhibited SU. The proportion of students’ responses categorized under the SAC category is 11.6 percent and none in NU category.

In item 10, 66.7 percent of the students exhibited SU. Meanwhile, the proportion of students’ responses categorized under the SAC category is 33.3 percent and none in NU category.

In item 11, 80 percent of the students have SU. The proportion of students’ responses categorized under the SAC category is 20 percent while none in NU category.

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Item 12 shows that 87.5 percent of the students who attended CUT exhibited SU. The proportion of students' responses categorized under the SAC category is 12.5 and none in NU category.

For item 13, 40.8 percent of the students who attended CUT exhibited SU. The proportion of students' responses categorized under the SAC category is 59.1 percent while none in NU category.

SU in item 14 is 60 percent, while the percentages of students' responses classified under SAC is 36.6 and those in the NU category is 3.3 percent as students could not provide correct answer in both the tier in this item.

For item 15, 46.7 percent of the students show SU. The proportion of students' responses categorized under the SAC category is 53.3 percent while none in NU category.

In item 16, SU is 100 percent. The proportion of students' responses categorized under SAC and NU are none.

In item 17, 44.2 percent show SU. The percentage of students' responses categorized under SAC is 51.6 while 4.2 percent of the students couldn't answer in either of the tier correctly so they fall in NU category.

For item 18, 60 percent show SU. The percentage of students' responses categorized under SAC is 48 while the percentage of students' response in NU category has none.

Table 4.2 Understanding level in each concept and overall percent in each understanding level

Concepts	**Items**	**SU**	**SAC**	**NU**
Spectrum formation by rain drop	6, 8, 12, 15 and 17	60.3%	37.5%	2.2%
Conditions for rainbow formation	7 and 9	79.2%	20.8%	
Shape of a rainbow	1, 2 and 3	68.2%	28.2%	3.6%
Color sequence	4, 5, 16 and 18	80.2%	19.8%	
Ray diagram	13 and 14	50.4%	47.9%	1.7%
Locating rainbow	10 and11	73.4%	26.6%	
Overall percent	All items	68.6%	30.1%	1.3%

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As can be seen from Table 4.2 the overall percent of students in sound understanding category is 68.6 percent. 30.1 percent of students fall under specific alternative conception and 1.3 percent of students are in no understanding category.

The finding shows that 68.6 percent of the students were able to answer correctly in both the tier indicating that students have understood the concept clearly and they have meaningful learning. 30.1 percent of the students either got the correct answers in the first tier, but wrong in the second tier or students got the correct answers in the second tier, but wrong in the first one. This indicates that in some way the learning for this group of students was not meaningful learning, but superficial and some type of rote learning. It also means that students do not have any idea why they got the answer correct. So it is all because of test-wiseness, meaning getting the right answer without really knowing as some correct answers can be guessed (Piontek, 2008). The percentage of student that could not answer in both tiers is 1.3 thus falling in no understanding category.

4.1.2 Normality test

As can be seen from Figure 4.2 the shape of histogram corresponds to a shape of a normal curve so the data is normally distributed.

In normal Q-Q plot, the dots are all along the line indicating that the data are approximately normally distributed (see also Figure 4.3).

In the box plots it can be seen that they have approximately symmetrical shape even if they are not perfectly symmetrical so they are good enough to consider the data as normally distributed (see also Figure 4.4).

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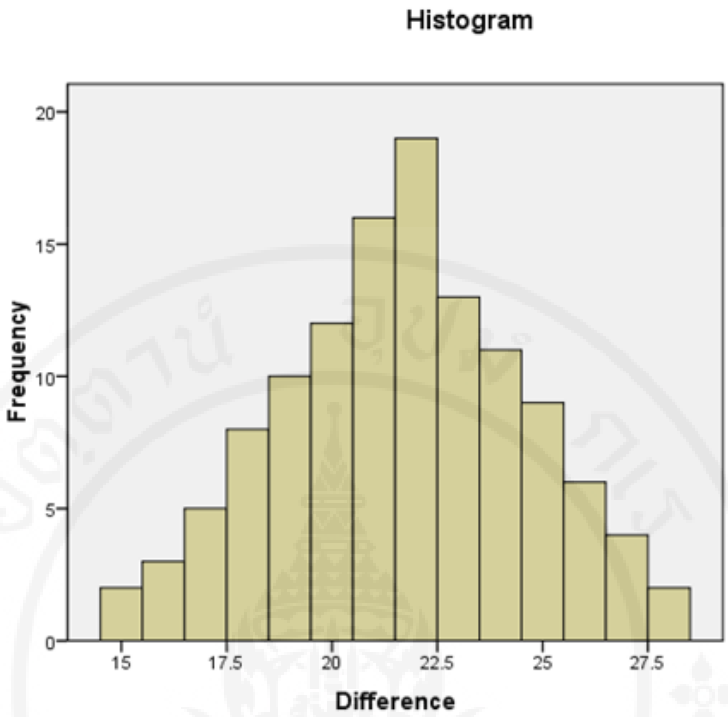

Figure 4.2 Histogram showing normal distribution

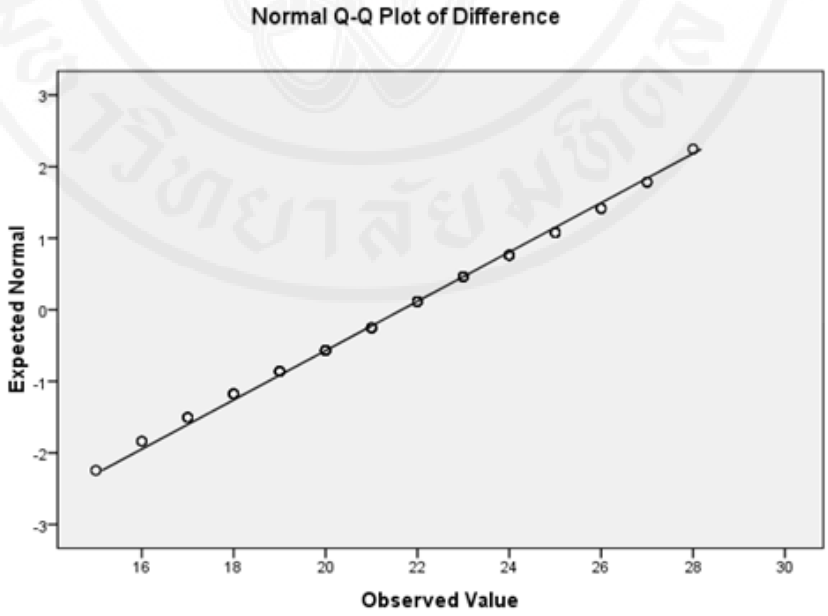

Figure 4.3 Normal Q-Q plots showing normal distribution

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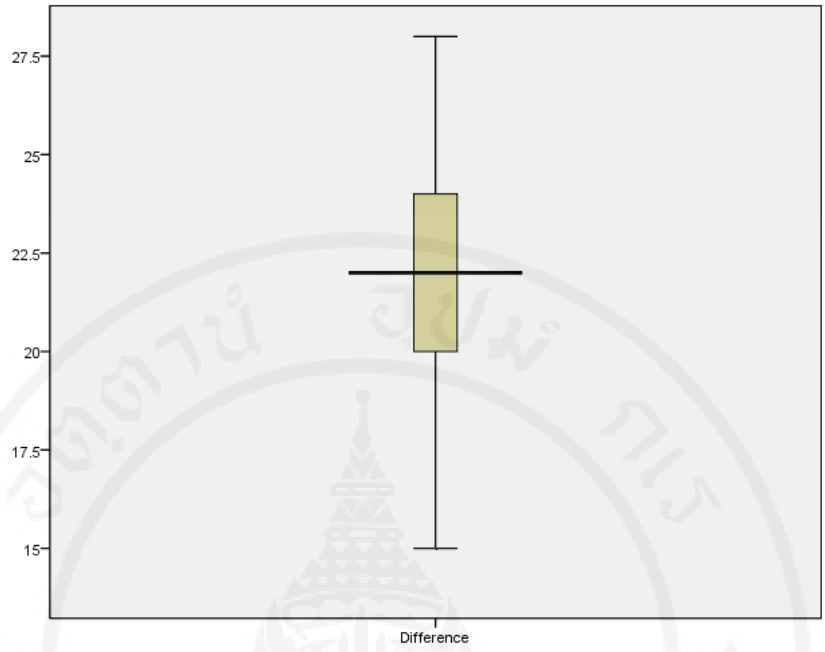

Figure 4.4 The box plots showing normal distribution

Form a Shapiro-Wilk's test p value obtained was 0.172 in which $p > 0.05$ (Shapiro & Wilk, 1965) and a visual inspection of their histogram, normal Q-Q plots and box plots show that CUT scores are approximately normally distributed, with a skewness of – 0.249 (SEM = 0.221) and a kurtosis of – 0.941 (SEM = 0.438).

Since the data obtained from the difference of post-test and pre-test was found to be normally distributed, parametric hypothesis test called paired sample t-test was used to decide if null hypothesis can be rejected. It is discussed in the following section.

4.1.3 Paired sample t-test

Table 5.3 Paired sample t-test between students' pre-test and post-test

Test	N	Mean	SD	t	df	Sig. (2-tailed)
Pre-test	120	8.30	2.33	– 96.49	119	.000
Post-test	120	29.66	2.91			

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From Tables 4.3, a paired samples t-test revealed a statistically reliable difference between the mean number of post-test (M = 29.66, SD = 2.906) and pre-test (M = 8.30, SD = 2.33) that the students have, t (119) = – 96.49, p = .000, α = .05.

The p-value was found to be less than the alpha level (α = 0.05), so the null hypothesis was rejected. This implies that there was improvement in the post-test result statistically and to show the percent gain in each concept, mean score and percent gain are discussed below.

4.1.4 Mean score and percent gain

The students' mean score in pre-test, post-test and percent gain in each concept are shown in Table 4.4. The lowest pre-test score of 7.2% is in the concept about conditions for rainbow formation while the highest score of 33.9% is in the concept on rainbow's shape. The post-test scores are higher than those of the pre-test scores in all the six concepts. The percentage gain in all the six concepts ranged from 40.8% to 81.6%. The highest gain is in the concept on conditions for rainbow formation while the lowest is in the concept on shape of rainbow. The average score increased from 23.3% in the pre-test to 82.3% in the post-test with the percentage gain of 59.

Table 4.4 Mean score of student's pretest and posttest in each concept

Concept	Pre-test		Post-test		Percent Gain (%Post - Pre)
	Mean ± SD	Percent	Mean ± SD	Percent	
1. Spectrum formation	0.297 ± 0.448	29.7%	0.833 ± 0.253	83.3%	53.6%
2. Conditions	0.072 ± 0.144	07.2%	0.888 ± 0.201	88.8%	81.6%
3. Rainbow shape	0.339 ± 0.372	33.9%	0.747 ± 0.221	74.7%	40.8%
4. Color sequence	0.142 ± 0.304	14.2%	0.797 ± 0.241	79.7%	65.5%
5. Ray diagrams	0.306 ± 0.409	30.6%	0.820 ± 0.254	82.0%	51.4%
6. Locating Rainbow	0.239 ± 0.410	23.9%	0.908 ± 0.227	90.8%	66.9%
Total	0.233 ± 0.348	23.3%	0.823 ± 0.237	82.3%	59.0%

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4.2 Students' opinion on LUOSQ

Table 4.5 to Table 4.10 shows the mean of each item and each theme.

Table 4.5 Mean score of students' opinion on topic and the lesson

No.	Item	Mean	Reverse recoding
1	The topic of the lesson was interesting	4.84	
2	The lesson was suitable with your level	4.76	
3	Lesson was well organized in a way that helped me learn better	4.62	
4	The lesson was useful for me to understand about rainbow formation	4.72	
5	The lesson was very difficult to understand.	1.43	4.57
	Average mean of the theme on topic and lesson (4.70)		

The students' opinions are indicated by the values in the Table 4.5 for each item. The values of the item no. 1, 2, 3 and 4 show the students have strong agreement with the items. The value of the item no. 5 shows students' strong disagreement with the item. Yet when coding of item no. 5 was reversed, the value item is 4.57 which implied that the students strongly agree to it. Consequently, average mean score in these aspects is 4.70.

This means that it is strongly agreed by the students that the topic of the lesson is interesting, suitable with their level, well organized in a way that helped them learn better, useful for them to understand about rainbow formation, and not very difficult for them to understand.

Table 4.6 Mean score of students' opinion about teacher

No.	Item	Mean	Reverse recoding
1	The teacher has been well prepared for the class	4.82	
2	The teacher has been open to students' opinion	4.73	
3	The teacher acted as resource person, working to support students investigation	4.75	
4	Language teacher used to describe things was very difficult to understand	1.30	4.70
	Average mean of the theme on teacher (4.75)		

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The students' opinions are shown by the values in the Table 4.6 for each item. The values of the item no. 1, 2 and 3 show the students have strong agreement with the items. The value of the item no. 4 shows students' strong disagreement with the item. Yet when coding of item no. 4 was reversed, the value item is 4.70 which show that the students strongly agree to it. Consequently, average mean score in these aspects is 4.75.

This means that it is strongly agreed by the students that teacher was well prepared, open, support students learning and used simple language to describe things which was understandable.

Table 4.7 Mean score of students' opinion on class activities

No.	Item	Mean	Reverse recoding
1	The instruction sheet and activity sheets were clear and easy to understand.	4.75	
2	The activities used in the lesson were engaging	4.60	
3	This lesson made me to learn by hands-on, eyes-on and minds-on	4.75	
4	This class gave me an opportunity to learn about the rainbow phenomenon through real classroom activities	4.82	
5	The majority of instruction in this class was through lecture	1.55	4.45
	Average mean of the theme on class activities (4.67)		

The opinions of the students are indicated by the values in the Table 4.7 for each item. The values of the item no. 1, 2, 3 and 4 show the students have strong agreement with the items. The value of the item no. 5 shows students' strong disagreement with the item. Yet when coding of item no. 5 was reversed, the value item is 4.45 which implied that the students strongly agree to it. Consequently, average mean score in these aspects is 4.67.

This means that students strongly agrees that their activity was guided by instructions sheet, engaging, involve wholly in the aspects of hands-on, eyes-on and minds-on, let them learn with rainbow and it had minimal lecture but guided learning signifying that teacher was mentoring and challenging students indicating that teacher's role were grounded based on theory of social constructivism.

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Table 4.8 Mean score of students' opinion on the Learning method

No.	Item	Mean	Reverse recoding
1	The learning method used were suitable with the topic	4.63	
2	The learning approach made me to think and be critical in a more inquiry-led approach.	4.51	
3	The P-O-E method help me to change my concept to be more scientific	4.65	
4	I do not prefer this learning method in future	1.28	4.73
	Average mean of the theme on learning method (4.63)		

The students' opinions are indicated by the values in the Table 4.8 for each item. The values of the item no. 1, 2 and 3 show the students have strong agreement with the items. The value of the item no. 4 shows students' strong disagreement with the item. Yet when coding of item no. 4 was reversed, the value item is 4.73 which implied that the students strongly agree to it. Consequently, average mean score in these aspects is 4.63.

This means that it is strongly agreed by the students that the learning method was suitable, made them think critically, made them understand the concept scientifically and prefer to learn using this method in future.

Table 4.9 Mean score of students' opinion on the indoor rainbow model

No.	Item	Mean
1	The Indoor rainbow model has really helped me to understand about rainbow formation	4.77
2	The Indoor rainbow model is safe to handle	4.74
3	The indoor rainbow model was made from easy to obtain inexpensive materials	4.76
4	The Indoor rainbow model was convenient to use in the bright room.	4.72
5	The Indoor rainbow model was easy to carry from one place to another.	4.80
6	I would describe this Indoor rainbow model as very innovative and interesting	4.71
	Average mean of the theme on indoor rainbow model (4.75)	

The students' opinions are indicated by the values in the Table 4.9 for each item. The values of the all the items show the students have strong agreement with the items. The average mean score in these aspects is 4.75.

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This means that it is strongly agreed by the students that Indoor rainbow model has helped them to understand concept, safe, inexpensive, convenient to use even in bright room, portable and innovative and interesting.

Table 4.10 Mean score of students' opinion on the overall learning unit

No.	Item	Mean
1	There wasn't any problem during the use of learning unit	4.66
2	The learning unit helped me to do the self-learning	4.71
3	The learning unit will certainly help me in retaining the new concepts learnt in this class in my long-term memory.	4.74
4	Overall, I am satisfied with the learning unit	4.91
	Average mean of the theme on overall learning unit (4.76)	

The students' opinions are indicated by the values in the Table 4.10 for each item. The values in the entire item show the students have strong agreement with the items. The average mean score in these aspects is 4.76.

This means that it is strongly agreed by the students that there was no problem using learning unit, it encouraged self-learning, retention of concept in memory and achieved full satisfaction using learning unit.

Table 4.11 Mean scores of different themes and overall mean of all items

Theme No.	Theme	Mean score	No. of items	Average mean
1	Topic and the lesson	23.51	5	4.70
2	The learning method	18.52	4	4.63
3	The teacher	19.00	4	4.75
4	The class activities	23.37	5	4.67
5	Indoor rainbow model	28.50	6	4.75
6	The overall learning unit	19.02	4	4.76
	Total	131.92	28	
	Mean of all items		4.71	

Table 4.11 shows the mean scores of different themes and overall mean of all items. It is evident that students' strongly agrees with the opinion on all the themes as all the mean was above 4.6. The mean on the theme topic and lesson is 4.70, the learning method is 4.63, the teacher is 4.76, the class activities is 4.67, the model is 4.75 and overall learning unit is 4.76.

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Finally, as can be seen from Table 4.11 the response of the students on learning unit opinion survey questionnaire (LUOSQ) items show strong agreement as the overall mean of all the items was 4.71.

4.3 Interview

The informations from the tape-recorded interviews were transcribed and the response of interviewees are categorised under three themes; the concept, the learning unit and overall view.

4.3.1 Concept

In this theme on concept, it was grouped into two sub category as easy concept and difficult concept and even the reasons are explored and stated as follows;

Easy concept

According to students who responded to the interview said that learning about the formation of spectrum in single drop was easy to understand and these are some of their reasons; “I learnt about properties of light such as reflection, refraction, dispersion, laws of reflection in the lower classes, and these all made me easy to relate and learn”. “The model helped me to understand the sequence of colors by observing it with my own eyes and it is easy for learning from the model than explaining theoretically”.

Difficult concept

Seven of the ten students responded that learning about formation of colors by two drops was difficult and this was the reason they gave “It was difficult to experiment with two spheres as it took more time to do this activity”

4.3.2 Learning unit

In this theme, there are four sub-categories based on students’ preference in the interview response which are as follows;

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Topic

Some students said that liked the topic giving following reasons “I liked the topic very much as I got chance to learn for the first time”. “The topic on rainbow

formation was very interesting to learn, I was very curious to learn this topic when I was small only".

Method

The students' response in the interview questions also showed that they liked the method used to learn the concept. The reason they stated are as follow; "Predict-observe-explain method suits with the lesson", "It was simple to follow", "It helped me to understand the concept better" and "It was easy, simple and interesting to follow".

Model

Students also said they liked the rainbow model and their reasons were, "It was quite interesting to observe from the model". "Model helped me to see the colors in it and could also show the angles too". "The formation of spectrum was really interesting to observe". "It gave me clear idea, if I just learn theoretically I have to memorize but when I observe and do experiment it help me to remember". "With the model we were learning by doing with our hands and seeing with our own eyes".

Teacher

One student said he liked the creativity as given "I liked the creativity that you have used to create this model to teach on rainbow formation"

4.3.3 Overall views

From the students statement following are some of their views as given below;

"I was quite content with the lesson. I saw with my very own eye the rainbow formation with glass beads". "I am fully satisfied with this lesson as it was interesting to learn with interesting topic, suitable method and with model". One of the interviewee also said, "When I first saw this model I thought it was invented by some other scientists and the researcher was just using it to teach us about the rainbow but later I came to know it was your effort and creativity to bring this into shape. It was really very good".

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4.4 The Discussion on the Conceptual Understanding Test (CUT)

The purpose of the conceptual understanding test (CUT) items was to investigate students' conceptual understanding on rainbow formation. The conceptual understanding test (CUT) items were grouped under six concepts. The six concepts are spectrum formation by raindrop, conditions necessary for rainbow formation, rainbow shape, color sequence in a rainbow, ray diagrams and locating rainbow. In the following section, the responses of the students in conceptual understanding test (CUT) have been discussed as follows;

4.4.1 The discussion on the students' level of understanding in conceptual understanding test (CUT)

As can be seen from Table 4.2 item 6, 8, 12, 15 and 17 correspond to the concept about spectrum formation by raindrop. In this concept 60.3 percent of students could achieve in sound understanding category indicating that they understood light is composed of different wavelengths that make up different colors, refractive index of rain drop separates the colors of light as the wavelength dependence of the refractive index of the raindrop produces the spectrum by raindrop thereby seeing a spectrum of colors when rain drop is illuminated by sunlight, the smaller bending of red light at the first surface causes it to strike the back surface of the drop at a greater angle of incidence and geometrically the angle of refraction subtended should be equal to angle of incidence in the raindrop. However, 37.5 percent of students were found to have some alternate conception. These percent of students either could not answer correctly in first-tier or second-tier indicating that students understood partially about the property of light and rain drop that contribute in forming spectrum, the processes that undergo in a raindrop to form spectrum, the reason for deflection of different color light at different angle by raindrop. This shows that the learning in this group of students was not meaningful learning, but superficial and some type of rote learning. It also means that students got the answer correct without really knowing the right answer but getting the answers correct through guessing. In addition, there were also 2.2 percent of students who could not understand the concept despite intervention of learning unit thus falling in no understanding category.

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Item 7 and 9 correspond to the concept on conditions for rainbow formation. In this concept 79.2 percent of students are in sound understanding category indicating that they understood that to see a rainbow, there has to be sun, rain and observer. Rainbows are seen in the direction opposite to the sun due to reflection and the relative position of sun with respect to observer has to be behind and above. Nevertheless, 20.8 percent of students still have some specific alternative conception. These percent of students thought that rainbow is seen in the direction opposite to sun because of refraction of light and they were also not so sure about the relative position of sun and observer during rainbow formation.

Item 1, 2 and 3 correspond to the concept about shape of a rainbow. As can be seen from Table 4.2 in this concept, 68.2 percent of students are in sound understanding category indicating that they understood that rainbows are bow-shaped because specific color light in a rainbow are reflected at fixed angle giving rise to circular shape, it is half-circle as the earth gets in the way otherwise a complete circle rainbow can be seen as in the case of rainbow seen in the atmosphere from an air plane when it is flying. However, 28.2 percent of students were found to have some alternate conception. These percent of students know that the shape of rainbow are bow-shaped from their experience but the reason they give for bow-shaped rainbow are because of the curved earth surface or spherical shape of rain drops. This shows that the learning in this group of students was superficial and some type of rote learning. There are 3.6 percent of students who could not relate the idea of the bow-shaped rainbow to analogy ‘If you point to a wall with your arm extended to make about 42º angle to the normal to the wall and rotate in a full circle while keeping the same angle, The finger sweeps out a circular shape on the wall’ and moreover students could not picture how the rainbow would be seen if seen from an airplane. This shows the importance of direct experience with the real world in learning.

In the concept on color sequence in a rainbow the four items are 4, 5, 16 and 18. In this concept students are to tell the position of different colors in a rainbow correctly, state the reason why different colors are deflected at different angle and at what angle red and violet color light are deflected by rain drop. It was found that 80.2 percent of students could answer the items correctly thus fall in sound understanding category. However, 19.8 percent of students were found to have some alternative

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conception that these percent of students could not relate the idea that the change in position of the observer led to new set of rainbow. The question was "If you are looking at a rainbow from the ground floor of an apartment building and notices that the kite is hovering in the green portion and if you were to go up to the second floor then in which color you would likely see the kite hovering in?" Some of them also had problem in understanding that looking along a same line of sight enables them to see the same color for example; 'violet color is seen in the inner part of the arc in rainbow because we are looking along a same line of sight that has a smaller angle (40 degrees) for the violet'.

Item 13 and 14 correspond to the concept about students understanding on ray diagram. This item was about identifying the ray diagram that represents the formation of spectrum by single rain drop and the position of red and violet colors in rainbow by two rain drops In this concept, 50.4 percent of students are in sound understanding category indicating that only about half of the students were able to correctly answer this item. Actually, in item 13, as can be seen from Figure 4.1 the number of students that got correct in first tier is 80 and 89 in the second tier. But only 49 students got correct in both the tiers. Therefore, 31 students got first tier correct but wrong in second tier and 58 students got second tier correct but wrong in first tier. This is the reason for getting lowest percentage among all the six concepts. As a result, 47.9 percent of students were found to fall in specific alternative conception category in this concept. For example the question in item 13 says "which ray diagram correctly represents the formation of spectrum by single drop?"

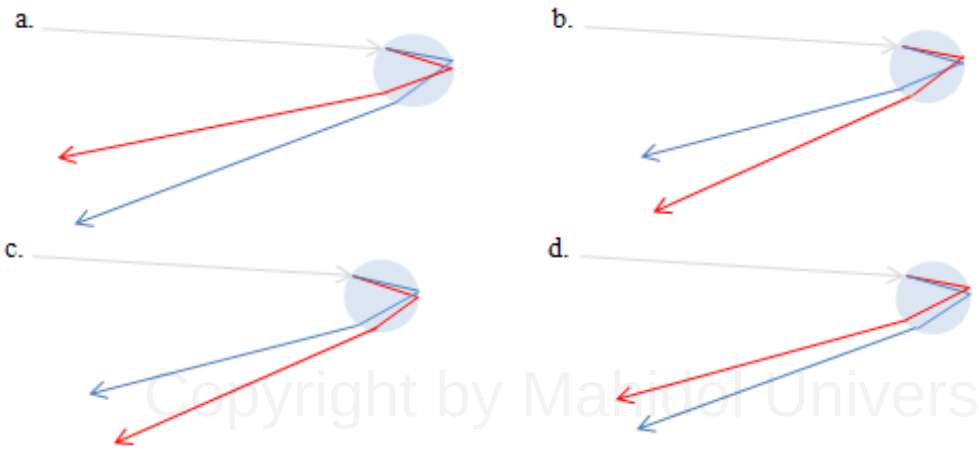

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Figure 4.5 To choose correct ray diagram for light's path in a rain drop

As can be seen from Figure 5.1, 89 students was able to respond to this question correctly by choosing the option b (see also figure 4.5) while 31 students selected other three options. 14 students chose option c and this group of students from their experience with model thought this is how red light is seen at bottom neglecting the fact that actually red light should be refracted less than violet before reflection at the back of the drop. 11 students chose option a and this group of students knew that white light separates into constituent color due to refraction and larger angle of reflection dominates in determining the overall deflection of the ray but refraction of red light should be less than violet is not taken care. 6 students chose option d taking into account that refraction of red light should be less than violet only and neglected that fact that the smaller bending at the first surface causes the red rays to strike the back surface of the drop at a greater angle of incidence than for the Violet rays. The red rays are reflected through a greater angle.

The percent of students in no understanding category in this concept is 1.7 as this group of students could not respond to the both tier correctly.

Item 7 and 9 correspond to the concept on locating rainbow. In this concept 73.4 percent of students are in sound understanding category indicating that they understood when and where to look for a rainbow if the conditions are suitable like if there are sun and rain. Nevertheless, 26.6 percent of students still have some specific alternative conception. These percent of students could not give the correct reason for setting and rising of rainbow below and above the horizon respectively as well as these students did not understand well where to look for rainbow in the evening and morning if the conditions are favorable.

Overall, with the intervention of learning unit it was found that 68.6 percent of students could understand well on all the six concepts about rainbow formation thus falling in sound understanding category. Biggs (1999) found that students can work collaboratively and in dialogue with others, both peers and teachers as per social constructivism theory. Good dialogue elicits those activities that shape, elaborate, and deepen understanding and this is one reason for having 68.6 percent in sound understanding category. Another reason is due to the use of POE learning cycle because (Coştu, Ayas, & Niaz, 2010) found that POE strategy helped students to achieve a better conceptual understanding. Third reason is due to the use of model for

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hands on learning. The result obtained from the study done by Hussain and Akhtar (2013) on "Impact of Hands-on Activities on Students' Achievement in Science" indicated that there was improvement of the students' science achievement. Moreover they also suggested that the results of this study are important especially for developing countries that cannot afford to use expensive science equipment to make the students physically active and engaged in learning science in which Bhutan is no exception. However, it was also found that 30.1 percent of students had some specific alternative conception while 1.3 percent of the students had no understanding about rainbow formation.

4.4.2 The discussion about percent gain from pre-test and post-test score on conceptual understanding test (CUT) items

As can be seen from Table 4.4 the maximum percent gain was in the concept of conditions necessary for rainbow formation. Item 7 and 9 correspond to this concept. The percent gain in this concept was 81.6% indicating that students have enhanced their conceptual understanding. Initially, students had minimal knowledge on this concept as can be seen from the pre-test percent (i.e., 7.2%). With the intervention of learning unit students achieved 88.8% in the post-test thereby resulting in maximum percent gain. Students understood that to see a rainbow, there has to be sun, rain and observer. Rainbows are seen in the direction opposite to the sun due to reflection and the relative position of sun with respect to observer has to be behind and above.

The minimum percent gain was in the concept of rainbow shape. The percent gain was 40.8 in this concept. Students' pre-test was found to be 33.9% which was the maximum from the entire concepts. It was because students knew the shape of rainbow is bow-shaped from their experience. With the intervention of learning unit student understanding about the shape of rainbow was enhanced to 74.7% in the post-test. This was the minimum from the entire concepts. Consequently, this concept has minimum percent gain.

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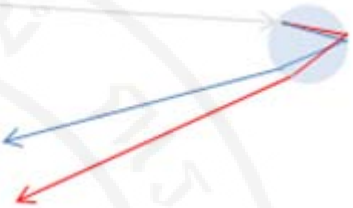
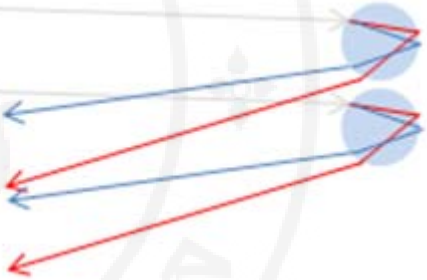
The percent gain in the concept about ray diagram was 51.4 with 30.6 percent and 82 percent in the pre-test and post-test respectively. In this concept students were required to identify correct ray diagram that the light would take its path

through rain drop(s). The correct representation of light's path in one and two rain drops as used in the pre-test and post-test questions are given in Table 4.12.

Table 4.12 The picture of light's path through rain drop(s)

	Pre-test	**Post-test**
One rain drop		
Two or more rain drops		

As can be seen from Figure 4.1, in the pre-test in second tier, 35 students choose the correct picture of light's path in one drop (see also Table 4.12). After intervention, in the post-test 89 students choose the correct picture. In case of choosing correct picture of light's path in two drops, in the pre-test there were only 7 students choosing right picture but with the intervention of learning unit, it was found that students choosing the correct picture increased to 88 in the post-test.

The percent gain in the concept about spectrum formation by rain drop is 53 with 29.7% in the pre-test and 83.3% in the post-test. One interesting finding with regard students prior knowledge associated in this concept about spectrum formation by rain drop was because they have learnt about spectrum formation concept with the use of prism in lower grades and moreover from their observation and experience, in the prediction phase all the student drew the shape of rain drop as tear-shaped (similar to prism) and spectrum being formed as it would in the prism as shown in Figure 4.6, when asked to predict and draw as of how spectrum would be formed by a rain drop.

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Later, students' conceptual understanding about the ray diagram was found to be shifted to correct understanding. This result was similar to findings of Watson and Konicek (1990) about the comparison between the experimental results and the predicted outcome helping the learner to be aware when a conceptual shift was needed.

Figure 4.6 Diagram of spectrum formations by a raindrop in prediction phase

To investigate students' concept about color sequence in a rainbow there were 4 items, item 4, 5, 16 and 18. It was found that the percent gain in this concept was 65.5. Students' pre-test score in this concept was 14.2% and post-test was 79.7%. For example as can be seen from Figure 4.1 in item 4 in the pretest 17 students were able to correctly identify rainbow from the four pictures given in Figure 4.7. It was seen that 60 students chose a, 43 students chose c and none opted for d. With the intervention of learning unit, in the post-test all the 120 students were able to give correct answer to item 4.

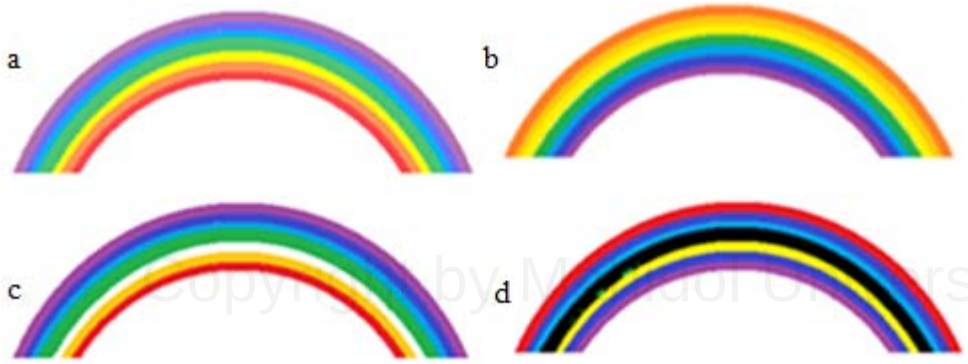

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Figure 4.7 Pictures for the students to identify rainbow

In the concept about locating rainbow the percent gain is 66.9 with 23.3% in pre-test and 90.8% in the post-test. This indicates that after the intervention of learning unit students were able to understand when and where to look for a rainbow if the conditions are suitable such as sunlight and rain.

In general, it can be seen that students' conceptual understanding was enhanced. This enhancement of their concept is due to involvement of the students both physically and mentally. As they were engaged in hands-on activities; they were also involved in a process of inquiry, discovery, investigation, and interpretation.

4.5 The Discussion of the Students' responses in the Learning Unit Opinion Survey Questionnaire (LUOSQ)

There were 28 items in learning unit opinion survey questionnaire items. For the purpose of analysis, these items were grouped into six themes and their average mean were found as can be seen in Table 4.11.

Simpson et. al (1994) have published an extensive review about students' opinion towards different science subjects. They found that generally, students have positive opinion towards a subject which was more interesting. Similarly, in this study the average mean on the theme "topic and the lesson" was 4.70. This means that the items were strongly agreed by the students that the topic of the lesson was interesting, suitable with their level, well organized in a way that helped them learn better, useful for them to understand about rainbow formation, and not very difficult for them to understand.

Liew (2004), in the study that investigated the effectiveness of POE activities, attempted to determine the impact of POE activities on students' science conceptions and achievement levels. As a result, it was observed that even those students exhibiting negative attitudes expressed their opinions using predict-observe-explain method. The study suggests that the method is influential in determining student achievement. In this study, although researcher did not attempt to study on students' attitudes, the mean score indicates some similarity with Liew's finding. The average mean on the theme "the learning method" was 4.63, this means that it is strongly agreed by the students that the learning method was suitable, made them think

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critically, understand the concept scientifically and students also prefer to learn using this method in future.

The average mean on the theme “the class activities” was found to be 4.67, this means that students strongly agrees that their activity was guided by instructions sheet, engaging, involve wholly in the aspects of hands-on, eyes-on and minds-on, let them learn with rainbow and it had minimal lecture but guided learning signifying that teacher was mentoring and challenging students indicating that teacher’s role were grounded based on theory of social constructivism.

Watson (2003) have described teaching as an intensely psychological process and believe a teacher’s ability to maintain productive classroom environments, motivate students, and make decisions depends on her personal qualities and the ability to create personal relationships with the students. Research by Larson and Silverman (2000) and Noddings (1984) has emphasized the importance of developing a caring and respectful relationship between teachers and students. Effective teachers genuinely care, like, accept, and value their students. These teachers will demonstrate kindness, share responsibility, accept diversity, foster individual instruction, and encourage creativity. In addition, the finding from this study suggest that teacher was well prepared, open, support students learning and used simple language to describe things which was understandable. The average mean on the theme “the teacher” was 4.75.

The average mean on the theme “indoor rainbow model” was 4.75 and this means that it was strongly agreed by the students that indoor rainbow model has helped them to understand concept, safe, inexpensive, convenient to use even in bright room, portable and innovative and interesting. From previous studies done with other models it can be seen that students prefer model if it encourages hands-on learning, exactly represent the real phenomenon, portable and user friendly. Moreover, according to Atecs and Eryılmaz (2011) students must perform hands-on and minds-on activities to learn physics better but special laboratory environment or complicated apparatus is not necessary.

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The average mean on the theme “the overall learning unit” has the maximum average mean of 4.76 indicating students’ strong agreement with the learning unit. Students strongly agreed that there was no problem using learning unit,

learning unit encouraged self-learning, use of learning unit helped in retention of the concept in long term memory and students achieved full satisfaction using learning unit.

Finally, as given in Table 4.11 the response of the students on learning unit opinion survey questionnaire (LUOSQ) items show strong agreement as the overall mean of all the items were 4.71.

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CHAPTER V
CONCLUSIONS

Overview

This chapter concludes and summarizes the whole research by answering research questions. The limitations of the study and recommendations for further study are also given in this chapter.

5.1 Summary of the Whole Research

There are two main purposes of the research described in chapter 1. They are 1) to investigate students' conceptual understanding about natural phenomenon on rainbow formation and 2) to investigate students' opinion on the developed learning unit.

In chapter 2, the educational researches on teaching and learning physics ranging from around the world to Bhutan are discussed followed by study about rainbow in Bhutanese curriculum. Studies on rainbows, review on the learning theory followed by hands-on learning and the POE learning cycle is also done in this chapter.

In chapter 3, the components, construction and uses of the model developed and used in this research study are explained. This chapter also has research design, participants, instruments and the details of the development of CUT, LUOSQ, and interview questionnaires.

In chapter 4, the results and discussions of this study is provided.

There were 18 two tier multiple-choice questions in the CUT items covering six concepts as follow; 1) Spectrum formation by rain drop, 2) Conditions for rainbow formation, 3) Rainbow shape, 4) color sequence 5) Ray diagrams and 6) Locating rainbow. The instruments were all prepared in English version and validated by two experts from Thailand from the field of education and physics education and

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three experts from Bhutan who had more than 5 year experience in teaching physics for higher secondary students.

The learning activity for students in this study was designed based on POE learning cycle covering same concept as CUT. Students were encouraged to learn from any conflict between their prediction and observation during the explanation phase. The actual intervention of the learning unit was for 2 periods (one period = 60 minutes). Students response to CUT were analyzed by finding the levels of students' conceptual understanding and comparing mean scores of pre-test and post-test (percent gain).

5.2 Answering the Research Questions

There are two research questions in this study. They are given in order as stated in chapter 1.

5.2.1 Research question 1

To what extent has the learning unit enhanced students in understanding the concept about Rainbow formation in Nature?

Answer

To answer this question the findings from students' conceptual understanding test (CUT) and learning unit opinion survey questionnaire (LUOSQ) was used. From CUT there are three findings and they are as follow;

First, through analysis of the students overall mean score in the pretest and posttest it was found that the average score in the pre-test was 23.3% and in the post-test was 82.3%. This clearly shows that there is increase in the average score in post-test by 59%. This is one proof to conclude that there was improvement in the post-test result indicating that students' conceptual understanding was enhanced.

Second, through looking at overall percent in each understanding level, it was found that students in the sound understanding category are the highest that was 68.6 percent. Rest 19.1 percent in partial understanding with specific alternative conception category, 11 percent in the specific alternative conception category and minimal in no understanding category it was just 1.3 percent. So 68.6 percent in the

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sound understanding also proofs that students' conceptual understanding was enhanced.

Finally, the overall mean in LUOSQ was 4.71. This shows that students strongly agreed that topic and lesson was interesting, teacher was well prepared and guided them to learn, learning method was suitable for them as well as with lesson, model helped them learn through hands-on, activities were engaging and overall they were satisfied with the learning unit. Therefore, these findings from LUOSQ also support the authenticity of the enhancement of students' conceptual understanding.

5.2.2 Research question 2

What are the students opinion on the developed learning unit used in the lesson?

Answer

The findings from students' response in LUOSQ item can be used to answer this research question. The findings from LUOSQ items are supported by interview responses wherever relevant. The findings according to the themes are as follow;

Topic and lesson

Students strongly agree to all the opinions in this theme saying that; the topic of the lesson was interesting, suitable with their level, well organized in a way that helped them learn better, useful to understand about rainbow formation and not very difficult for them to understand as the mean were 4.84, 4.76, 4.62, 4.72, and 4.57 respectively.

Student's response in interview also justifies that the topic was interesting as quoted here "The topic on rainbow formation was very interesting to learn, I was very curious to learn this topic when I was small only".

The teacher

The students' opinion in this theme also showed strong agreement saying that teacher was well prepared for the class, open to students' opinion and supported students' investigation by being a resource person and used simple language to describe things which was easy to understand. The mean are 4.82, 4.73, 4.75, and 4.70 respectively.

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Students' responses in interview also showed that students had high regard with teacher because of creating model as given here "I liked the creativity that you have used to create this model to teach this topic on rainbow formation".

The class activities

The students' opinions regarding the theme on class activities also showed strong agreement. They strongly agree that the instruction sheets and activity sheets were clear and easy to understand, the activities used in the lesson were engaging, the lesson made them learn hands-on, eyes-on and minds-on, gave them opportunity to learn with rainbow and had minimal lecture but guided learning. The mean on each items are 4.75, 4.60, 4.75, 4.82, and 4.45 respectively.

The learning method

In this theme also students opinion showed strong agreement that the learning method was suitable, made them think critically, made them understand the concept scientifically and prefer to learn using this method in future. The respective mean are 4.63, 4.51, 4.65, and 4.73.

Students in response to interview said POE method was simple to follow and effective in learning as quoted here, "POE was quite a good method as it helped me to understand the concept better", and "It was easy, simple and interesting to follow".

The indoor rainbow model

The students' opinion in this theme also showed very strong agreement as they strongly agreed that Indoor rainbow model has helped them to understand concept, safe, inexpensive, convenient to use even in bright room, portable and innovative and interesting. The mean are 4.77, 4.74, 4.76, 4.72, 4.80, and 4.71 respectively.

The following are some of the response from interview about model. "I liked the rainbow model". "It was quite interesting to observe from the model". "Model helped me to see the colors in it and could show the angles too". "The formation of spectrum was really interesting to observe". "It gave me clear idea, if I just learn theoretically I have to memorize but when I observe and do experiment it help me to remember". "With the model we were learning by doing with our hands and seeing with our own eyes".

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The overall learning unit

Students strongly agreed in this theme too saying that there was not any problem during the use of learning unit, the learning unit helped them to do the self-learning, the learning unit certainly helped them to retain the new concepts learnt in their long-term memory and overall, they agreed that they achieved full satisfaction using learning unit. The respective mean are 4.66, 4.71, 4.74, and 4.91.

The students' response in the interview also showed strong agreement with learning unit as quote here "I was quite content with the lesson. I saw with my very own eye the rainbow formation with glass beads". "I am fully satisfied with this lesson as it was interesting to learn with interesting topic, different method and with model".

The overall mean in LUOSQ items was 4.71. This indicated that the opinion of students shows strong agreement with all the themes about the learning unit. Students strongly agreed that topic and lesson was interesting, teacher was well prepared and guided them to learn, learning method was suitable for them as well as with lesson, model helped them learn through hands-on, activities were engaging and overall they were satisfied with the learning unit.

5.3 Limitations of the Study

The study has some limitations which need to be considered as follows:

The sample in this study was drawn from one district in Bhutan.

The test was administered immediately after carrying out the learning unit and it does not provide information whether students will remember later.

5.4 Recommendations for Further Study

The recommendations for further study are as follows:

If samples can be collected from other districts in Bhutan as well as schools from other countries and compare the findings.

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Test to be administered few months after intervention of learning unit to check the effectiveness of learning unit and students' long term memory.

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APPENDICES

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APPENDIX A

LESSON PLAN

Topic: Rainbow (Part I) **Subject**: Physics.
Grade: XI **Time:** 60 minutes

Prerequisite knowledge:

Dispersion

The splitting of light into its different components is called dispersion of light. Example a prism is used to disperse light into its different components. ("ROYGBIV" is an acronym for these wavelengths, which are the colors of the ***visible spectrum.***

Reflection

A ray of light striking a mirrored surface at an angle to the perpendicular will be reflected back at the same angle on the other side of the normal.
The laws of reflection are as follows:

- The incident ray, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane.
- The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal.
- The reflected ray and the incident ray are on the opposite sides of the normal.

Refraction

If a light ray passes from one medium into another of different optical density (and at an angle other than perpendicular to the surface between the two media), the ray will be 'broken'. This behavior is called refraction, and is caused by the change of speed of the light as it passes between transparent media of different optical densities.

Critical angle

The critical angle is defined as the angle of incidence that provides an angle of refraction of 90 degrees. For the water-air boundary, the critical angle is 48 degrees. For the crown glass-water boundary, the critical angle is 61 degrees.

Total internal reflection (TIR)

Total internal reflection is the phenomenon that involves the reflection of the entire incident light off the boundary. Total internal reflection only takes place when both of the following two conditions are met:

i. A light ray is in the denser medium and approaching the less dense medium.
ii. The angle of incidence for the light ray is greater than the so-called critical angle.

Teaching strategy: Predict-Observe-Explain (POE) learning cycle

Lesson Objectives: On completion of the lesson, each student should be able to;

i. Tell the conditions necessary for forming rainbow.
ii. Describe the mechanism of how different color/spectrum is formed by rain drop.
iii. Draw the ray diagram showing the path of Violet and Red color in a water droplet.
iv. Draw ray diagram to show the position of how two colors can be seen from two raindrops, especially red and violet color.
v. Give reason about how different colors are seen in a rainbow.

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Main Concept:

An arc of spectral colors that appears in the sky opposite the sun as a result of the refractive dispersion of sunlight in drops of rain or mist is called rainbow.

The rainbow is caused by light from the sun interacting with raindrops falling from the air. These raindrops are mostly spherical. A ray of light entering such a droplet is bent (refracted) and decomposed into all possible colors (wavelengths) which the white light consists of. The ray then reflects internally in the droplet, and emerges roughly into the direction it came from when it entered the drop. Since the rays of the different colors all exit at slightly different directions, we see a color band in the sky.

In a droplet, Red light will be deviated more because the smaller bending at the first surface causes the red rays to strike the back surface of the drop at a greater angle of incidence than for the blue rays. The red rays are reflected through a greater angle, according to the law of reflection. This larger angle of reflection dominates in determining the overall deflection of the ray.

The color of primary rainbow from outside are arranged in the following sequence as red, orange, yellow, green, blue, indigo, and violet.

The rainbow we normally see is called the **primary** rainbow and is produced by one internal reflection and the rays exit the drop at an angle of 42°degrees for the red primary bow. Violet light emerges at an angle of 40 degrees°. Thus, the arc shows red on the outer part and violet on the inner side.

Materials needed:

- ✓ Indoor rainbow model of size 72 x 50 x 7.5 centimeters
- ✓ Glass spheres
- ✓ light source
- ✓ Pencils
- ✓ Protractor
- ✓ Ruler
- ✓ Pictures of rainbow
- ✓ Instruction sheet
- ✓ Activity sheet 1A, 1B and 1C

Teaching Plan Concepts	Activities	Expected Outcomes
Introduction Teacher: We see that the spectrum formation taking place in nature. What is the spectrum that we see in nature called? Teacher: Yes, It is 'Rainbow' (teacher writes the topic on the board) Teacher then shows the pictures of rainbows and asks following questions to seek basic information that student already know about rainbows. Teacher: When do we see a rainbow? Teacher: Great! As you say, to see a rainbow, we need the sun and rain or any other source of water droplet. Do you remember when you last saw a rainbow? Teacher: What was your direction	Divide the class into groups of 4 students each. Student responds to the teacher about what they see from the picture.	"Rainbow" We see rainbow only when there is sunlight and rain or when there is another source of water droplets such as a garden sprinkler. Yes sir!

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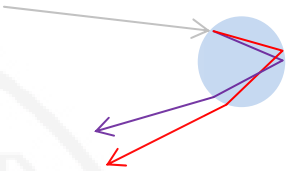
relative to the Sun and rain, when you last saw a rainbow? Teacher: The sun was behind you? Teacher: Yes you are right! We have to face away from the sun to see rainbows. But tell me, why do we have to face away from the sun to see a rainbow? Teacher: Reflection! If it is reflection then how is reflection responsible for giving off different colors in a rainbow? Teacher: Yes, you are coming to the point, keep going. Teacher: Excellent! That's it. The light first refracts when it enters the drop, splitting into different colors and then it is reflected off the inside and finally undergoes refraction once again (like prism dispersing light and placing a mirror to reflect the colors). Okay, now let us try to define what a rainbow is?	Student responses to the teacher to the questions that have been asked.	I was facing the rain and of course the sun was behind me. The rainbow appeared on the opposite side of the sky from the sun. Yes sir! Um… since rainbows are seen on the side away from the sun, the cause of rainbow is due to reflection from the water droplets. Yes, straight reflection would not involve in separating the white light into its constituent colors. To separate colors in white light there must be refraction. Thank you sir. Firstly, when the light enters the raindrop, due to difference in the density of medium it refracts-splitting the light into different colors. Then it bounces off the inside, the arriving light is hitting every possible position on half of the raindrop; but we only see the light that happens to be headed towards us. An arc of spectral colors that appears in the sky opposite the sun as a result of the refractive dispersion of sunlight in drops of rain or mist is called rainbow.
Predict Teacher: Excellent! Teacher then distributes **activity sheet 1A** to the students to be used in this stage. Teacher: Now, we know that the light first refracts when it enters the drop, splitting into different colors and then it is reflected off the inside and finally undergoes refraction once again. If this is the case draw neat rays diagram	Students draw and independently write their prediction of what they think they will see and why they think this.	Ray diagrams would vary.

to show how the rays would travel in single drop. You just show two colors; Violet and Red only to represent spectrum. Teacher: okay, now let us see what our model has to show us all about these.		Varied answers
Observe Teacher gives **instruction sheet 1** and **activity sheet 1B**. The details of how the activities to be carried out are given in the **instruction sheet 1**. Teacher also introduces the model and explains how to use it.	Allow time to focus on observation. Students carryout their work with the model following the instructions from the instruction sheet	
Explain (activity sheet 1C) Teacher: Discuss and answer the following questions in your group. After you have finished answering, anyone from the group can present the group's finding to the whole class. 1. What did you observe from the indoor rainbow model? 2. How do you think different colors are formed by the sphere? 3. Write down the sequence of the color as you saw from the model. 4. Where did you see red color light in the spectrum? 5. Which color light is diverted through a larger angle? Why? Teacher: Summarize the steps involve for rainbow formation as follow; - Light from sun strike raindrop - Some of the light is reflected - The rest of the light is refracted - Light splits into component colors - Reflected at a rear of raindrop - Refracted again as it leaves raindrop - Colors are further dispersed.	Students amend or add to their explanation to take account of the observation. After students have committed their explanations to paper, discuss their ideas together. (Students also discuss briefly about the angles formed by normal and refracted rays inside the circle given in the picture at the right hand side)	We saw different color in the sphere. The sphere was able to form different colors due to refraction. ROYGBIV from bottom. The red color light was below other colors in the spectrum The smaller bending at the first surface causes the red rays to strike the back surface of the drop at a greater angle of incidence than for the Violet rays. The red rays are reflected through a greater angle, according to the law of reflection. This larger angle of reflection dominates in determining the overall deflection of the ray.
Predict Teacher gives **activity sheet 2A** to the students to be used in this stage. Teacher: in the earlier case we saw that red light is diverted through a larger angle than violet light. Am I right? Now note down, what color will be at the top and bottom of the rainbow? Why?	Let them draw and make their prediction of what they think they will see and why they think this.	Yes sir Varied answers The red color will be at the top and blue color will be at the bottom.

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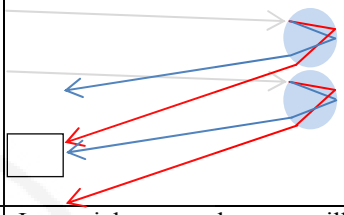
Draw ray diagram to show how the rays would travel in two droplets placed vertically to each other?		(varied reasons) The ray diagram would vary.
Observe Teacher gives **instruction sheet 2** and **activity sheet 2B.** The details of how the activities to be carried out are given in the instruction sheet 2.	Allow time to focus on observation. Students carryout their work with the model following the instructions from the instruction sheet	
Explain (activity sheet 2C) Teacher: Where does an observer see Red and Violet color in a rainbow? Why? Teacher: great! But why? Write down the sequence of the color in a rainbow.	Students amend or add to their explanation to take account of the observation. After students have committed their explanations to paper, discuss their ideas together.	In a rainbow an observer will see red on the outer side and blue in the inner side. It is because; the rays exit the drop at an angle of 42°degrees for the red and Violet light emerges at an angle of 40 degrees.

Evaluation

To evaluate students' conceptual understanding of the lesson teacher looks into some selected works of students in the activity sheet and asks questions given below to few students;

i. Draw a ray diagram on the board to show the path taken by light ray to form spectrum by single spherical water drop.
ii. With the help of the diagram from the board explain the mechanism for forming spectrum by single spherical water drop
iii. Draw a ray diagram on the board to show the path taken by light rays to form spectrum by two spherical water drops at vertical to each other.
iv. With the help of the diagram on the board explain the mechanism for forming spectrum by two water drops.
v. Give reason for the sequential arrangement of colors as seen in a rainbow.

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Topic: Rainbow (Part II) **Subject**: Physics.
Grade: XI **Time:** 60 minutes

Lesson objectives:
i. Give reasons for the bow-shaped rainbows (geometry).
ii. Tell when and where to look for rainbow if the conditions are favorable?

Main concept:
The rainbow is the arc of a circle, whose center is on a line from the observer's viewpoint; the arc of the rainbow is displaced about 42 degrees from that centerline. We don't see a full circle because the earth gets in the way. The lower the sun is to the horizon, the more of the circle we see right at sunset; we would see a full semicircle of the rainbow with the top of the arch 42 degrees above the horizon. The higher the sun is in the sky, the smaller is the arch of the rainbow above the horizon.

The center of the circular arc of the rainbow is in the direction opposite to that of the sun. So, our shadow will be formed at the center of the rainbow.

The sky is brighter inside a rainbow. Notice the contrast between the sky inside the arc and outside it. When one studies the refraction of sunlight on a raindrop one finds that there are many rays emerging at angles smaller than the *rainbow ray*, but essentially no light from single internal reflections at angles greater than this ray. Thus there is a lot of light within the bow, and very little beyond it. Because this light is a mix of all the rainbow colors, it is white. Therefore a dark region outside a rainbow is called Alexander's Dark Band, in honor of Alexander of Aphrodisias who discussed it some 1800 years ago!

The rainbow is not located at a specific distance, but comes from any water droplets viewed from a certain angle relative to the sun's rays. Thus, a rainbow is not an object, and cannot be physically approached. Indeed, it is impossible for an observer to see a rainbow from water droplets at any angle other than the customary one of 42 degrees from the direction opposite the sun. Even if an observer sees another observer who seems "under" or "at the end of" a rainbow, the second observer will see a different rainbow—further off—at the same angle as seen by the first observer. As the eyes of two people cannot occupy the same place in space at the same time, each observer sees a different rainbow because the raindrops are constantly in motion so its appearance is always changing. Each time you see a rainbow, it is unique in its own spectacular way.

Materials required:
- ✓ Tiny glass beads
- ✓ Black cloth
- ✓ Light source
- ✓ Pencils
- ✓ Activity sheet 3A, 3B and 3C

Teaching Plan Concepts	Activities	Expected Outcomes
Introduction To recall previous lesson ask a volunteer student to draw a diagram to show how colors are seen from two drops. Explain briefly the mechanism of how rainbow colors are seen from water droplets.	Divide the class into groups of 5 students each.	
Predict Teacher gives **activity sheet 3A** to the students to be used in this stage. Teacher: make your prediction for the following questions; - What will you notice if light is	Let them write their prediction of what they think they will see and why they think this.	Rainbow The top portion of the rainbow colors will set and rise.

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shine on a layer of beads ball on a black screen? - What will happen if light source is moved vertically up and down? - Where will the shadow of your head fall in a rainbow?		In the center of a rainbow
Observe Teacher gives **activity sheet 3B.**	Allow time to focus on observation. Students carryout their work with the model	
Explain (activity sheet 3C) Why rainbows are bow/arc shaped? And why full circle rainbows are not seen? Where would the shadow of our head be in the rainbow? Where in the sky would you expect to see a rainbow in the evening? At what time of day and in what direction would you look to see the top of a rainbow set below the horizon? If an observer sees his kite hovering in green portion of the rainbow from ground floor of an apartment building and if s/he moves to 1st floor then in which portion (Red or Violet) of the rainbow does s/he expect to see his/her kite hovering in? Why?	Students amend or add to their explanation to take account of the observation. After students have committed their explanations to paper, discuss their ideas together.	As the sunlight enters tiny water droplets, some of it is reflected by its surface. But each frequency bounces back at a different angle and that separates the white light into its spectrum of all colors. When it comes back to the eyes of observer, it is as a rainbow of roughly 40 degrees circle. As seen from the ground, it is only an arc of a circle as the bottom half is blocked by the earth. The center of the circular arc of the rainbow is in the direction opposite to that of the sun. So, our shadow will be formed at the center of the rainbow. Towards the east. Morning, towards the west. Violet portion. Because as the observer moves up to the 1st floor, the position of the sun and the kite remains almost stationary and because of the slightly change in the angle of the position of an observer's eye, the rainbow seem to rise above, thus the kite will be seen hovering in the Violet portion.

Evaluation

To evaluate students' conceptual understanding of the lesson teacher looks into some selected works of students in the activity sheet and asks questions given below to few students;

i. Explain why rainbows are bow shaped?
ii. Why full circles rainbows are not seen?
iii. Tell some conditions to see a full circle rainbow.

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APPENDIX B

ACTIVITY SHEETS

Activity 1A

Instruction: Base on the Rainbow phenomena in our everyday life, please predict and answer following questions.

i. What will you observe on the glass sphere if you shine white light on it?

……
……
……
……

ii. Draw rays diagram to show how the rays would travel in single rain drop by showing just two colors; Violet and Red only.

iii. Write the reasons why you think it will happen this way.

Because……
……
……
……
……
……

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Activity 1B
Instruction: Please answer the following questions, after the experiment.

i. What did you observe on the glass sphere when you shine white light on it?
……
……
ii. Which colored light is diverted through larger angle? Why?
Color
……
Because……
……
iii. Draw a ray's diagram to show how the rays traveled in a glass sphere (follow the instructions to from instruction sheet).

iv. Fill up the blanks to complete the mechanism of forming of spectrum by a water drop.
   a. The sunlight …… on the water drop
   b. Due to the change in the medium, the light rays …….. away from normal.
   c. As a result, the light rays splits into constituent color. The Violet color is refracted …… than Red color inside the water drop.
   d. The colored lights then strikes at the back of the drop. The angle of incidence for Violet light is ……. than that of Red light.
   e. At the back of the water drop, as the color lights are reflected the angle of …… is equal to the angle of …….
   f. Thus Violet light is deviated …… than Red light because the smaller …… at the first surface causes the red rays to strike the back surface of the drop at a greater angle of incidence than for the Violet rays. The red rays are reflected through a greater angle, according to the law of reflection.

Activity 1C

Instruction: Discuss and answer the following questions in your group. After you have finished answering, anyone from the group can present the group's finding to the whole class.

1. What did you observe from the indoor rainbow model?

Ans:……
……
……
……

2. How do you think different colors are formed by the sphere?

Ans:……
……
……
……
……

3. Write down the sequence of the color as you saw from the model.

Ans:……
……
……
…….

4. Where did you see red color light in the spectrum?

Ans:……
……
……
……
……

5. Which color light is diverted through a larger angle? Why?

Ans:……
……
……
……
……
……

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Activity 2A

Instruction: Based on the Rainbow phenomena in our everyday life, please predict and answer following questions.

i. What will you notice from the two spheres?

Ans:……
……
……
……
……

ii. Draw rays diagram to show how two colors lights can be seen from two drops.

iii. Write the reasons why you think it will happen this way.

Because……
……
……
……
……

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Activity 2B
Instruction: Please answer the following questions, after the experiment.

i. What did you notice from the two spheres?
Ans:……
……
……
……
ii. Write the reasons why it happened this way.
Ans:……
……
……
……
iii. Draw rays diagram to show how two colors lights can be seen from two drops

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Activity 2C

Instruction: Discuss and answer the following questions in your group. After you have finished answering, anyone from the group can present the group's finding to the whole class.

1. Where does an observer see Red and Violet color in a rainbow? Why?

Red:

……
……

Violet:

……
……

Because:……
……
……
……
……
……

2. Write down the sequence of the color in a rainbow.

Ans:……
……
……
……
……

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Activity 3A

Instruction: Base on the Rainbow phenomena in our everyday life, please predict and answer the following questions.

1. What will you notice if light is shine on a layer of beads ball on a black screen?

Ans:.....……
……
……
……
……
……

2. Where will the shadow of your head fall in a rainbow? Why do you think so?

Ans:.....……
Because……
……
……
……
……..

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Activity 3B
Instruction: Please answer the following questions after observing from the model.

1. What did you notice when light is shine on a layer of beads ball on a black screen?
Ans:.....……
……
……
……
……
……

2. Where did the shadow of your head fall in a rainbow? How did you know this?
Ans:.....……
Because……
……
……
……
……

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Activity 3C

Instruction: Discuss and answer the following questions in your group. After you have finished answering, anyone from the group can present the group's finding to the whole class.

3. Why rainbows are bow/arc shaped?

Ans:……
……
……
……
……
……

4. Why full circle rainbows are not seen?

Ans:……
……
……
……
……
……
……

5. Where would the shadow of our head be in the rainbow?

Ans:……
……
……
……
……
……
……

6. Where in the sky would you expect to see a rainbow in the evening?

Ans:……
……
……
……
……
……

7. At what time of day and in what direction would you look to see the top of a rainbow set below the horizon?

Ans:……
……
……
……
……
……
……

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APPENDIX C

INSTRUCTION SHEETS

Instruction Sheet 1
Follow the instruction, observe the experiments, and then answer the questions in Activity 1B.

How to do experiment with model

1. In the model adjust the eyepiece in such a way that you can see the spectrum. When you can see the spectrum carefully move the eyepiece to see Red light and note down the angle made by the pointer and tabulate below.

No. of experiments	Angle deflected (θ) for red light	Angle deflected (θ) for violet light
1		
2		
3		
Total		
Mean		

Using the equations; $r = Sin^{-1} (\sin i/ \mu)$ and $\theta = (4 r - 2i)$, calculate the value for r and θ for both red and violet light and tabulate it in the table below. (Given refractive index of glass for Red and violet light are 1.515 and 1.533 respectively).

i	r	θ
20		
30		
40		
50		
60		
70		

Figure out the maximum deflection (θ), for each color from the table.

How to draw rays diagram

Procedures;

1. Draw a circle to represent a glass sphere
2. Draw horizontal line AB as light ray. Draw another horizontal line PQ parallel to AB below the circle.
3. Draw normal N_1 from the center of circle O to point B and extend it.

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4. Place the protractor straight to the normal N_1 and its center at point B. Measure angles obtained from the calculation for red and violet light respectively and mark with dot. Draw lines from point B to these points and extend till the back of the circle at point C and D.
5. Draw normal N_2 and N_3 from the center of circle O to point C and D. Extend this line.
6. Place the protractor straight to the normal N_2 and its center at point C. Measure angles as obtained from calculation for red light. Draw lines from point C to these points and extend till in the front of the circle at point E. Extend the line further to meet the horizontal line PQ at point G.
7. Place the protractor straight to the normal N_3 and its center at point D. Measure angles as obtained from calculation for violet light. Draw lines from point D to these points and extend till in the front of the circle at point F. Extend the line further to meet the horizontal line PQ at point P.
8. Measure the angles subtended at point G and P. This will be the total angle of deflection for red and violet light respectively.

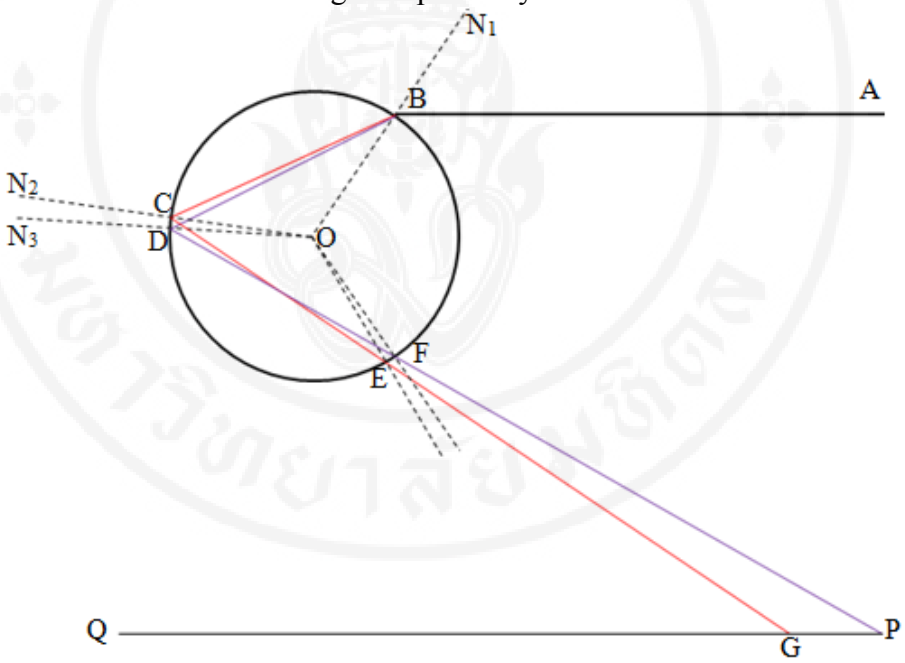

Figure showing sample ray diagram of how the rays traveled in a rain drop for red and violet light

Instruction Sheet 2

How to draw rays diagram (Hint)

1. Draw 2 circles of same radius aligned vertically to each other.
2. Follow the same procedure as in single sphere.
3. The red light from upper sphere and violet light from lower sphere directs to eye of an observer.
4. The violet light from upper sphere and red light from lower sphere deviates out of sight.

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APPENDIX D

REVISED CUT ITEMS

Previous version of item 4 and 16

1. a. Which color is seen inside a rainbow?

☐ Red

☐ Violet

b. The acronym that shows the correct order of rainbow color from inside is

O VIBGYOR

O ROYGVIB

O RVIYOGB

O VRBGOYI

16 a. The colors in a rainbow is seen at different angles

☐ True

☐ False

b. Because

O Violet light is deviated more.

O Red light is deviated more

O Both red and violet light are deviated equally

O None of them

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Revised Version of item 4 and 16

4 a. In a rainbow, blue color is seen in the outer part of the bow

☐ True

☐ False

b. Because the correct order of rainbow color from inside is

O Violet, Indigo, Blue, Green, Yellow, Orange and Red

O Red, Orange, Yellow, Green, Blue, Indigo and Violet

O Red, Violet, Indigo, Yellow, Orange, Green and Blue.

O Blue, Indigo, Violet, Yellow, Orange, Green, and Red

16 a. The angle of deviation of violet light is more than red light.

☐ True

☐ False

b. Because

O The violet rays exit from the drops at an angle of 41°degrees and red light emerges at an angle of 40 degrees from the drops.

O The red rays exit from the drops at an angle of 40°degrees and violet light emerges at an angle of 41 degrees from the drops.

O The violet rays exit from the drops at an angle of 42°degrees and red light emerges at an angle of 40 degrees from the drops.

O The red rays exit from the drops at an angle of 42°degrees and violet light emerges at an angle of 40 degrees from the drops.

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APPENDIX E

TABLE OF THE INDEX OF ITEM-OBJECTIVE CONGRUENCE (THE IOC INDEX)

Pre-test questionnaire

Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (pre -test)	1. condition necessary for forming rainbow	7a. When Rainbows are seen raindrops should be in the direction opposite to the Sun True False b. An observer sees a rainbow because of the Refraction of light Reflection of light Interference of light Dispersion of light			
		9a. In order to see a rainbow, the observer must have the Sun behind them True False b. Then, where in the sky would you expect to see a rainbow in the morning? northern sky southern sky eastern sky western sky			
	2. Mechanism of spectrum formation	6a. The primary optical phenomena responsible for seeing colors in a rainbow is reflection True False b. I think this because Refraction of light helps to separate into constituent color and make us see the colors in a rainbow Diffraction of light helps to separate into constituent color and make us see colors in a rainbow Reflection of light helps to separate into constituent color and make us see colors in a rainbow Interference of light helps to separate into constituent color and make us see colors in a rainbow			
		8a. The formation of color in a rainbow is mainly due to refraction True False b. Because The frequency dependence of the refractive index of the raindrop produces the colors of the rainbow The wavelength dependence of the refractive index of the raindrop produces the colors of the rainbow The reflection of light produces color and not the refraction of light The wavelength of light produces color and not the refraction of light			

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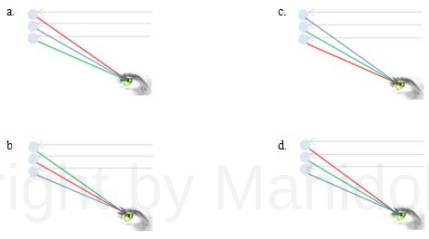
Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (pre -test)	2. Mechanism of spectrum formation	12a. Every single rain drop when illuminated by sunlight is capable of producing rainbow color True False b. Because; A spectrum of color is seen in the drop A spectrum of color is seen from a faraway drop A single color is seen in a drop A single color is seen from a faraway drop			
		15a. The position of Violet light in the spectrum formed by water drop will be seen at bottom True False b. Because The greater bending at the first surface causes it to strike the back surface of the drop at a greater angle of incidence. The greater bending at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence. The smaller bending at the first surface causes it to strike the back surface of the drop at a greater angle of incidence. The smaller bending at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence.			
		17a. After the light rays are refracted inside the water drop it strikes at the back of it, when this happens the angle of incidence inside the back of water drop should be greater that critical angle. True False b. Because The light rays are totally dispersed into constituent colors The light rays are totally refracted at the back of the water drop. The total inter reflection takes place inside the water drop. The interference of light rays takes place inside the water drop.			
	3. Ray diagram	13a. The Violet color light will be refracted more in a rain drop? True False b. Which diagram represents the formation of spectrum by a water droplet? 			
		14a. Red color light will be deviated less True False b. Which diagram shows the way rainbow colors are seen from water drops? 			

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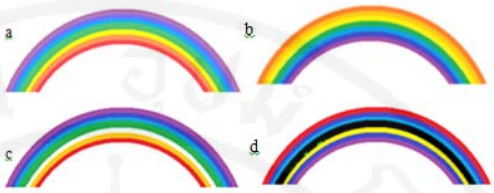
Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (pre -test)	3. color sequence in a rainbow	4a. The red color in a rainbow is always seen inside the bow. True False a. Which picture shows the actual color of rainbow that we normally see?  			
		5a. If your line of sight to water droplet makes an angle of 41 degrees with the direction of the sunlight, you would probably see green color. True False b. Because It lies in between violet and red. Violet color in a rainbow is always seen around 42 degrees and Red around 40 degrees It lies in between green and orange. Green color in a rainbow is always seen around 40 degrees and orange around 42 degrees It lies in between orange and green. Orange color in a rainbow is always seen around 42 degrees and green around 40 degrees It lies in between red and violet. Red color in a rainbow is always seen around 42 degrees and violet around 40 degrees			
		16a. In a rainbow the violet color is seen outside a bow True False b. Because The red violet exit from the drops at an angle of 41°degrees and red light emerges at an angle of 40 degrees from the drops. The violet rays exit from the drops at an angle of 40°degrees and red light emerges at an angle of 41 degrees from the drops. The red rays exit from the drops at an angle of 42°degrees and violet light emerges at an angle of 40 degrees from the drops. The violet rays exit from the drops at an angle of 42°degrees and red light emerges at an angle of 40 degrees from the drops.			
		18a. We see the Red light on the outer part of the arc True False b. because We are looking along a same line of sight that has a smaller angle (40 degrees) for the red. We are looking along a different line of sight that has a greater angle (42 degrees) for the red. We are looking along a same line of sight that has a greater angle (42 degrees) for the red. We are looking along a different line of sight that has a smaller angle (40 degrees) for the red.			

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Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (pre -test)	4. Shape of a rainbow	1a. Rainbows are normally seen as curved shaped True False b. Because; Water droplets are spherical The Earth surface is curved The Sun is a spherical body Water droplets displaces light rays at some degrees from that centerline			
		2a. If you point to a wall with your arm extended to make about 42º angle to the normal to the wall, then rotate your arm in a full circle while keeping the same angle, then the shape that your arm will describe is a cone True False b. Which statement supports the above analogy? All color lights are reflected by single raindrop at a fixed angle to an observer's eye The color lights could be seen in the light scattered by raindrops at a fixed angle to an observer's eye Rainbow is formed due to collective reflection of light rays by the rain drops Only one color could be seen in the light scattered by every rain drops.			
		3a. You expect to see the shadow of your head on the upper part of a rainbow while observing it. True False b. The reason for my answer is The center of a rainbow is in the straight line with observer's head and the sun so shadow will fall in the center of a rainbow. The top part of observer's head is straight to the sun and upper part of rainbow so shadow will fall in the upper part of the rainbow. The atmosphere will be dark so no shadow will be formed. The clouds will be too dark when a rainbow is seen so no shadow will be formed as dark clouds will prevent us from seeing it.			
	5. Locating a rainbow	10a. In the morning you would you see the top of a rainbow rise above the horizon True False b. Because; As the sun rises from the east in the morning the top of the rainbow also rises above the horizon As the sun rises from the east in the morning the top of the rainbow sets below the horizon As the sun sets in the west in the evening the top of the rainbow also sets below the horizon As the sun sets in the west in the evening the top of the rainbow rises above the horizon			
		11a. It may be before noon if you saw a rainbow at western True False b. Because; The sun is in the West The sun is in the South The sun is in the North The sun is in the East			

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Post-test questionnaire

Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (post-test)	1. condition necessary for forming rainbow	7a. Rainbows are seen in the direction opposite to the sun True False The reason is due to Reflection of light Interference of light Refraction of light None of them. These processes have nothing to do with the rainbow's position			
		9a. To see a rainbow, relatively the sun must be between raindrop and the observers True False Then, where in the sky would you expect to see a rainbow in the evening? northern sky southern sky eastern sky western sky			
	2. Mechanism of spectrum formation	6a. Reflection is responsible to let you see spectrum in a raindrop True False b. What is the correct process to form rainbow. Reflection, refraction and reflection. Refraction, reflection and reflection. Refraction, reflection and refraction. Reflection, refraction and refraction.			
		8a. The formation of color in a rainbow is mainly due to reflection. True False b. Because The reflection of light produces color The wavelength of light produces color The frequency dependence of the refractive index of the raindrop produces the colors of the rainbow The wavelength dependence of the refractive index of the raindrop produces the colors of the rainbow			
		12a. Every single rain drop is capable to produce a rainbow color True False b. Because; A spectrum of color can be seen in a drop illuminated by sunlight A single color is seen from a faraway drop A spectrum of color can be seen from a faraway drop A single color can be seen in a drop illuminated by sunlight			
		15a. The position of red light in the spectrum formed by water drop will be seen at bottom True False b. Because The greater bending of red light at the first surface causes it to strike the back surface of the drop at a greater angle of incidence. The greater bending of red light at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence. The smaller bending of red light at the first surface causes it to strike the back surface of the drop at a greater angle of incidence. The smaller bending of red light at the first surface causes it to strike the back surface of the drop at a smaller angle of incidence.			

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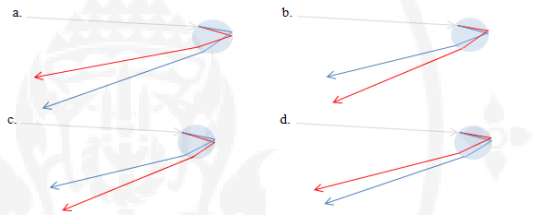
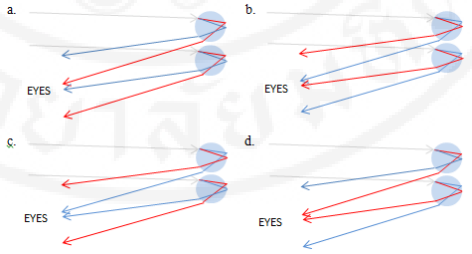
Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (post-test)	2.Mechanism of spectrum formation	17a. The angle of refraction subtended inside the water drop will be equal to angle of incidence subtended inside the back of the water drop. True False b. This is because The triangle formed by two normal and refracted ray is isosceles triangle The triangle formed by two normal and refracted ray is scalene triangle The triangle formed by two normal and refracted ray is right angle triangle The angle formed by two normal is an acute angle.			
	3. Ray diagram	13a. Red color light will be refracted more than violet color in a rain drop True False b. Which ray diagram correctly represents the formation of spectrum by single drop? 			
		14a. Red color light will be deviated more than violet True False b. Which ray diagram correctly represents the formation of spectrum by two drop? 			
	4. Color sequence in a rainbow	4a. Red color is seen at the outer part of a rainbow True False b. Which option shows the correct order of rainbow color from inside? Violet, Indigo, Blue, Green, Yellow, Orange and Red Red, Orange, Yellow, Green, Blue, Indigo and Violet Red, Violet, Indigo, Yellow, Orange, Green and Blue. None of them			
		5a. The red color is seen at an angle of 40 degrees in a rainbow True False b. If you are looking at a rainbow from the ground floor of an apartment building and notice that the kite is hovering right in the green portion. If you were to go up to the second floor, where would you be likely to see the kite hovering in? The red portion of the rainbow The blue portion of the rainbows The yellow portion of the rainbow The green portion of the rainbow only			

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Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
Students' conceptual understanding test (post -test)	4.Color sequence in a rainbow	16a. In a rainbow the red color is seen outside a bow True False b. Because The violet rays exit from the drops at an angle of 41°degrees and red light emerges at an angle of 40 degrees from the drops. The red rays exit from the drops at an angle of 40°degrees and violet light emerges at an angle of 41 degrees from the drops. The violet rays exit from the drops at an angle of 42°degrees and red light emerges at an angle of 40 degrees from the drops. The red rays exit from the drops at an angle of 42°degrees and violet light emerges at an angle of 40 degrees from the drops.			
		18a. We see the Violet light on the inner part of the arc True False b. because We are looking along a same line of sight that has a smaller angle (40 degrees) for the violet. We are looking along a different line of sight that has a greater angle (42 degrees) for the violet. We are looking along a same line of sight that has a greater angle (42 degrees) for the violet. We are looking along a different line of sight that has a smaller angle (40 degrees) for the violet.			
	5. Shape of a rainbow	1a. Rainbows are normally seen as half circle True False b. Because; The colors are reflected from the back part of water droplets which is curved The Earth surface is curved The earth gets in the way Water droplets displaces it at some degrees from that centerline			
		2a. If you point to a wall with your arm extended to make about 42º angle to the normal to the wall, then rotate your arm in a full circle while keeping the same angle, The finger sweeps out a circular shape on the wall. True False b. Which statement supports the above analogy? A single raindrop reflects all the color light at any angle to an observer's eye Every single rain drop reflects same color light to an observer's eye Rainbow is formed due to collective reflection of light rays by the rain drops Every single rain drop reflects same color at a time at a fixed angle.			
		3a.When seen from an airplane, a rainbow sometimes forms a complete circle. When this happens, we expect to see the shadow of the plane True False b. The reason for my answer is The center of a rainbow is in the straight line with plane and the sun so shadow will fall in the center of a rainbow. The plane at that particular instant is straight to the sun and upper part of rainbow so shadow will fall in the upper part of the rainbow.			

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Variable	Objectives of the lesson	Items	IOC		
			+1	0	-1
	5. Shape of a rainbow	The atmosphere will be dark so no shadow will be formed. The clouds will be too dark when a rainbow is seen so no shadow will be formed as dark clouds will prevent us from seeing it.			
Students' conceptual understanding test (post -test)	6. Locating a rainbow	10a. Sometimes we can see a rainbow set below the horizon True False b. Because; As the sun rises from the east in the morning the top of the rainbow will also rises above the horizon As the sun rises from the east in the morning the top of the rainbow will set below the horizon As the sun sets in the west in the evening the top of the rainbow will also sets below the horizon As the sun sets in the west in the evening the top of the rainbow will rise above the horizon			
		11a. At around 5 PM you are in an airplane. If you saw a rainbow then you are flying towards western sky. True False b. Because; The position of the sun will be in the East The position of the sun will be in the West The position of the sun will be in the South The position of the sun will be in the North			

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Learning unit opinion survey items

Variable	Themes	Items	IOC		
			+1	0	-1
Students' opinion towards developed learning unit	1.Topic and the lesson	The topic of the lesson was interesting			
		The lesson was suitable with your level			
		Lesson was well organized in a way that helped me learn better			
		The lesson was useful for me to understand about rainbow formation			
		The lesson was very difficult to understand			
	2.Teacher	The teacher has been well prepared for the class			
		The teacher has been open to students' opinion			
		The teacher acted as resource person, working to support students investigation			
		Language teacher used to describe things was very difficult to understand			
	3.Class activities	The instruction sheet and activity sheets were clear and easy to understand.			
		The activities used in the lesson were engaging			
		This lesson made me to learn by hands-on, eyes-on and minds-on			
		This class gave me an opportunity to learn about the rainbow phenomenon through real classroom activities			
		The majority of instruction in this class was through lecture			

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Semi-structure Interview Questionnaire.

Variable	Themes	Items	IOC		
			+1	0	-1
To check students' conceptual understanding of the lesson and their opinion towards developed learning unit	Lesson and concept	1. What did you learn from this lesson? Prompt: Please, can you elaborate it further?			
		2. Which concept was easy/difficult for you to learn in this lesson? Prompt: Why do you think so?			
		3. Do you think the model has helped you to understand the concept on rainbow formation? Prompt: If yes, how?			
	Learning unit	1. What did you like/dislike about the learning unit used in the lesson? Prompt: what makes you feel this way?			
		2. Do you have any suggestions regarding learning unit used in this lesson? Prompt: If yes, how?			
	Overall view	1. What is your overall view towards the learning unit?			

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