TEACHING COLLOIDS: HANDS-ON ACTIVITY LEARNING UNIT TO ENHANCE STUDENTS' UNDERSTANDING ON THE EFFECT OF PARTICLE SIZE IN SOLUTION

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ABSTRACT

Understanding the role played by size of the particles is very important as manipulation of such materials in a nanoscale has brought wider societal implications. Such technology has touched our life and it is therefore vital for our students to at least have some awareness of such an emerging field. Teaching of concepts in this field is popular in colleges and the need of infusion is felt at the school level also. However, the Bhutanese curriculum is still in its infancy and availability of technologies and equipment are difficult and expensive. However, the colloid concept under the science curriculum of grade XI-XII chemistry provides an opportunity for the students to explore and relate the effect of size of particles by relating to the scattering of light. Since most of the teachings in Bhutanese classrooms are dominated by traditional style, the use of active hands-on learning involving more of an inquiry approach is recommended. In addition, studies show that the hands-on activity and inquiry lab as an effective drive for learning chemistry. Therefore, a hands-on activity learning unit based on the inquiry lab learning approach was designed to help students understand about the effect of size of particles in the solution through the teaching of colloid concept and also to see their perception towards the learning unit.

One group pretest-posttest design was implemented to 43 grade XI science students in one of the schools located in the southeastern region of Bhutan. The whole activities of the learning unit are encapsulated into two lessons for enhancing students' understanding about the effect of size of particles. The guided inquiry lesson includes activities to differentiate solution, suspension and colloids through the properties of filterability, homogeneity, gravitational, the Tyndall effect and appearance. The structured inquiry lesson involves the preparation of colloids through the sol-gel process with the use of LED laser to understand about the nanoparticle and the scattering by nanoparticles. A Total of five instruments were used to collect data through the implementation of teacher-designed activities. The data from the colloidal achievement test, students' reflection, perception questionnaire, semi-structured interview and students' document show enhancement of students' understanding of the effect of particle size in the solution and positive perception towards the learning unit. The results also show some challenges and difficulties which students faced due to little or lack of experience learning from such an approach. Some of the key points expressed by the students like laboratory experience, new learning approach, tools and materials, interest, group work and time issues are discussed along with its implication and limitation.

KEY WORDS: PARTICLE SIZE / INQUIRY LAB / HANDS-ON ACTIVITY / COLLOIDS / LIGHT SCATTERING / TEACHING NANOSCIENCE

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LIST OF ABBREVIATIONS

DRCD	Department of Curriculum and Research Development
BCSEA	Bhutan Council for School Examination and Assessment
e.g.	Example
et.al	ed. All (Latin) and others
MCQ	Multiple choice question
MoE	Ministry of Education
NEF	National Education Framework
NEP	National Education Policy
NM (nm)	Nano Material
NP (np)	Nano Particle
PbI	Physics by inquiry
REC	Royal Education Council
Soln.	Solution

CHAPTER I
INTRODUCTION

Overview

This chapter provides the overall basis of the research, containing the background and rationale of the study. It provides the problem statement, research questions and significance of the study.

1.1 Background and Rationale of the study

Understanding the effect of size of the particles is very important as investigating and working on small scale (nanoscale), it has brought a wide societal implications of new technologies (Sederberg, 2009). Manipulation of such materials in nanoscale are an emerging fields of nanoscience and nanotechnology that have caught the attention of the world (Duncan et al., 2010). It is interesting to learn that the nano particle of materials behave differently from the bulk even if the materials are made up of the same substance. We have to accept the fact that atom at the surface of mass is different from the atom at the center of the mass. So, availability of size as a new parameter which allows the alteration of chemical properties has immensely stretched the potential of chemistry (Roduner, 2006). Therefore understanding the importance of role played by size of the particles by student is of great significance.

The teaching of nanoscience and nanotechnology is popular in university and infusion of such concept is felt important in the school. However, Bhutanese curriculum is still in its infancy and availability of technology and equipment are difficult and expensive for the developing country like ours. Nevertheless, few goals of science curriculum in Bhutan includes understanding scientific concepts and acquiring skills appropriate to their level of learning and for their lives as citizens or as future science professional; developed their skills of inquiry in order to carry out investigations and experiment and be able to transfer their skills of inquiry to be active and critical citizens (DCRD, 2013).

The colloids under the topic surface chemistry of grade XII syllabus of Bhutan, is usually taught in grade XI. This topic provides an opportunity to help students to understand the importance of size of particles at the nanoscale; as colloids are molecular assemblies in which size of structures ranges from 1 nm to 1,000 nm (Ball, 1994). Colloid was first termed by Thomas Graham in 1861 which in Greek words mean "glue like". The properties of colloidal system with varying particle sizes which falls in the range from 1 nm to 1 micron are important feature of nanoscience. It provides interest in nanotechnology due to unique properties of materials with dimension less than 100 nm (Nordell, Boatman, & Lisensky, 2005; Todebush & Geiger, 2005).

One of the unique properties of colloid is its ability to scatter light, commonly described as "Tyndall Effect" by John Tyndall in 19^{th} century. A beam of light can be traced due to a scattering of light by colloidal particles and is found described in many textbook (Madan & Bisht, 2013). The scattering of light is governed by three parameters. There are size and shape of the particles, wavelength of light, and refractive index (Lurton et al., 2014; Muñoz & Hovenier, 2011). The key idea of such parameter is explained by Rayleigh scattering and Mie scattering in which the intensity of scattering is proportional to size of the particles and inversely proportional to 4^{th} power of wavelength (Kutzner, 2013). Which means bigger the size of the particle, more scattering of light and the light with short wavelength scatter more than the one with longer wavelength. The concept is helpful in explaining some of the natural phenomenon like blue sky, red sunset, whiteness of cloud, rainbow, appearance of halos etc., (Muñoz et al., 2010).

A number of experiments in chemical education have explored light scattering to study and monitor the growth of particles and measure particle sizes relevant to polymer and colloid science (Ahn & Whitten, 2005). Mostly demonstration was used like optic laboratory tools to trace the rays of light (Kutzner, 2013); Pecina, Smith, Johnson, & Snetsinger (1999) demonstrated Rayleigh scattering in optically active and inactive system; light scattering in heterogeneous system by Petruševski, Monković, & Ivanovski (2006); measuring nanoparticles by light scattering technique

Brar & Verma (2011). Ahn & Whitten (2005) used light scattering using red and violet diode laser to monitor particle growth. However, in education field, not many literatures are found about colloids primarily focusing on size of particle in high school level. Therefore, relating scattering of light with colloids can be used to help students understand about an importance of size of the particles perspective to curriculum and at standpoint of awareness to emerging field of nanoscience and nanotechnology and also the natural phenomenon that we experience every day.

Given the importance of its implication, however teaching of chemistry is found difficult due to its abstract nature and teaching chemistry to majority of students is still problematic (Gabel, 1999; John K. Gilbert, Onno De Jong, Rosaria Justi, David F. Treagust, & Jan H. Van Driel, 2002; Nakhleh, 1992; Sirokman, 2014; Türk, Ayas, & Karslı, 2010). To address the issue teachers are encouraged to use different approaches, new strategies, techniques, methods and develop appropriate activities (Kurt & Ayas, 2012; Nakhleh, 1992; & Türk et al., 2010) which should be designed for constructivist learning environment (Yadigaroglu & Demircioglu, 2012). It is because the setting in which students learn affects the way students process new information (Gabel, 1999). From the constructivist point of view, learning is active; learning is the interaction of ideas and processes; learning is augmented when students engage in discussions of ideas and processes involved (Bybee, 2002). The department of curriculum and research division (DCRD) under Ministry of Education, Bhutan (2012) recommends active hands-on learning as effective pedagogy involving more of inquiry learning that requires learner to think and be critical. Childs, Tenzin, Johnson, & Ramachandran (2012) pointed out development of more learner-centered pedagogies in classes 9–12 along with widening teachers' understandings of the role of practical work in science learning as they found that students were taught mostly through traditional approach. Hofstein & Lunetta (2004) states that the important role of hands-on activity in chemistry lies on laboratory activities as it benefits students develop understanding of scientific concepts, scientific inquiry skills and perceptions of science. Ornstein (2006) suggest that hands-on activity and inquiry lab as an effective drive for learning and recommend it for effective use in chemistry education. The hands-on activity involving inquiry lab according to research, help enhance and promote students understanding in chemistry and improve their positive attitude

(Sesen & Tarhan, 2013; Scott, 2014). VanDorn, Ravalli, Small, Hillery, & Andreescu (2011) states that flexibility of such pedagogy is appropriate for grades 11 and 12 in high school and also in college level that offer STEM (full name) courses.

It is therefore with the recommendation of Bhutanese science curriculum in light with constructivism, and also in view of strong support from review on use of hands-on activity and inquiry lab in chemistry education, all in all, the appropriateness of such pedagogic approach in the implementation of the current study, the approach is embraced in order to aid students in understanding the concepts and also to check their perception towards such learning approach. To sum up, such new approach provides the opportunity to explore and discover more meaningful insight of students' understanding and perception by keeping in aligning with curriculum, syllabus and literature.

1.2 Problem Statement

Many studies show the importance of the role played by manipulating particle size at the nanoscale and provide promising impact in the field of industry, medicine, environment especially in the area of nanoscience and nanotechnology. Such technology has touched our lives and it is therefore vital for our students to at least have some awareness of such emerging field that the fundamental idea behind all such idea is based on size of the particle. The concept may be difficult for high school students and inappropriate to this level to learn in-depth about nanoscience and nanotechnology yet it is important to understand about the role played by size of the particles (Sederberg, 2009).

Some topics in chemistry of high school level offer an opportunity to explore the concept. The opportunity however should be suited with the particular aspect of curriculum design and syllabus. Much of the studies in the field of colloids are done on basic science and only few studies are found in educational field focusing on high school level. Likewise, these concepts are taught without emphasizing on the particle size. Bhutanese students are mostly taught through traditional approach as Childs et al., (2012) mentioned that the classes 9–12, their findings indicated predominantly teacher-led lessons with rote learning from textbooks and classroom interactions were barely at used. Therefore, the colloid concept provides an opportunity to explore and relate the effect of size of particles with an appropriate pedagogy. The Department of curriculum and research division (DCRD) (2012) under the ministry of education, Bhutan strongly recommends using hands-on activity using inquiry approach as effective pedagogy. Studies also show hands-on activity and inquiry lab as an effective drive for learning in chemistry and literature suggests to develop activities with different approaches and strategies to overcome the difficulty of teaching chemistry. VanDorn et al., (2011) stated that flexibility of such pedagogy is suitable for high schools by grade 11 & 12.

To address the above issues, the main purpose of the study is to design a hands-on activity learning unit based on an inquiry lab learning approach to help students understand about the effect of size of particles in the solution through the teaching of colloid concept. The learning unit is in perspective to Bhutanese curriculum by focusing on the colloid syllabus of grade XI & XII.

1.3 Research Objectives

The objectives of the study are:

1. To develop inquiry based, hands-on activities learning unit using a lab based method on the concept of colloid for grade 11 students.

2. To investigate Students' understanding of the effect of learning unit developed for grade 11 students.

3. To examine the students' perception towards the learning unit.

1.4 Research Questions

This study aims to investigate the following research questions

1. Does the inquiry hands-on activities through lab based method enhance students' understanding about effect of size of particles in solution?

2. What is students' perception towards the developed learning unit?

1.5 Significance of the study

The study is developed in perspective to the syllabus and goals of science curriculum in Bhutan and through the learning unit it can help students understand about the role played by size of the particles in solution. Along with it, students can learn different properties of colloids through the activities and relate particle size and scattering of light and also learn about the some natural phenomenon that we experience every day. It can serve as an interdisciplinary approach of chemistry and physic and the whole process moves the approach away from the traditional style of teaching and learning that is mostly dominant at the present situation.

The instructional activities use new approach in the field with available resources that are cheap, available and easily adaptable for implementation in the normal class. The learning unit should also serve as an educational resource of teaching colloids and through learning and doing can aware the students the emerging field of nanoscience and nanotechnology by explicitly focusing on the role played by particle size. It also enables students to understand the top-down and bottom-up method of nanoparticle process through preparation of colloids using the sol-gel method. The newly developed hands-on activity learning unit based on lab inquiry can offer guidelines for further development of teaching professionals in designing and implementing such learning unit in the classroom.

Most importantly, this learning unit should help students develop a understanding of scientific concepts, scientific inquiry skills and perception of science through active engagement and involvement. It provides students with enough flexibility to learn by doing and by doing so, help students to take responsibility for their own learning. The learning unit creates a platform for students to experience a new environment for those who are new to the approach; and for those who are familiar with the approach, it should serve as support to further enhance their capability and knowledge. Accordingly, it should promote students' understanding in chemistry, the nature of science and improve or develop their positive attitude towards learning.

The learning unit should also provide the prospect of teacher-designed activities associated with challenges and difficulties. Through this advantage and disadvantage view of points, it should offer potential for further improvement and enhancement. Overall, the development of this learning unit is based on the proposition of many aspects like goals and objectives of Bhutan science curriculum, syllabus, constructivism, less educational resource in high school level about colloids, pedagogic point of view, interdisciplinary, teacher-designed activities, innovation, perception and attitude which are all merged to common point to understand the effect of particle size to address its importance in current field of science and technology. It should therefore offer an example of the possibility of integration and amalgamation of various aspects of insight view and the potential that such development can offer to researchers and teachers. It is important to consider it as example for insight and further improvement rather than considering it as a piece of perfection.

CHAPTER II
LITERATURE REVIEW

Overview

The whole section is divided into three broad fields, science curriculum in Bhutan, theoretical framework and conceptual framework. The First section provides the brief impression of education system in Bhutan focusing on some goals and objectives of science curriculum in the country. The theoretical framework, then describes about the theoretical basis of constructivism on hands-on activity and lab-based inquiry approach covering some aspects of teaching chemistry in general on which the pedagogy or learning approach of the study is built on. The conceptual framework section describes reviews on colloids and scattering of light in which the concept of instructional design is based on.

2.1 Science Curriculum in Bhutan

The modern education system came to Bhutan around six decades ago when the third king, his Majesty King Jigme Dorji Wangchuk opened the door to rest of the world. The education system, then worked on curriculum borrowed from the neighboring country. Over the period of time, the concern over lack of content and stress on development of investigative skills and fair test opposed to traditional learning resulted in criticism and difficulty (Childs et al., 2012). Since then Bhutan brought lots of changes in its education system from revision of textbook in 2001, reviewing of curriculum in 2002 by UNESCO, localization of syllabus for classes IX-XII and hence education system has been central player in transformation of Bhutan from traditional society to dynamic, confident participant in regional and global affairs (Education sector review commission, 2008). Many challenges exist as Bhutan endeavor to institute democracy and will find new ways through education to integrate their society appropriately within their own 21st century understandings of how democracy can work for them (Hébert & Abdi, 2013).

In Bhutanese education system, the formal educational structure consists of 6 levels. The primary contain pre-primary (PP)-grade VI; lower secondary from grade VII-VIII; middle secondary from grade IX-X; higher secondary from grade XI-XII, degree level and vocational training institutes. The pre-primary to grade 10 is considered as basic education level as every student on attainment of age 6 can enroll in the school and till grade 10, education is provided free by the government. All the students are required to complete their basic education in time. After that, the government enroll minimum of 40% of cohort graduating from grade 10 annually in the government higher secondary schools on merit basis. All the students appear board exam in grade 10 for merit listing according to policy. Those failing to get selected enroll in private schools through self-finance, join vocational training institutes or enter the job market. Those who enroll in higher secondary in grade XI-XII, students can specify their choice of subject that is offered in three fields: science, commerce and arts. With the option, student appears board exam in grade 12 which provides another benchmark for students to pursue their study in tertiary education. The enrollment is strictly done on merit basis and depends on the capacity of slots issued by the Royal University of Bhutan (RUB) and also various scholarship programs within and outside the country. Those who fail to get selected, study through self-finance, join vocational training institutes or enter job market. According to national education policy (NEP) under the ministry of education (National Education Policy, 2012) to ensure effective resource allocation and management and more importantly the continuity in students learning, schools around the country operate one of the following levels: 1. Primary – pre-primary to grade VI; 2. Secondary – grade PP/VII to grade X; and 3. Higher secondary – grade PP/VII/IX to grade XII.

Bhutanese curriculum is now guided by constructivist approach on the ground where children learn through active participation; children learn in diverse ways and at different pace; learning is both an individual and group process where children learn and make meaning of their experiences and that learning is interrelated and is an ongoing process (Royal Education Council, 2012). The Curriculum is designed by specifically focusing on three key stages: early childhood care and development (ECCD), basic education (primary and secondary) and pre university education and VET (vocational education and training) in which the science curriculum strand is organize into scientific inquiry, life processes, materials and their processes and physical process (Royal Education Council, 2012). The National Education Framework, 2012 has also highlighted some essential learning area like interdisciplinary and cross curricular studies and 21st century skills.

Science education in Bhutan starts from pre-primary as environmental science. From grade IV till grade VIII, students learn it as separate subject. The distinction of science into separate disciplines as biology, chemistry and physics are studied in grade IX and X. After that, the subject becomes more specialized. For class XI and XII, physics and chemistry form the integral subject while math and biology are elective. The Student has an option to take both biology and math (bio math) with chemistry and physics or they can either drop biology to enter the field of mathematics (pure science) or drop math to enter the field of biology (bioscience). Few of the many goal of the science curriculum in Bhutan includes to develop and apply the skills of inquiry, investigation, problem solving and logical reasoning and to prepare learners for higher studies in science and technology. As a result of school science education learners should understand scientific concepts and acquire skills appropriate to their level of learning and for their lives as citizens or as future science professionals; develop their skills of inquiry in order to carry out investigations and experiments and be able to transfer the skills of inquiry to be active and critical citizens (DCRD, 2013)

For learning chemistry according to Department of Curriculum and Research Division (DCRD) and Bhutan Council for Secondary Examination and Assessment (BCSEA) (2012) states that the students should have the opportunity to

i) Learn through inquiry;

ii) Learn through investigatory approach;

iii) Work in cooperation with others and even independently;

iv) Gain experience through practical works, taking care of safety measures;

v) Learning the subject through problem solving, involving in literary activities and science exhibition;

vi) Examine critically and think positively;

vii) Inculcate the habit to do independent research through print, electronic media and experiments and learn through assigned projects.

Some of the students learning outcome include understanding the chemical concepts, facts and principles, applying the knowledge of contents in day to day life and have analytical approach (CAPSD & BBE, 2012). According to chemistry syllabus of grade XI-XII, the whole topics are divided into three sections. The section A comes under physical chemistry and contain 7 chapters for grade XI and 9 chapters for grade XII; section B, Inorganic chemistry contain 3 chapters for grade XI and 4 chapters for grade XII; and section C Organic chemistry and contain 6 chapters for grade XI and 8 chapters for grade XII. The grade XI consists of 16 chapters and grade XII consists of 21 chapters in total. The overview of the chapter that are given in the syllabus of grade 11 & 12 in the science curriculum of Bhutan is given in table 2.1.

Table 2.1 Overview of chapters covered under chemistry syllabus of grade 11 & 12

Grade	Section A: Physical chemistry	Section B: Inorganic chemistry	Section C: Organic chemistry
Eleven	1. Atoms and Molecules 2. Atomic structure 3. The Periodic table 4. Chemical bonding 5. Gaseous State 6. Chemical kinetics 7.Chemical equilibria	8. General survey of groups of elements 9. Isolation, manufacture, properties and uses of magnesium as metal and chlorine and Sulphur as non-metal. 10. Preparation, manufacture, properties and uses of compounds	11. Introduction to organic chemistry 12. Hydrocarbons 13. Halides 14. Alcohols 15. Preparation of Grignard Reagent and its uses 16. Analysis, Formulae and structure of organic compounds

Table 2.1 Overview of topics covered under chemistry syllabus of grade 11 & 12 (Cont.)

Twelve	1. Solution 2. Nuclear Chemistry 3. Chemical bonding 4. The Solid State **5. Surface Chemistry** 6. Chemical Kinetics 7. Phase equilibria 8. Ionic equilibria 9. Electrochemistry	10. Chemical Thermodynamics 11. Coordination compounds 12. Extraction, properties of metals and non-metals 13.Types of chemical reaction	14. Isomerism 15. Ethers, aldehydes, acetone, carboxylic acid and their derivatives 16. Glycine 17. Oil, fats and detergents 18. Cynides and isocynides 19. Carbohydrates 20. Aromatic compounds 21. Polymers & polymerisation

The colloid come under surface chemistry of grade XII syllabus but is usually learned in grade XI. The syllabus under surface chemistry covers the topic of adsorption, colloidal solution, emulsions; catalysis including theories of the mechanism of catalysis. The scope of the chapter on colloids mentioned the coverage of concepts like colloidal solution- preparation of both hydrophilic (starch and gelatin) and hydrophobic (S and As_2S_3); precipitation as evidence that colloidal particles are charged; purification of colloids (dialysis, ultra filtration); properties of colloidal solution such as Brownian movement, Tyndall effect, coagulation, protection; idea of gold number and Hardy-Schulze rule; application of colloids in life; and emulsion: preparation and its application. The weightage of the chapter is 3% out of 21 chapters and time allocated for the syllabus is 250 minutes.

The DCRD recommends active hands on learning as effective pedagogy involving more of inquiry approach that requires learner to think and be critical. The investigative approaches activities like asking questions, designing investigations, building explanations, and testing these explanations in contradiction of recent scientific knowledge and communicating their ideas to others in a wide range of ways learn to think and be critical both in the science classroom and in their daily lives as educated citizens (DCRD, 2013).

2.2 Theoretical Framework

Chemistry is the branch of science concerned with properties and interactions of the substances of which matter is composed (Gilbert et al., 2002) and often described as the scientific study of matter (Seager & Slabaugh, 2004). They refer chemistry as central science because it serves as a foundation to many scientific disciplines. Given the importance, ideas of chemistry are found very difficult and teaching chemistry to majority of student's still problematic (Gabel, 1999; Gilbert et al., 2002; Nakhleh, 1992; Sirokman, 2014; Türk, Ayas, & Karslı, 2010). Gabel (1999) attribute the complex nature of chemistry concepts to various aspects like the threefold representation of matter, practical work, unfamiliar materials, language, and the structure of the discipline. Many chemistry educators have significantly contributed to address the complexity nature of learning chemistry, the constructivist approach been the core of its learning theory. Due to abstract nature of chemistry, teachers are encouraged to use different approaches, new strategies, technique, and method and develop appropriate activities (Kurt & Ayas, 2012; Nakhleh, 1992; & Türk et al., 2010). Duvarci (2010) states that student-centered teaching approaches, specifically activity-assisted teachings have many advantages for teaching of the chemistry topics. Using demonstration increase motivation and interest (Kaya & Geban, 2011); working in group saved time, complete complex task and provide opportunities to discuss (Miller, Nakhleh, Nash, & Meyer, 2004); learning through inquiry and argumentation scaffold students understanding of science (Kingir, Geban, & Gunel, 2012) and laboratory work provide opportunity to improving conceptual understanding (Gabel, 1999). So, it is essential that teachers should develop their skills for designing constructivist learning environment (Yadigaroglu & Demircioglu, 2012) as the way students process new information is affected by the setting in which they learn (Gabel, 1999).

Therefore, educational theory underpinning the study is based on constructivism on the belief that learning is active; learning is interaction of ideas and processes; new knowledge is built on prior knowledge; learning is enhanced when situated in contexts that students find familiar and meaningful; complex problems that have multiple solutions enhance learning; and learning is augmented when students engage in discussions of the ideas and processes involved as stated by (Bybee, 2002). Constructivism is based on the theory where the learners make meaning from experience which focuses on how the learner creates an interpretation through their interaction with the world based upon their past experiences (Bryceson, 2007). The constructivist theory in education has been widely accepted. The whole picture of constructivist theory is most vibrantly explained by the works of Jean Piaget and Lev Vygotsky.

Personal constructivism or Cognitive Constructivism is based on John Piaget (1977) who combines aspects of both Cognitive Theory and Constructivism and argues that learning is a process of accommodation, assimilation and equilibrium. He suggested that when learner constructs new knowledge based on their experience, assimilation occurs when the learner uses existing concepts to deal with new experiences or information from outside world. On the process, if the learners come in conflict between the new information and existing mental picture, accommodation takes place. Accommodation result from inadequate existing of concept of learners that need restructuring or replacing in order to understand the new experiences. This adaptation enables learner to master the new information thus leading to balance between assimilation and accommodation. The attainment of balance state is called equilibrium.

The learning theory of Social Constructivism on other hand goes a stage further. Lev Vygotsky (1978) argues that learning is not purely an internal process or passive. He states that deep learning occur when learning process occurs first on interpersonal level through social interaction. In other words, the learners thinking and meaning making is constructed through social interaction and cooperative learning. He describe about Zone of Proximal Development (ZPD), an intangible area in which optimal learning takes place and that, through a process of 'scaffolding' in the ZPD, a learner can be extended beyond their current capabilities (Bryceson, 2007).

Bächtold (2013) distinguish the two kinds of constructivism, Piaget cognitive constructivism and Vygotsky social constructivism on three fronts. Cognitive constructivism focuses on individual where it considers the construction process is based primarily on the learners' interaction with the material environment and pay attention to concepts and knowledge constructed by the individual in order to organize his/her experimental world. On the other hand, social constructivism focuses on group where construction process is based primarily on his/her social environment and focuses on language to enable communication among learners, or between the learner and teachers. In short Piagetian constructivism emphasizes the construction of knowledge by individual while sociological constructivism emphasizes the negotiation of meaning and knowledge construction by a group of individuals (Berg, 2006). However the differences, the constructivism seems to be associated with pedagogic approaches that promote active learning, in other word learning by doing (Bybee, 2002). The core positions of constructivism pedagogy seem to involves intervention and mediation from teachers and broader organization of educational activities (van Compernolle & Williams, 2013); and commitment that teacher facilitate in constructing knowledge that is actively build by learner (Duit & Treagust, 1995).

Ultanir (2012) gave a glance of commonality in regards to knowledge learning process of a child as proposed by Dewey, Piaget and Montessori as all of them agree that acquisition of knowledge and learning is about constructing meaning as opposed to passive reception. Social constructivism sound more pronounced when it comes to science education as the approach create a learning community in the classroom where teacher acting as a mentor and problem solver- scaffold each students' performance to higher levels of mental functioning (Derry, 2007). Several constructivist models and approaches have been proposed and various approaches in pedagogy are derived from constructivist. Derry (2007) describes it as a pedagogical process of promoting engaged learning through hands-on activities with concrete tools. The likes of inquiry approach, problem based learning, learning cycle, project based learning, etc., are few of many listed in the literature. The current study stands on the constructivist approach of hands-on activity and inquiry learning using laboratory as pedagogy derived on basis of constructivism.

2.2.1 Hands-on activity

Haury & Rillero (1992) states “if student are not doing hands-on science, they are not doing science”. They state that hands-on comprise three dimensions. The inquiry dimension uses activities to make discoveries, the structure dimension refers to amount of guidance given to students where each step is detailed like a cook book style and does not recommend as it does not increase students’ problem solving abilities. And, thirdly the experimental dimension which involves aspect of proving the discoveries. Hand-on activity simply means learning by doing and many studies showed that the performance of many hands-on activities showed higher interest, positive motivational outcome (Holstermann, Grube, & Bögeholz, 2010) and also affect their knowledge (Türk et al., 2010). Holstermann et al., (2010) in their findings state that many hands-on activities provide the opportunity and prospective to influence students’ interest in the activities positively. The inform discussion about integrating hands-on activity in science curricula, they said can meet the interests of learners as they found that the quality of hands-on experiences showed positive correlations with interest in the respective hands-on activities. Since the studies provide evidence of postulation of hands-on activity leading to positive motivation outcome, Osborne, Simon, & Collins, (2003) indicated that motivation is very important pointer to focus for future research as such kind of classroom environment and activities have the potential to promote students’ interest in studying school science. Ayyildiz & Tarhan (2012) have seen in their study that the use of such hands-on activities in the classroom environment showed positive attitudes towards chemistry.

One of the meanings of Hands-on activities is considered as a teaching strategy where the students usually work in groups, interact with peers to manipulate various objects, ask questions that focus observations, collect data and attempt to explain natural phenomena (Satterthwait, 2010). Flick (1993) considers hands-on activity as necessary for those students with little exposure to experiences that are important for learning as it can help develop experiential background for learning about the natural world. Hofstein & Lunetta (2004) pointed out the influence of experience on students' attitude is very important for science education as the positive attitude experience could benefit students interest and their learning.

Lee (2012) states that students learning outcomes can be enhanced by providing more "doing" activities and by facilitating "thinking" activities so Wen-jin, Chia-ju, & Shi-an (2012) in their study suggest that hands-on activities should be considered in science teaching strategies as hands-on activity permit a wide arena of application in terms of the role of the experiment and teaching methods (Jodl & Eckert, 1998). So Flick (1993) provided three conditions necessary for a teacher to truly engage students in hands-on activity and the absence of anyone of these condition, he stressed, will invalidates the claim in engagement of hands-on science. These three necessary conditions are a) students individually or in groups should be manipulating objects or events in the natural environment; b) students should apply various aspect of their intelligence for the purpose of understanding a part of their natural environment; and c) students should be held accountable for their observation, inferences and conclusion.

Hands-on activity encourages learning through discovery and exploration whereby children engage and have direct experience and through action-enables learners to understand the real-life illustrations of knowledge and as well improve their reflective skills and retentions (Haury & Rillero, 1992). Bulunuz, Bulunuz, & Peker (2014) on the other hand suggested that there is need to include a variety of hands-on science activities as those found in the science textbook are not enough to understand the basic concepts. So it is imperative from the review that the constructivist approach of learning should involve active hands-on activities and Flick (1993) said that hands-on activities are an active strategies which are essential part of teprocess even though it fails to generate all the beneficial interactions by themselves. Bulunuz & Jarrett (2010) reviewed that hands-on activity with inquiry to be more effective in clarifying conceptual understanding; enhance opportunities for construction of knowledge, make students more active learner and make the lesson more interesting and enjoyable to the students. The previous research also points out important role played by hands-on activity is found in lab activities and all teachers should recognize the importance of lab based hands on activities and inquiry (Ornstein, 2006) as it produce more positive attitude towards chemistry and as well in conceptual understanding.

2.2.2 Laboratory based inquiry

Chemistry is learned best by doing and involving in the learning process and in classes that incorporate active learning. And with hands-on activities, student will start doing science and at the same time learn the content (Eisen, Marano, & Glazier, 2014). One of the conditions of inquiry learning is providing freedom to students to design experiments in order to answer their own scientific questions and carrying out activity to test their hypothesis. The learning process includes working in the classroom, laboratory or outdoor. Many studies showed increases in conceptual understanding when teaching strategies that actively engage students in learning process through scientific investigation is employed. Minner, Levy, & Century (2010) findings across 138 analyzed studies indicate a clear, positive movement favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data.

The National Science Education Standards characterize inquiry instruction as involving students in a form of active learning that emphasizes questioning, data analysis, and critical thinking (Bell, Smetana, & Binns, 2005). It is constructivist understanding of how people learn and emphases on constructing understanding of a concept from experiences, observations, or existing knowledge (Cloonan, Andrew, Nichol, & Hutchinson, 2011). Bell et al., (2005) describes four levels of inquiry in increasing complexities and cognitive demand. The level 1 is confirmatory where students verify a concept as the questions and procedure are provided and the expected result is known in advance. The level 2 is structured inquiry. Students investigate a teacher-presented question with the procedure that is already provided. The difference between level 1 and level 2 is level 2 activities answer research question where the lab is presented before the concept is being taught. Students engage in data collection and making inferences to answer the research question and take greater ownership of their own learning. They considered both level 1 and level 2 as cook book lab. The level 3 is guided inquiry and differs from above two levels on the basis of procedures. Here the teacher-presented question is given to the students, but require students to design and select the procedures to carry out their investigation. Students have to come up with their own procedures of answering the research questions and therefore provide potential to take student engagement and ownership of the lab to a new level. But it should be noted that teacher should approve the student procedures before they conduct the investigation and also should ensure that proper safety guideline is followed. The last, level 4, the open inquiry leaves whole matter, the problem, solution and method to the students. They formulate their own question and design their own method to solve the problem.

Guided inquiry according to Xu & Talanquer (2013) seemed to promote the most desirable types of student interactions but argues that changing the level of inquiry of laboratory experiments may be a necessary but not sufficient condition for creating a learning environment in which students collaboratively engages in high levels of cognitive processing. Therefore, Bell et al., (2005) suggested that scaffolding of inquiry should be seen as continuum. They mentioned that students should progress gradually from lower level to higher level as students need to practice in inquiry to reap benefit from open and complex levels. The inquiry approaches has many benefit like developing mastery; learning the scientific process; increased communication skills; learning procedural organization and logic; better performance on non-inquiry labs; learning the chemistry concepts; improved ability to correct or to explain mistakes or erroneous results and increased interest (Deters, 2005). Teaching inquiry produce greater learning (and long-term retention) for students compared to traditional methods (Blanchard et al., 2010). The recent study showed and viewed inquiry as helpful for enhancing student thinking (Rushton, Lotter, & Singer, 2011) and in stimulating excitement among students when learning science (Shamsudin, Abdullah, & Yaamat, 2013)

Lab-based inquiry or Inquiry-based labs guide students to observe phenomena, explore ideas, and find patterns allowing students to answer questions they have developed themselves. One of the changes in pedagogy described by researchers to improve student learning in chemistry beside inquiry is laboratory, which allows student to learn by doing experiments. Högström, Ottander, & Benckert (2010) strongly mentioned that laboratory work is essential in promoting students' learning of science and of scientific inquiry. It provides an ideal setting for accessing the aspects of science that may be missing in the lecture (Walker & Sampson, 2013) as students have chance to engage in hands-on activities. One of the benefits that students can acquire lies in school laboratory as school laboratory activities provide special potential for learning. It provides arena to enhance students' interest; motivate students by delivering problem solving abilities and practical skills which will not only help them to internalize knowledge but students can develop ideas about the nature of a scientific community and the nature of science (Hofstein, 2004; Türk et al., 2010). Hofstein & Lunetta (2004) states the importance of laboratory where students develop their understanding of scientific concepts, science inquiry skills, and perceptions of science. They also mentioned that it plays a fundamental and distinctive role in science education as rich benefits in learning accrue from using laboratory activities. They suggest that science educators need to conduct more intensive, focused research to examine the effects of specific school laboratory experiences and associated contexts on students' learning.

Eisen et al., (2014) states that traditional textbooks are not designed for a student-centered classroom environment so the review echoes the importance of the need of alternate teaching strategies from other resources. Many studies indicate that inquiry-based laboratory instruction has been measured by changes in student attitudes and increases student performance on lecture exams (Scott & Pentecost, 2014). Sesen & Tarhan (2013) in their findings suggested that inquiry-based laboratory activities should be developed and applied to promote students' understanding in chemistry subjects and to improve their positive attitudes. The flexibility of such pedagogic approach according to (VanDorn et al., (2011) makes it suitable for both college-level STEM courses and high school (grades 11 and 12). So based on the goals and objectives of science curriculum in Bhutan and on the light of reviews favoring strong support from constructivism, the hands-on activities with lab-based inquiry approach is deemed suitable as effective pedagogy. And also on recommendation as the implementation involves grade 11 chemistry students.

2.3 Conceptual Framework

The whole design of instruction is particularly focused to enhance students' understanding about effect of size of particles in the solution. The scientific concept underpinning the study takes the colloidal science for high school students. The colloid chapter under syllabus of grade XI-XII in Bhutan science curriculum provides an opportunity to explore the idea of colloidal concept with a scattering of light in understanding the effect of size of particles. The unique feature of colloid is its particle size and its ability to scatter light and can be distinguished from other dispersion system. The intensity of scattering of light in the visible spectrum depends on its wavelength and size of the particles. So infusing colloids with scattering of light by using different wavelength and also by varying the size, the effect of particle size can be shown macroscopically to the students. The concept is simple in comprehending the idea. Hence colloid with varying particle size uses a simple, light scattering technique involving laser light of different wavelength (red and green) through various activities to enhance students understanding about the effect of particle size in solution.

2.3.1 Colloids

Colloid was first termed by Thomas Graham in 1861 when he was working on separation of substance through semi-permeable membrane and filter paper. He found out that some substance like salt, sugar and urea easily diffuse through vegetable or animal membrane and other substance like gelatin, starch and gum exhibit little or no tendency to diffuse through the membranes. He termed the former one as crystalloids and later one as colloids. The term colloid was derived from the Greek words Kola (glue) and Eidos (like) and suggests glue like. The activity in the guided inquiry lesson uses filter paper and cellophane as semi-permeable membrane to differentiate the filterability property of solution, colloids and suspension.

In 1869, Russian botanist I. Borshchov rejected Thomas Grahams' division of substance into colloids and crystalloids as many crystalloids, like common salt, can be obtained in the form of colloids proving that some substance can behave like colloids in some solvent and like crystalloids in others. Thus, the sharp demarcation between colloids and crystalloids gradually disappeared and hence it is more precise to refer colloids as a state of matter rather than a kind of matter (Glinka, 1960). Seager & Slabaugh (2004) in their book "Introductory to chemistry for today" define colloids as a homogenous mixture of two or more substances in which the dispersed substance are found as larger particles than one found in solutions.

Therefore colloids are molecular assemblies in which size of structures ranges from a nanometer (size of medium size molecules like C_{60}) to a micrometer (comparable to size of bacterium) (Ball, 1994) and usually differentiated according to the states of dispersion medium and dispersed phase. The sharp boundary can be drawn between colloidal solution and true solution in one hand, and colloidal solution and suspension in other hand (Madan & Bisht, 2013). And, all the differences in property are because of differences in size of the particles. Thus, colloids encompasses vast range of substances like paints, grease, smoke, fog, milk, ink, butter, cheese, liquid crystals, soap bubbles, foam etc., thus making colloidal science-an eminently applied discipline and is very broad field (Ball, 1994)

Madan & Bisht (2013) in their book classify the colloids on the basis of three characteristics: a) according to the state of the dispersed phase and dispersed medium; b) nature of interaction between dispersed phase and dispersed medium; and c) types of particles of the dispersed phase. The distributed substance is known as dispersed phase (internal phase) and continuous medium around it is called dispersed medium (external phase). On the classification according to state of dispersed phase and dispersed medium the colloids consists of 8 different types as given in the table 2.2 below.

Table 2.2: Types of colloids based on state of dispersed phase and dispersed medium

Dispersion Medium	Dispersed Phase	Type of Colloid	Example
Solid	Solid	Solid sol	Ruby glass
Solid	Liquid	Solid emulsion/gel	Pearl, cheese

Table 2.2: Types of colloids based on state of dispersed phase and dispersed medium (cont.)

Solid	Gas	Solid foam	Lava, pumice
Liquid	Solid	Sol	Paints, cell fluids
Liquid	Liquid	Emulsion	Milk, oil in water
Liquid	Gas	Foam	Soap, whipped cream
Gas	Solid	Aerosol	Smoke
Gas	Liquid	Aerosol	Fog, mist

On the basis of the nature of interaction between dispersed phase and dispersed medium, colloids are classified into lyophilic (solvent loving) and lyophobic (solvent hating). If water is used as solvent, we called it hydrophilic and hydrophobic colloids based on their affinity towards the water. The lyophilic colloids, e.g., sol are stable and do not precipitate easily and are also called a reversible sols. Examples include gum, gelatin, starch, protein and certain polymers and organic solvent. While on the other hand lyophobic sol precipitates easily, not stable and are irreversible. Examples include metal sols and insoluble compounds like Sulphides and Oxides. The third classification on the types of dispersed phase, the colloids consists of Multimolecular colloids, Macromolecular colloids and associated colloids. Multimolecular colloids are aggregate or cluster of various smaller size atoms or molecules to form a size range of colloidal state, e.g. Gold sol and Sulphur sol which are held together by Van der Waal force. Macromolecular colloids are naturally occurring macromolecules polymer like polyethylene, polystyrene, nylon etc., whose size is in colloidal range. Finally the associated colloids or Micelles are those substances (electrolytes) on higher concentration and at certain temperature aggregate to exhibit colloidal characteristics but on dilution they revert back to ions. Examples are soaps and detergents.

The concept of colloids is extensively used and applied in many fields. One of the fields of study is in the sol-gel process. Brinker & Scherer (1990) in their book “Sol-Gel science-the physics and chemistry of sol-gel process” defined colloids as a suspension in which the dispersed phase is so small (~1-1000nm) with negligible gravitational force and dominated by short range force like Van der Waal force of attraction and surface charges. Colloidal silica has been growing steadily in industrial application and other fields as diverse as catalysis, metallurgy, electronics, glass, ceramics, paper and pulp technology, optics, elastomers, food, health care, and industrial chromatography (Bergna, 1994). He mentioned that the term sol-gel science which was coined in the 1950s is refered to the art of manufacturing materials by preparation of a sol, gelation of the sol, and removal of the solvent. One of the widely uses of sol-gel process was in ceramic processing due to its advantages of increased chemical homogeneity, high surface area of gel or powder produced, high maintenance of chemical purity and range of products in various forms can be prepared with relative ease from simple solution.

Yoshida in the book "the colloid chemistry of silica" by Bergna (1994) discuss various method of preparing silica sol and silica gel which includes dialysis process, electro-dialysis, peptization, acid neutralization and ion-exchange from sodium silicate. The structured inquiry lesson of the learning unit involves the process of sol-gel process where students prepare silica sol and silica gel through acid-base catalysis process of neutralization and condensation method. Sodium silicate is used as precursor with acetic acid (vinegar) and sodium hydroxide soln. as acid and base catalyst. A. Venkateswara Rao et al. (pg. 108) in the book Aerogels handbook by Aegerter, Leventis, & Koebel (2011) discuss the sol-gel route by neutralization and condensation process. According to them, in neutralization reaction the water glass (sodium silicate) is converted into silicic acid through partial protonation of $Si\text{-}O^-$ Centre which is achieved by addition of H^+ from acid resulting in exchange of Na^+. Then the free silicic acid is treated with small equivalent of base to increase the pH value which initiates condensation reaction leading to gel formation. They mentioned that to form silica sol and silica gel, the formation of free Si–OH and the overcoming of electrostatic repulsion interactions between silica species are prerequisites.

The preparation of colloidal silica in the current study involves the precursor water glass (sodium silicate). The water glass used in the preparation of sol-gel involves the neutralization of sodium silicate by adding acid. The acid used is acetic acid (vinegar). The Na^+ of water glass is replaced by H^+ of acid through ion exchange to form silicic acid (H_2SiO_3) which upon addition of base initiates gelation. The base used is sodium hydroxide.

[$Na_2SiO_3 + CH_3COOH \rightarrow H_2SiO_3$ *(silicic acid)* $+ xH_2O +$ *Sodium salt*]…….. *(1)*

The silicic acid forms a dimer. The formation of silica gel involves first dispersion of particles through neutralization by adding acid in which the large particles of sodium silicate break down into small particles of silica sol; and with condensation by adding base, the sol forms 3 dimensional network resulting in formation of gel. By maintaining the pH at 5-10, the gelation occurs preferably. The overall view of chemical reaction of gel formation of neutralization and condensation is given in figure 2.1.

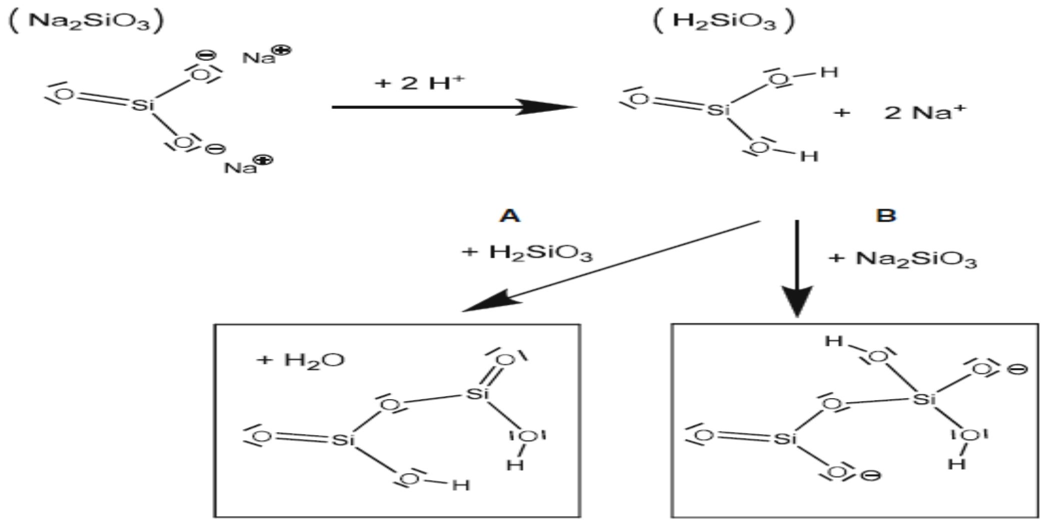


Figure 2.1 The Sol-Gel Process for Making Silica Gel from Sodium Silicate Solution using acid (Aegerter et al., 2011)

The production of silica gel and powder are of special interest to scientist as they provide opportunity to work with very pure system and well-controlled ultimate particle size and specific surface area (Bergna, 1994). The particle size and shape are of considerable importance in setting the properties of colloidal system and those properties that vary with particle size are very important feature of Nano scale materials (Nordell, Boatman, & Lisensky, 2005). Todebush & Geiger (2005) pointed out that the colloidal domain, which typically falls in the range of 1 nanometer to 1 micron deals with an intermediate length scale between true solutions and bulk materials. Therefore, they mentioned that it provides area of interest in nanotechnology due to the unique properties of materials with dimensions less than 100 nm. It is evident from the studies that colloidal particles have established extensive use in many capacities such as chemical engineering, pharmaceutics, photonics, biotechnology and agriculture (Jeong, Herricks, Shahar, & Xia, 2005). Some of the industrial sectors that deal with colloidal matter of their product development include paints, pigments, pharmaceuticals, food and beverages, cosmetics, ceramics, personal care products, and lubrications (Hassan, Rana, & Verma (2014).

Many studies focus on particles sizing and shape of the particles and have actively explored in the form of Nano and micro particles. Thus, particle size characterization of colloids is found very important in present days of application in various fields. It play important role in product development, applications in biomedical separation and diagnostics, determining soil productivity and pollutant transport, boost environmental quality and sustainability through pollution prevention, treatment, and remediation, and promoting drug delivery (Aramrak, Flury, Harsh, Zollars, & Howard P. Davis, 2013; Chamely-Wiik, Haky, Louda, & Romance, 2014; Jeong et al., 2005; Hassan et al., 2014; Todebush & Geiger, 2005). In the field of environmental studies Lapworth, Stolpe, Williams, Gooddy, & Lead (2013) discussed about importance of pollutant colloids interactions which can be studied through quantifying the size, structure and surface chemistry of colloids. They mentioned that natural nanoparticles (NP), particles with one dimension between 1 and 100 nm, and colloidal material, particles with one dimension between 1 nm and 1 μm, are important vectors for contaminants in the environment. Beside diverse uses of colloids, colloids properties arise from the uniqueness of its size. Many interesting property of colloids are seen in nature. The rain, blue color of the sky, tail of the comets, blood, milk, soil and formation of deltas can all be attributed to specific properties of colloids like Tyndall effect, coagulation, electrical properties, adsorption etc.,(Madan & Bisht, 2013)

2.3.2 Scattering of light

"Light" is radiant energy residing in a specific and very narrow band of electromagnetic spectrum whose wavelength ranges from 400nm to 750nm. The electromagnetic energy is packaged is called a photon and each photon which is associated with specific wavelength have a specific quantity of energy. And the number of photons emitted per unit time is function of the intensity of light associated with specific wavelength (Webb, 2000).

We rarely observe light directly. We observe the indirect light from the source after interaction with objects in its direct path. The possible interaction occurs through reflection, refraction and diffraction resulting in scattering of light and some interaction resulting in absorption of light. The interaction between radiation emitted by the Sun and the Earth's atmosphere, not only helps to sustain life, but also gives rise to the observed display of colors in the Earth's atmosphere. The interaction between electromagnetic radiation emitted by the Sun and the Earth's atmosphere is responsible for the depth of blue in the sky, the red sky at sunset, the yellowness of the Sun, rainbows, the whiteness of clouds, the appearance of haloes around the Sun and moon, and the vivid array of colors that might appear in the sky after volcanic eruptions (Kokhanovsky, 2013). The information about the origin and structure of our celestial bodies and their atmosphere is retrieved through light scattering technique (Muñoz et al., 2010). It plays a very important role and hence Hahn (2009) describe scattering as the redirection of light that takes place when an electromagnetic (EM) wave (i.e. an incident light ray) encounters an obstacle or non-homogeneity, in our case the scattering particle.

Light-scattering techniques are of two principal types: classical and dynamic. Brar & Verma (2011) describes classical light scattering (also known as static, Rayleigh or multi-angle light scattering) is one that provides a direct measure of particle size and therefore very useful for determining whether the native state of a particle is simple or complex while dynamic light scattering [also known as photon correlation spectroscopy (PCS) or quasi-elastic light scattering (QELS)] uses scattered light to measure the rate of diffusion of the particles. Some differentiate the scattering of light based on wavelength of scattered light and the incident light. The three types are Elastic scattering in which the wavelength of scattered light and incident light are same (Rayleigh scattering and Mie scattering); in Inelastic scattering the emitted radiation has frequency different from that of incident radiation (Raman scattering, fluorescence); and Quasi-elastic scattering where the wavelength of the scattered light shifts (e.g. in moving matter due to Doppler shift).

There are many theories that describe the scattering of light. Out of many one is the theory of Rayleigh scattering (after Lord Rayleigh) that is originally formulated and applicable to only small, dielectric (non-absorbing), spherical particles. The second is the theory of Mie scattering (after Gustav Mie) that encompasses the general spherical scattering solution (absorbing or non-absorbing) without a particular bound on particle size (Hahn, 2009). Brar & Verma (2011) divided light scattering into three domains based on a dimensionless size parameter (α) which is defined as: $\alpha = \frac{\pi Dp}{\lambda}$ where πDp = circumference of a particle, and λ = wavelength of incident radiation. Based on the value of (α), these domains are if (α) < 1, it is considered as Rayleigh scattering (small particle compared to wavelength of light); if (α) = 1 then its known as Mie scattering (particle about the same size as wavelength of light); and if (α) > 1 it is called Geometric scattering (particle much larger than wavelength of light). The researcher found that three parameters govern the scattering of light. They are the refractive index; the size and shape of the particulate and wavelength of light as they play key factors in the scattering process (Lurton et al., 2014; Muñoz & Hovenier, 2011). From the parameters it is understood that the intensity of scattering is directly proportional to size of the particles and inversely to wavelength of the light. But as the size of the particles become bigger, the dependence on wavelength of light diminishes (Ahn & Whitten, 2005; Pecina, Smith, Johnson, & Snetsinger, 1999). Figure 2.2 shows light scattering by different size of particles.

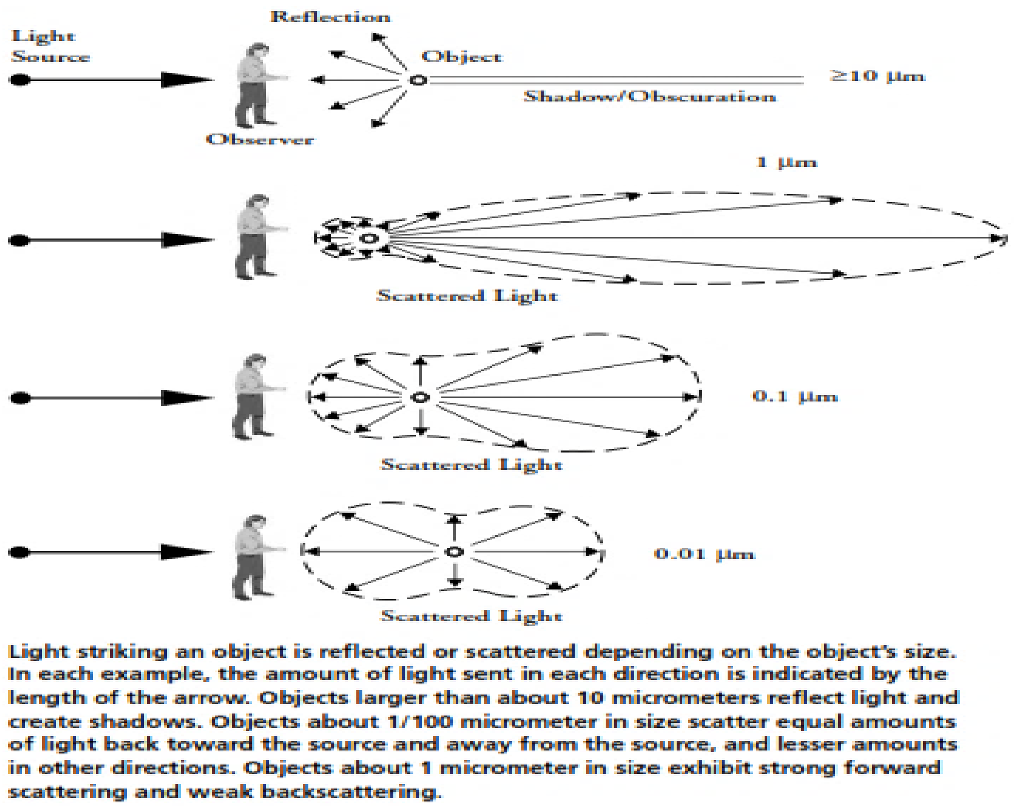


Figure 2.2 Light scattered by the different size of particles (National Aeronautics and Space Administration, 2001)

So, the dependence of scattering of light on the wavelength is limited to the size of the particles. As the size of the particle increases, at certain point of parameter, scattering become independent of wavelength of light as seen in the clouds. For instance, molecules being the smallest size will interact with incident electromagnetic radiation of particular wavelengths, i.e., the shorter wavelengths, such as blue light. As the size of particles increase with respect to the wavelength of incident electromagnetic radiation, i.e., size is equal to incident wavelength, results in processes such as refraction into the particle, and internal reflection around the particle (Kokhanovsky, 2013). Though not much studies are focused on education field especially which is suitable to school level yet several chemical education experiments have explored light scattering to study and monitor the growth of particles and measure particle sizes relevant to polymer and colloid science (Ahn & Whitten, 2005).

The idea of scattering of light with relation to size of the particle and wavelength of light is infused in both the guided inquiry and structured inquiry lesson. In guided inquiry lesson, students use red and green laser to observe the Tyndall effect occurring in suspension, solution and colloids. They infer their observation to differentiate the three dispersion system on the basis of particle size and to find the differences between scattering of light by different wavelength of light using red and green laser. The solution does not show Tyndall effect while suspension and colloids exhibits Tyndall effect. The green light scatters more than red light due to shorter wavelength and high frequency. With this idea, students use it as prior knowledge in structured inquiry lesson where they prepare silica sol and silica gel through sol-gel process. Through scattering process of green and red light, students infer their observation in each step based on differences in scattering of light to understand changes in particle size brought about by acid-base catalysis. They conclude their result by understanding the fundamental process of preparing colloids by top-down (dispersion) process and bottom-up (condensation) process.

Petruševski, Monković, & Ivanovski (2006) states that students often have vague idea about scattering of light and provide a very effective way to perform a demonstration of light scattering using diode laser (laser pointer). The use of laser is known since earlier time and has been used as handy devices for performing ray traces in geometric optics demonstrations and laboratory (Kutzner, 2013). The laser is found available in the market and students are somehow familiar with it as many products like in toys are available. It is also seen in science fiction movies and is used as pointer in classroom. People are fascinated by its remarkable properties of brightness and long length collimated light which can be availed by teacher or general educator to develop instructional instruments in laser topic (Tanamatayarat, Arayathanitkul, Emarat, Chitaree, & Sujarittham, 2012). Laser pointers are mono chromatic light that gives intense beam of light. The five basic properties described by Tanamatayarat et al., (2012) states that laser is a mono chromatic light that emits a light with a narrow spectral width. It is highly directional and diverges with a very small angle. Its intensity decrease along the axial distance but the tendency of decreasing is different from isotropic light and travel in speed of light. Petruševski, Monković, & Ivanovski, (2006) states that laser pointers enable instructor to make old demonstrations more attractive and vivid. They said that the use of red and green laser now a day at affordable price can be used mainly in demonstrations in general chemistry and physics, optics, organic and analytical chemistry and so on. They suggest that such demonstrations can strengthened the knowledge and motivate the students to widen their science horizons.

Several chemical education experiments have explored light scattering to study and monitor the growth of particles and measure particle sizes relevant to polymer and colloid science (Ahn & Whitten, 2005). They used light scattering using red and violet diode laser to monitor particle growth. Pecina et al., (1999) demonstrated Rayleigh scattering in optically active and inactive system; mostly demonstration was used like Kutzner (2013) used it as optic laboratory tools to trace the rays of light; Petruševski, Monković, & Ivanovski, (2006) used light scattering in heterogeneous system; and in measuring nanoparticles by light scattering technique (Brar & Verma, 2011)

The current study employs laser diode, red laser (650nm) and green laser (532nm) in light scattering technique (optical activity) or Tyndall effect. It enables the instruction to use scattering of light to understand the effect of size of particle with different wavelengths. It plays a key role in instruction as scattering technique in relationship with particle size and different wavelength is used explicitly in activities to understand differences between dispersion systems, preparation of colloids, natural phenomenon, the nature of light etc.,. The possibility of such scattering technique in the classroom takes advantage of the availability of laser because it is cost effective and its remarkable property and the familiarity of its use in science, movies and toys. The previous study used laser mostly as demonstration but the current study provides students in group to explore it by themselves provided that the safety issues are properly followed and assured.

CHAPTER III
RESEARCH METHODOLOGY

Overview

This chapter presents a new hands-on learning unit developed on the concept of colloids to enhance students' understanding of the effect of size of particles based on the lab based inquiry approach. The development and implementation of the learning unit are described. Data collecting tools and data analysis process are also presented.

3.1 Development of learning unit

The learning unit consists of two lesson plan of 3 hours each. The lab based inquiry approach learning unit consists of a guided inquiry lesson and structured inquiry lesson. The learning unit attempts to enhance students' understanding of the effect of the size of particles in the solution. The development of learning unit is based on the syllabus of grade 11 and 12 chemistry under the science curriculum framework of Bhutan, 2012. The concept colloid under the surface chemistry is usually taught in grade 11.

The guided inquiry lesson involves students' activity to distinguish between solution, colloids and suspension. Students work in groups of 4-5. They are provided with materials and equipment. They design their own procedures, collect data, and interpret their results followed by whole class presentation and discussion before coming to a conclusion. The students with prior idea and knowledge from the first lesson proceed to second lesson where they learn to prepare colloids through condensation and dispersion method. This lesson is structured as it introduces the Sol-Gel process, which is a complete new idea for students. While working in the same group, students are provided with procedures, they work according to procedure, but collect data, interpret their results which is again followed by whole class presentation and discussion before coming to a conclusion. Both lessons are linked with each other in order to achieve the main objective which is to understand the effect of size of particles in the solution through the teaching of colloids. The instruction cannot be moved to second lesson directly without learning first one because the learning goals of second lesson require the prior knowledge and information which can be achieved from the first lesson. The details of development of instruction are described. Both the lessons are guided by questions in which the researcher plays the role of facilitator.

This instructional design is explored through various studies to come up with the main aim of an understanding the role played by size of the particles in our life. The design takes into account the need of students to be aware of such prospect with nanoscience and nanotechnology, though the present study does not focus on its area rather focus on the effect of size of particles. However, the syllabus under the study, on the topic colloids provides an opportunity to infuse the concept and idea to the students by introducing the sol-gel process, relating to the scattering of light, discusses some natural phenomenon and more by studying colloids, which is in perspective to syllabus and curriculum design. The design also infuses lab based inquiry approach as an instructional strategy to study the impact of students' understanding and as well as their perception towards the learning unit.

3.1.1 Guided inquiry lesson

Key concept: Dispersion system is a system made up of a substance distributed or scattered as minute particles through another substance. The distributed substance is known as dispersed phase (internal phase) and continuous medium around it is called dispersed medium (external phase). Depending upon the degree of dispersion, the solution is a system of the homogenous mixture in which molecules or ions of solute are dispersed in the mass of solvent. Due to a high degree of dispersion, there is no dispersed phase and as a result, the whole system is single phase. The size of the particles is less than 1 nanometer (nm) (Madan & Bisht, 2013).

The size of the colloidal system is from 1 nm to 1 micron **(**Ball, 1994; Madan & Bisht, 2013). The sizes of the particles of colloids are bigger than the size of the particles of the solution, but smaller than the coarse suspension. Under the microscope, the colloid is characterized by two distinct phases. The systems in which the particles are larger than 1 micron are called suspension. The difference in the size of the particles of these three systems attributes to many physical properties like filterability, appearance, gravitational, Brownian motion, optical activity, adsorption, electrical properties, etc. It is important that the emphasis on the size of particles attributing to differences in physical property need to be addressed rather than based on mere observation.

The lesson aims to distinguish between solution, colloids and suspension through guided inquiry activities. The distinction is based on physical properties of differences like optical property (scattering of light), filterability property, gravitational property, appearance and homogeneity. The lesson involves three phases, which are pre-lab, during-lab, and post-lab. Figure 3.1 shows the outlook of the guided inquiry lesson.

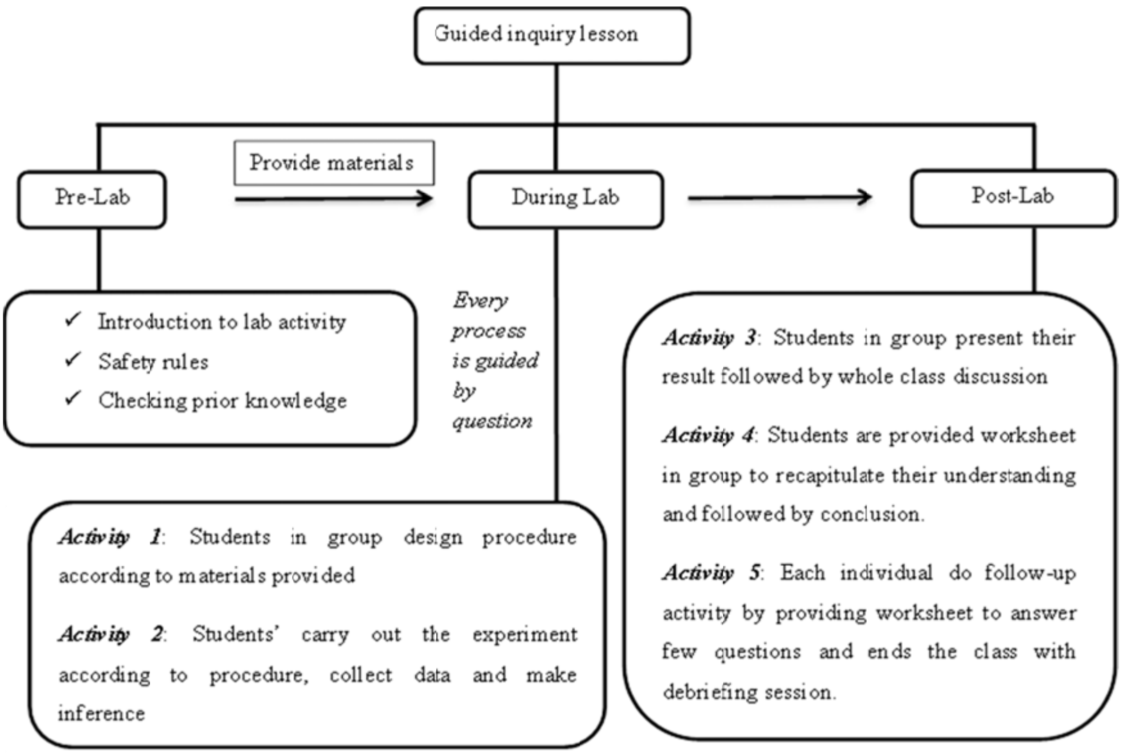


Figure 3.1 Outlook of Guided inquiry instruction

This lesson has three objectives, 1. Differentiate between solution, suspension, and colloids (*Cognitive)*; 2. Design and perform the experiment by themselves in groups *(Psychomotor)*; and 3. Relate the importance of the size of particles and the relationship with a scattering of light *(Affective)*.

Pre lab: The students are debriefed about the activities. Next, students are checked about prior knowledge. Student need the understanding of terms like wavelength, frequency, visible spectrum, and some ideas about separating mixtures by physical method that had been learned in their lower grade in order to do and learn from the activities. For instance, the relationship about frequency and wavelength; the separating technique like filtration using filter paper and color composition of visible light are important. Then students are briefed about laboratory safety rules which are followed by random selection of students into groups that are done before the implementation. The class consisted of 10 groups of 4-5 students in each group.

During Lab: Each group is provided with the materials. The materials include sand, sugar, milk powder, water, filter paper, semi permeable membrane (cellophane), laser pointer red (650 nm) and green laser pointer (532 nm), and basic laboratory equipment like beaker, test tube, conical flask, glass rod, measuring cylinder, spatula etc.,

Each group was provided with Lab-Report Format (Appendix E) that is used and found in the syllabus. The question was displayed on the blackboard in the lab. It reads "What are the differences between these three mixtures? (Sand + Water, Milk + Water and Sugar + Water) as in figure 3.2.

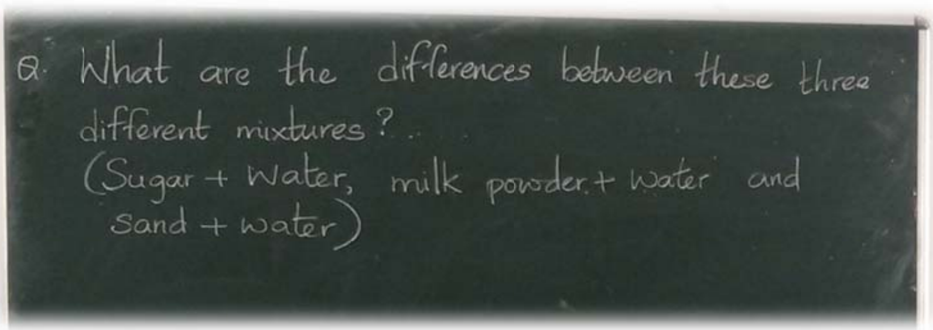


Figure 3.2 Question of the day

Activity 1: Student designs the framework of the lab activity. They design a procedure accordingly with the materials that are provided to them. Students are provided with lab report format and papers to do their rough work. Time limit for designing a lab activity is 45 minutes. Once the design is completed, students' lab design is reviewed and revised. Once the revised lab design is approved, then the students in groups carry out with the lab activity according to their design. The figure 3.3 shows students in group designing procedures.

Figure 3.3 Students in group designing procedures

Activity 2: Students in each group carry out the experiment according to their design. They record their observations and results in each proceeding steps. The role of the teacher plays a very important part. They act as facilitator and guide the students throughout the activity with questions. The guiding questions enable students to think properly in designing their procedures, recording observation and the results. It serves not only as guidance in designing but also in reflection and reasoning behind their observation and results. Some examples of the guiding questions are given in the table below. It should be noted that the questions differ from group to group depending on their design. However, some common questions which are framed to guide them to intended procedures, recording, reasoning, etc.., are given in the table 3.2. The table 3.1 shows the intended procedural design and activities that are expected from students to carry out during the lab.

Table 3.1 Intended procedural design and activities.

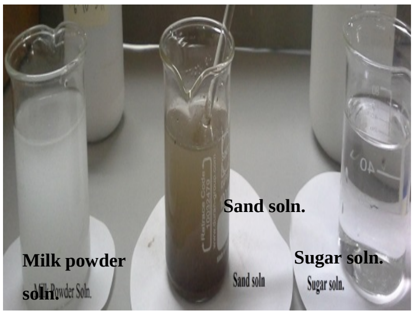
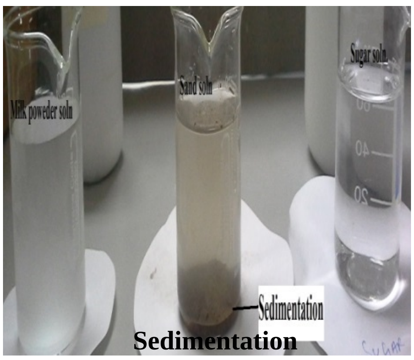
Instructional activities	Learning goals	Learning activities
1. Homogeneity and appearance 	1. Students are able to differentiate the difference between solution, suspension, and colloids based on their appearance and homogeneity.	1. Students in the group make the solution mixture and record the observation. They look at the differences in appearance and make inferences.
Students mix water with sand, milk powder and sugar respectively to make the solution mixture. ***colloids are actually a heterogeneous mixture as the presence of separate phase can be seen if observed under the microscope.*	2. Students are able to reason their observation with respect to particle size.	2. The Solution is clear and homogenous. Colloids are translucent and homogeneous while the suspension is opaque and heterogeneous. The differences in homogeneity and appearance are due to differences in particle size of the mixture.
2. Gravitational property 	1. Students are able to infer that sedimentation in suspension occurs due to a large particle.	1. Students while making the observation on appearance and homogeneity, they observe sedimentation occurring in suspension while colloids and solutions remain as it is.

Table 3.1 Intended procedural design and activities (cont.)

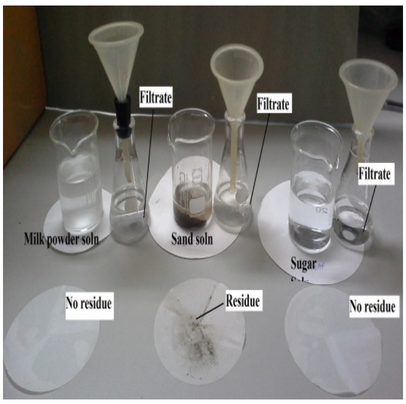
The mixtures are to be left for some period of time (2-3 minutes). ***phase separation can also occur in colloids if we stand it for very long duration without disturbance*	2. Students should able to support their observation by differentiation the different between solution on the basis of difference in particle size	2. Students record and make an inference. The sedimentation support further role played by particle size. The particle size of suspension (sand) being bigger, it settles down as the distinct layer between sand and water is formed which shows two phase system. The colloids and solution, particle size being small remains suspended. The larger sand particle sediment quickly while the smaller one takes time.
3. Filterability Property  Separate the mixture using filter paper	1. Students understand the difference between cellophane and filter paper on the basis of pore size.	1. Students in the group use filter paper to filter the 3 different mixtures. They record the results and make the inference.

Table 3.1 Intended procedural design and activities (cont.)

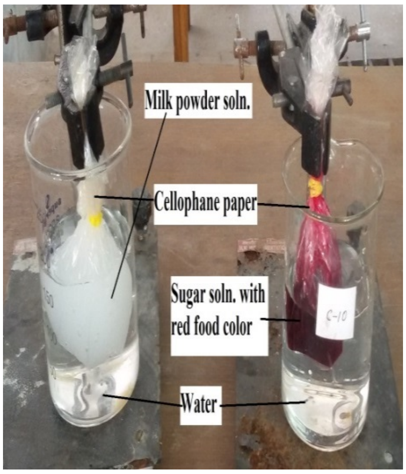
	2. The Students should understand that due to large particle size of suspension (sand mixture), filter paper can easily separate the mixture from colloids and solution.	2. Sand mixture is filtered while milk powder and sugar cannot be filtered. The filtrate and residue are obtained. Students differentiate the mixture on the basis of their result and observation.
They use cellophane (semi-permeable) to further filter colloids (milk powder soln.) and solution (sugar soln.). Students take the sugar soln. and milk powder solution to filter as sand soln. is not required since it could be filtered by filter paper. Students add different food color to both the soln. to observe the change.	3. Students should understand that cellophane paper can filter colloids from solution as the size of the colloids is bigger than the pores of cellophane.	3. They observe that sugar soln. can pass through the cellophane indicated by a color change in the beaker while milk powder soln. cannot. They make the inference on the basis of particle size of solution and colloids with pore size of cellophane
***The use of cellophane is tricky as it need concentration gradient. It cannot be used like filter paper using funnel. The result depends on amount of mixture taken by students.* ***Less volume, less time and vice versa. So it is suggested to*	4. Students should be able to reason the differences in the filterability on the basis of particle size and pore size of filter paper and cellophane	4. Due to difference in particle size, sugar soln. can pass through the cellophane as pore size of cellophane is bigger to allow it, but not the colloids whose size is

Table 3.1 Intended procedural design and activities (cont.)

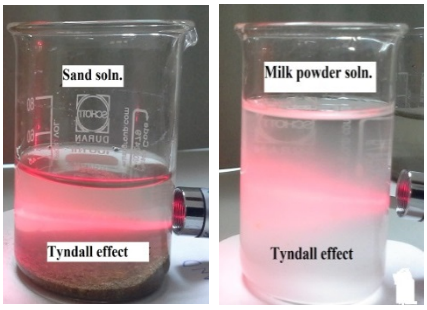
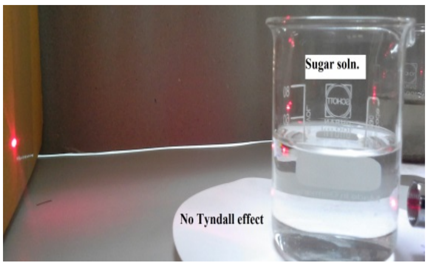
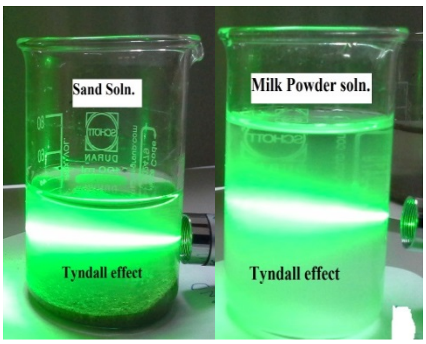
prepare beforehand to show the result if in case students take more volume of the mixture.	paper.	bigger than the pores. The differences in filterability property shown by filter paper and cellophane are based on difference in particle size.
4. Optical property (Tyndall effect)   Students use a red laser to see the optical activity (the Tyndall effect)	1. Students should understand that the reason the colloids and suspension undergo the Tyndall effect is due to the size of the particles.	1. Students use red and green laser to see optical activity (the Tyndall effect). They observe the scattering of light in different mixtures and infer their results. Students find that scattering of light occur in sand soln. and milk powder soln. while sugar soln. does not show any optical activity.
	2. Students should understand that the distinctive property behind a scattering of light is particle size.	2. Students compare the intensity of scattering by a different source of light and record their observations and inference. The particle size of the solution is not in the range to scatter light. They observe that

Table 3.1 Intended procedural design and activities (cont.)

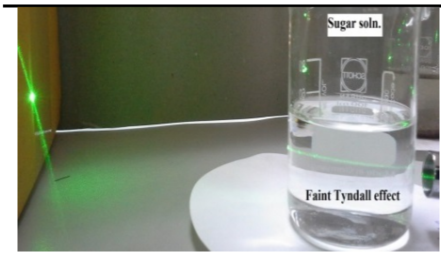
 Students use green laser to see the optical activity.		green light scatter more than the red light. They relate their inference with scattering of light with wavelengths of light and the sizes of the particle.
*** The green laser shows a faint the Tyndall effect in sugar soln., which should not be happening. Perhaps due to the presence of some impurities it shows, but still then it can be used to help students understand about relationships of wavelength of light with the scattering of light*	3. Students are able to relate the scattering of light with the wavelength of light and the particle size.	3. Scattering is directly proportional to the size of the particle and indirectly proportional to the wavelength of light.

Table 3.2 Some guiding questions used during the activities

Guiding questions	Objective
✓ Why are you using different equipment for different solution? ✓ Why you have to take a small and equal amount of substance? ✓ How are you going to record your observation? Why?	To control the experiment with a solution and guide on some skills of laboratory techniques and data recording.
✓ What are the differences in visibility and appearance? Why? ✓ Is there any precipitate? Why?	To understand and reason the differences in property of homogeneity and gravitational property.

Table 3.2 Some guiding questions used during the activities (cont.)

✓ What is the difference between filter paper and cellophane paper? ✓ Can the mixture be separated by filter paper? Why? Why not? ✓ Can the mixture be separated by cellophane paper? Why? Why not?	To understand and reason the property of filterability based on the pore size of filter paper and cellophane.
✓ What is the difference between red and green laser? Why? ✓ What do you observe when the laser is passed through the mixture? Why? ✓ What differences do you see when red laser and green laser passes through a different mixtures? Why?	To understand the relationship of scattering of light with different mixtures using different sources of light having different wavelength. Focus on optical property (Tyndall effect).
✓ Can you relate any of such phenomena that you experienced in your daily life. ✓ What do you think is the main reason behind all the differences of these three mixtures? Give some evidence from your observation.	To relate to the daily life phenomenon and ultimately to emphasis on the size of particles as the fundamental difference.

The figure 3.4 shows gravitational property and filterability property by filter paper and cellophanes while figure 3.5 shows optical property (Tyndall effect)

(a) **(b)** **(c)**

Figure 3.4 The gravitational property (a) and filterability property with filter paper (b) and (c) filterability property with cellophane

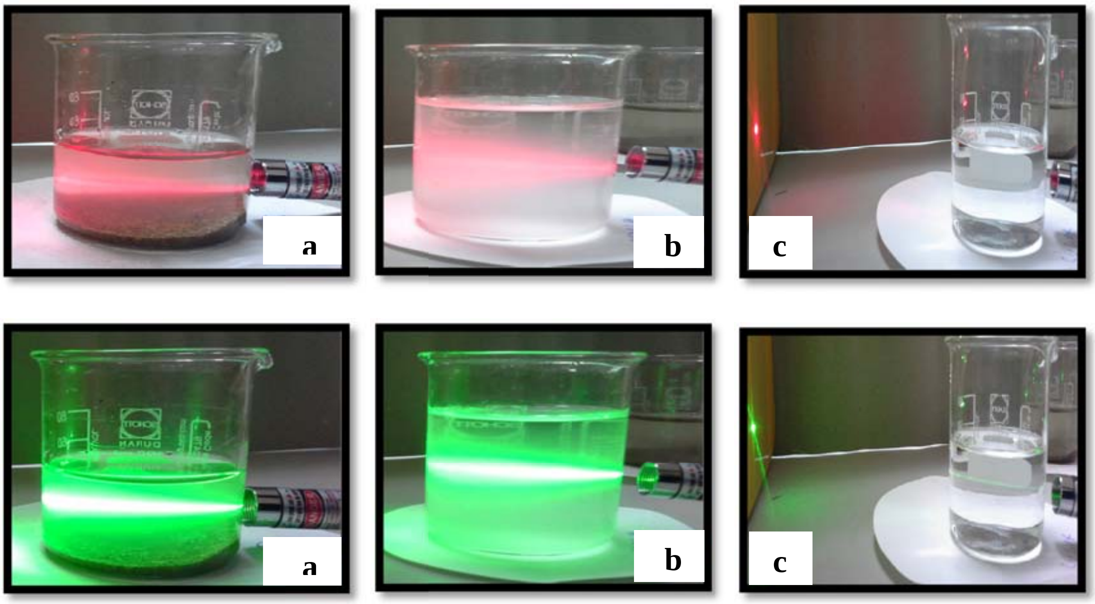


Figure 3.5 The optical property (Tyndall effect) on (a) suspension, (b) colloids and (c) solution by red laser and green laser

Post Lab: This session involves the presentation of the findings of each group.

Activity 3: Each group reports their findings to the whole class. The presentation is followed by a discussion where students in the group defend their findings and observation based on the results. The discussion is carried out with the facilitator asking the questions based on their presentation. The discussion enables them to analyze their findings; and the result of comparison among groups facilitates their understanding of the concept under study.

Activity 4: Once the class ends with presentation and discussion, students are provided with worksheets (Appendix F) to revisit their observation and recapitulate their findings from the class discussion. Next, the class discusses that sand solution as suspension, milk powder solution as the colloids and sugar solution as the solution followed by discussion of the properties of homogeneity, filterability, gravitational effect, appearance and optical property (Tyndall effect). The optical property is emphasized more by relating the differences between different source of light (green and red) with different types of mixtures under the study. The students use this understanding as prior knowledge in the second lesson. The table 3.3 shows the properties of dispersion system.

Table 3.3 Properties of dispersion system (Madan & Bisht, 2013)

S.No	Property	Solution	Colloidal Solution	Suspension
1	Particle size(diameter)	Less than 1nm	Between 1 nm - 1,000 nm	More than 1,000 nm
2	Appearance	Clear and homogenous	Generally clear and homogenous	Opaque and heterogeneous
3	Nature	Homogenous, stable, one phase systems	Heterogeneous, stable, two phase system	Heterogeneous, metastable, two phase system.
4.	Filterability property	Not possible	Possible only by equivalent to semi-permeable membrane	Possible
5	Optical property (Tyndall effect)	No	Yes	Yes
6	Gravitational effect	No	On long standing	Yes

The lesson draws to the conclusion by following questions in order to achieve the important objective of the learning unit that is “Size of the particles as the fundamental differences behind the differences in the properties of different mixtures”. Some of the key guiding questions are given in the table 3.4.

Table 3.4 Some guiding questions used for assessment

Properties of mixtures	Question	Objective
All the properties under study	1. What are the differences between three types of mixture?	To assess students' understanding of suspension, colloids, and solution
Gravitational property	1. Why suspension sediment while the others do not? 2. What do you conclude from the difference?	To reason that size of the particles in suspension is large while that of colloids and solution are very small to settle
Filterability property	1. Why suspension can be separated by filter paper? 2. Why colloids can be separated by cellophane while the solution cannot? 3. What can you say about the size of the particles?	To understand that filterability of suspension, colloids, and solution through filter paper and cellophane is due to the differences in pore size and particle size of the mixtures.
Optical property (scattering of light) or Tyndall effect	1. Why colloids scatter light while solution does not? 2. Why does green light scatter more than red light? 3. What is the difference between the scattering of red light and green light?	To understand the relationship between scattering of different wavelength of light with the size of the particles

Activity 5: To end the lesson, each student was given a worksheet (Appendix G). It consisted of two questions where individual have to answer to evaluate their understanding. All the students come to the conclusion that the main difference between them is basically the size of the particles. Teacher summarizes the lesson in power point. The explanation includes the effect of size of particles and scattering by laser. The increase in size of the particles will increase the intensity of scattering. The explanation will be followed by understanding of different classes of colloids with examples.

3.1.2 Structured inquiry lesson

Key concept: There are different types of colloidal system. Based on it there are basically two methods of preparing the colloidal solution given in the syllabus, the dispersion methods and condensation methods (Madan & Bisht, 2013). The dispersion method is a disintegration method in which large bulk of materials is disintegrated into small particles of colloidal size like the process of top-down method in nanotechnology in which large particles are converted into small particles. Dispersion method is usually done by mechanical method such as mechanical dispersion, electro dispersion (Bredigs arc method), ultrasonic dispersion and peptization. In condensation method the particles of colloidal sizes are produced by the growth of smaller units to form bigger units like the process of bottom-up process in nanotechnology. Condensation is usually done by chemical method like oxidation, reduction and hydrolysis.

The preparation of colloidal silica in this experiment involves the precursor water glass (sodium silicate). The water glass used in the preparation of sol-gel process involves the neutralization of sodium silicate by adding acid. The Na^+ of water glass is replaced by H^+ of acid through ion exchange to form silicic acid (H_2SiO_3) which upon addition of base initiates gelation. The silicic acid forms a dimer and have link between each dimer and form the 3 dimensional network throughout the solution. The figure 3.6 shows the process for making silica gel by sol-gel process from sodium silicate and figure 3.7 shows the structure of silica gel.

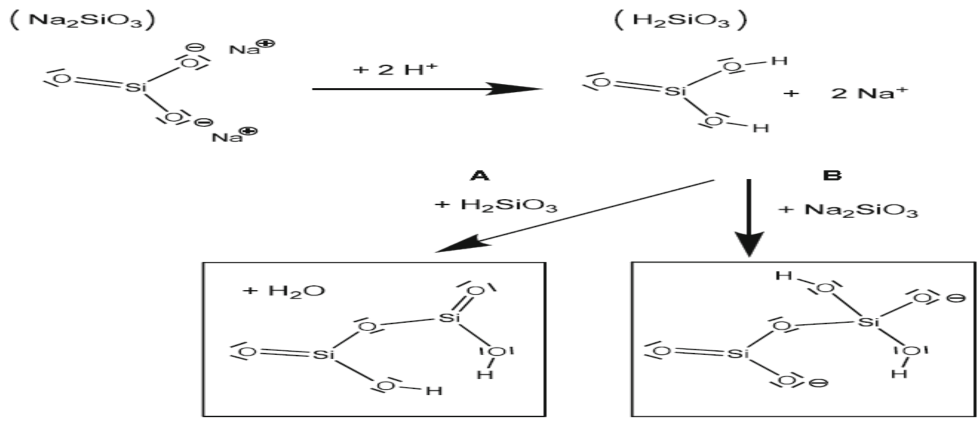


Figure 3.6 The Sol-Gel Process for Making Silica Gel from Sodium Silicate Solution (Aegertel et.al, 2011)

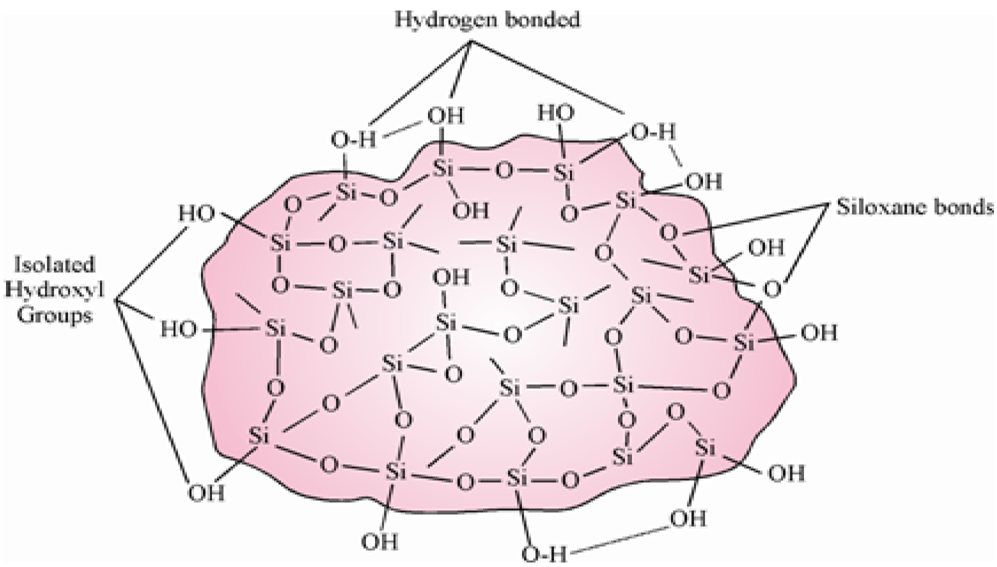


Fig 3.7 Structure of silica gel depicting the various types of hydroxyl groups that interact with the functional groups of solute/solvent molecules (http://goo.gl/iUITvz)

The formation of silica gel involves first dispersion of particles through neutralization by adding acid in which the large particles of silica sol break down; and with condensation by adding a base, the small particle of silica sol forms 3 dimensional network throughout the solution resulting in the formation of a gel. By maintaining the pH at 5-10, the gelation occurs preferably. So the mechanism of silica sol and silica gel formation occurs through acid-base catalysis reaction which has been manipulated in the lab before implementation. The manipulation of this process involved using both acid catalysis and base catalysis process. In acid-catalyzed process, the vinegar (5 % CH_3COOH), which is available in the market, is used under the dispersion process to form a silica sol. Then, in base catalyzed process, the 0.5 M solution of sodium hydroxide (NaOH) is added to silica sol to form silica gel. The concentration and volume are worked out to fit the experimental time of study. Such manipulation is done mainly to align the method given in the textbook by the Sol-Gel process and also to relate by scattering of light, thus designed to achieve the objective of students' understanding about the role played by particle size and also the ways of preparing colloids.

The formation of silica sol from sodium silicate on adding acid results in decreasing in size of particles while formation of silica gel on adding base to silica sol results in the formation of 3 dimensional network, forming a gel. The use of Rayleigh scattering is in line with the size of colloids which is smaller than the wavelength of the light beam (laser) used in this study. The intensity of scattering of light is directly proportional to the square of the size of the particles and inversely to a fourth of the power of wavelength. The formula implies that scattering of light increases with increase in size of particles and vice versa, while light with lower wavelength, or high frequency scatter more than the one with higher wavelength or low frequency. This phenomenon can be shown macroscopically with the help of different laser through their intensity of scattering of light. The addition of acid, 40 ml of 0.5M of 5 % vinegar in a 20 ml of 5% solution of sodium silicate (Na_2SiO_3), the student observes changes in turbidity (become clear) and decrease in intensity of scattering of light by laser light-indicate decrease in size of particles. Next, the addition of base, 0.5 M NaOH result in changes of turbidity (form gel) and increase in intensity of scattering of light by laser showing an increase of size of particles as the reaction starts to form a 3 dimensional network. The figure 3.8 shows clarity and transition of silica sol to silica gel and figure 3.9 shows differences in scattering of red and green laser as seen in each transition. The figure 3.10 provides an outlook of structured inquiry lesson.

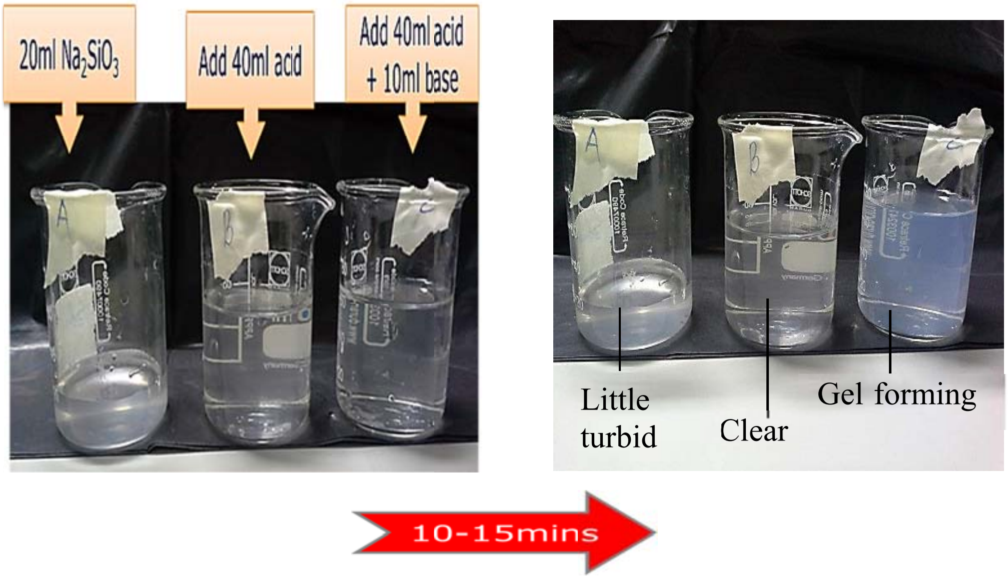
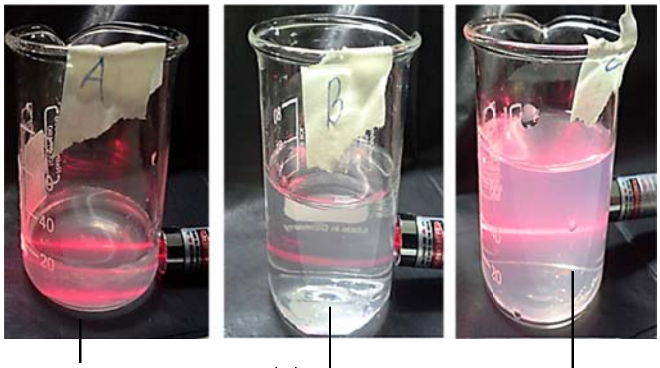
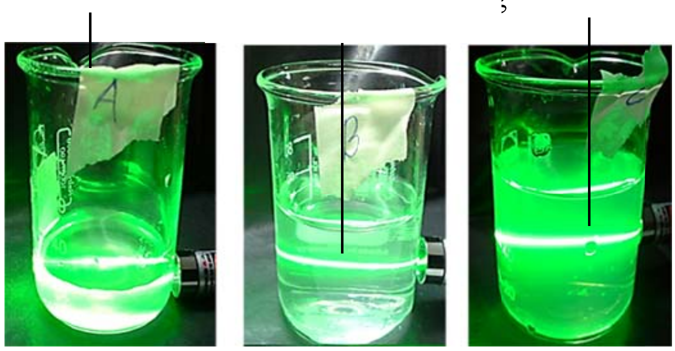


Figure 3.8 Changes in clarity and transition of silica sol to silica gel



(a)



(b)

Figure 3.9 Difference in scattering of light by (a) red laser and (b) green laser during each transition

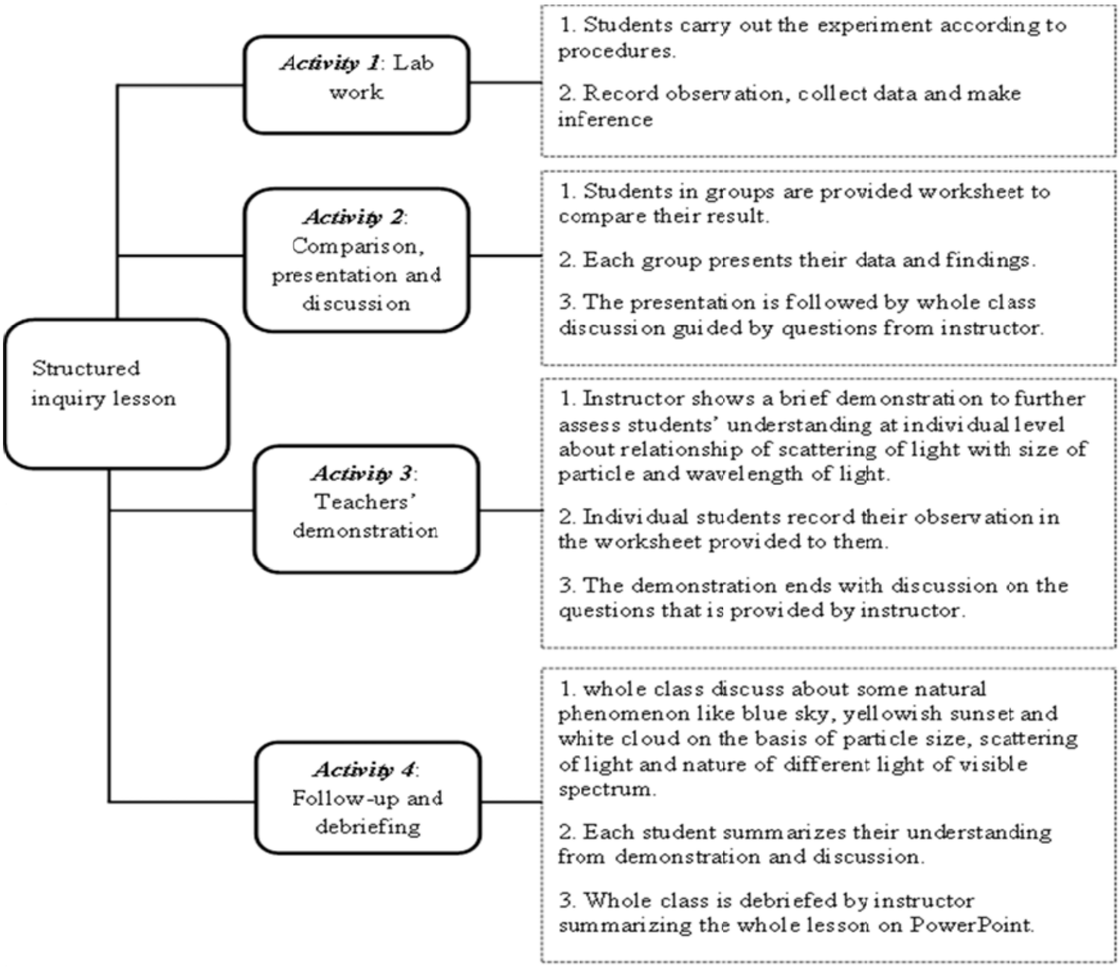


Figure 3.10 Outlook of structured inquiry instruction

Activity 1 Lab work: Students in the group are provided with lab activity procedure. Students carry out the activity accordingly with procedure and record every possible observation in the work sheet. The teacher guides the students with key questions. The steps of the procedure are described in table 3.5.

Table 3.5 Laboratory work activity

Instructional activity	Learning goal	Learning activity
Step 1: Students take 3 test tubes or beaker and mark A, B and C. Add 20 ml of 5% sodium	1. Students should be able to observe the turbidity and	1. Students observe that sodium silicate soln. is little turbid. The scattering is

Table 3.5 Laboratory work activity (cont.)

<table>
<tr>
<td>silicate (each in a test-tube or beaker)


Observe the clarity of the solution and record. Then, with the help of laser, they direct the light towards the solution separately. They record and tabulate the data below.
Observation table 1.
<table>
<tr><td colspan="3">5% Na_2SiO_3 (20ml)</td></tr>
<tr><td colspan="2">Observation1. (Turbidity)</td><td></td></tr>
<tr><td rowspan="2">Observation 2. (Scattering)</td><td>Red Laser</td><td></td></tr>
<tr><td>Green Laser</td><td></td></tr>
</table>
</td>
<td>differences in the scattering of different laser light.

2. Students should be able to infer the difference on the basis of particle size and the wavelength of light.</td>
<td>strong for both red and green lights. The green light scatters more than the red light.

2. Students are then asked key questions like
- Is there any difference in the turbidity? Why?
- What differences do you see in the scattering of light? Why?

3. 5 % Sodium silicate contains large particles which add to its turbidity and more scattering of light. The green scatter more than red due to shorter wavelengths of light.</td>
</tr>
<tr>
<td>Step 2: Students add 40 ml of 0.5 M of 5 % vinegar to test tube B and C that already contain 20 ml of 5% Na_2SiO_3.</td>
<td>1.The Student should be able to recognize through observation the decrease in size of the particles as is</td>
<td>1. Students observe that the turbidity decrease on adding acid on beaker B & C. The sodium silicate soln. becomes clear by adding acid.</td>
</tr>
</table>

Table 3.5 Laboratory work activity (cont.)

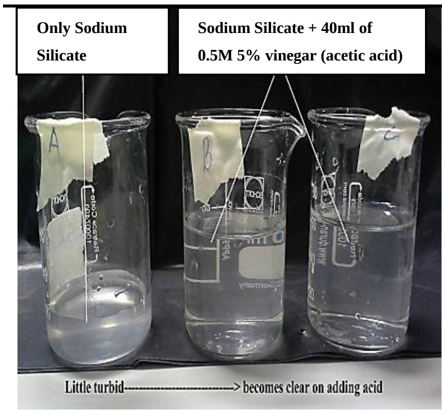
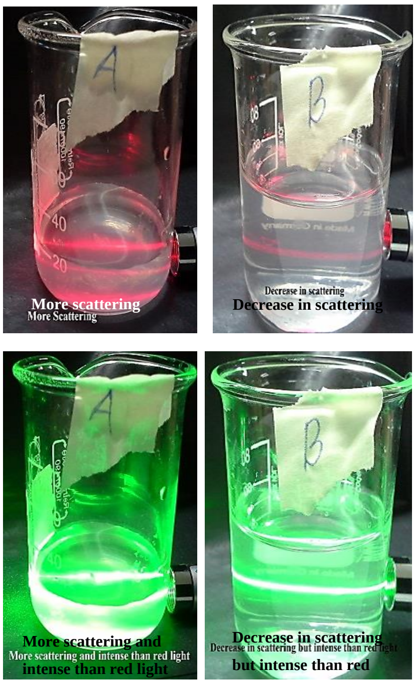
 Observe the change and record the clarity of the solution. Again, with a laser, they direct the light towards the solutions. They Observe and record the data in the table.  Observation table 2	shown by solution becoming clearer and decrease in scattering.	Students also observe the decrease in scattering of light on beaker B and C of both red and green lights.
	2. Students should be able to relate it as dispersion process or top-down process of preparing colloids through silica sol using acid catalysis.	2. Students make the inference based on their observations on the basis of size of particles that decreases in scattering of light and the solution becoming clearer indicates breaking down of sodium silicate into smaller particles of silica sol due to addition of acid. It is a dispersion process or top down process where big particles break into smaller particles.
	3. Students are able to conclude the result with their observation based on prior knowledge of scattering of light and turbidity and scattering of light.	3. Students are then asked key questions like - Is there any change in the turbidity? Why? - What differences do you see in the scattering of light? Why? - Are there any differences in the intensity of scattering

Table 3.5 Laboratory work activity (cont.)

<table>
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<td>
<table>
<tr><td colspan="3">5% Na_2SiO_3 (20ml) + 40ml of 0.5M of 5% vinegar.</td></tr>
<tr><td colspan="2">Observation1. (Turbidity)</td><td></td></tr>
<tr><td rowspan="2">Observation 2. (Scattering)</td><td>Red Laser</td><td></td></tr>
<tr><td>Green Laser</td><td></td></tr>
</table>
</td>
<td></td>
<td>of light with observations made in first procedure?</td>
</tr>
<tr>
<td>

Step 3: In the final step, students add 10 ml of 0.5M of NaOH to test-tube C. They keep the solution to stand for 5-10 minutes.

Together with it, they observe the change, record and again with the help of laser, direct the light towards the solution and record their observations in the table.
</td>
<td>

1. Students are able to relate that increase in turbidity and scattering of light is brought about by an increase in particle size due to addition of base (NaOH).

2. Students should understand the formation silica gel from silica sol as condensation process (bottom-up process) in preparation of colloids through base-catalysis.

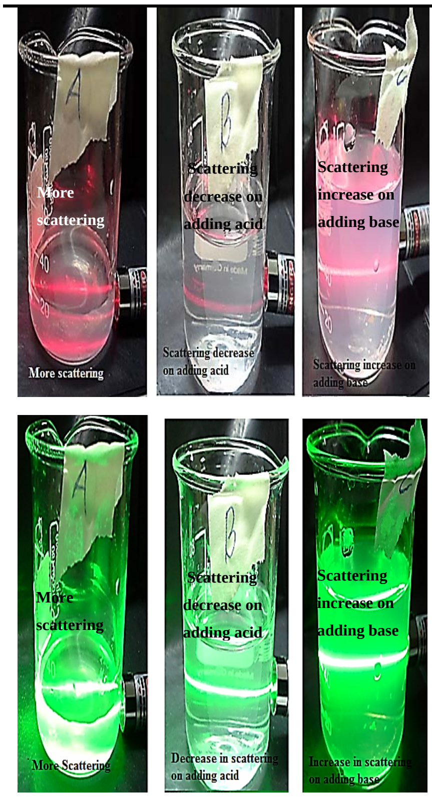
3. Students should conclude the
</td>
<td>

1. Students upon adding base on beaker C, observe changes in the turbidity. It starts to form gel within 5-10 minutes. Students also observe changes in scattering of light. The intensity of scattering increases on adding base as gel is formed.

2. The silica sol upon addition of base undergoes condensation or bottom-up process where silica particles start to arrange themselves to form large networks of gel. Students infer their observation with particle size.

3. Students, through their observation on turbidity
</td>
</tr>
</table>

Table 3.5 Laboratory work activity (cont.)



Observation table 3

5% Na_2SiO_3 (20ml) + 40ml of 0.5M of 5% vinegar + 10ml of 0.5M NaOH		
Observation1. (Turbidity)		
Observation 2. (Scattering)	Red Laser	
	Green Laser	

relationship of particle size with a scattering of light to understand the preparation of colloids through dispersion and condensation method

and scattering of light during formation of silica sol and silica gel infer their understanding on the preparation of colloids through dispersion method (top-down) and condensation method (bottom-up). Their inference is based on the increase and decrease of particle size as observed through scattering and clarity of solution and also with the wavelength of light.

4. Students are then asked key questions like

- Is there any change in the turbidity? Why?
- What changes do you see in the scattering of light? Why?
- Are there any differences in the intensity of scattering of light with observations made in 2nd procedure?

******Limitation**: the present experiment takes the 5% of Sodium Silicate, 0.5M of NaOH and 0.5M of 5% Acetic acid (vinegar).The volume taken is 20 ml of sodium silicate, 40 ml of acetic acid and 10 ml of 0.5M of NaOH which is worked out to suit the experiment time by adjusting the volume by maintaining pH value. The stock solution can work out with the same concentration but the experiment should be worked out with volume to ensure the result formation before implementation. Therefore, the volume taken in this experiment cannot be taken as constant as pH value is affected by different environment and situation. So it is always advised to work out with the volume before the implementation and manipulate the volume to adjust the pH of both dispersion and condensation process to adjust to class time and also to avoid problem during the implementation.*

Activity 2: Comparison, presentation and discussion: Students in a group are provided with a worksheet (Appendix H) after the experiment. Students compare their observation made in each step and tabulate in the worksheet. The difference between each procedure is linked with dispersion on addition of acid and condensation on addition of base. Students in each group present their results to the whole class. Students point out the differences with possible reason and the whole class discuss about it. Some of the guiding questions asked during the process are given in the table 3.6

Table 3.6 Some guiding questions for the lesson

Guiding questions	Objective
✓ Why the turbidity decreases when acid is added to 10 ml solution of sodium silicate? ✓ Why the intensity of scattering decrease when acid is added to a solution of sodium silicate? ✓ What does the decrease in turbidity and intensity of	To understand the dispersion process where the addition of acid results in breaking down of sodium silicate to silica sol.

Table 3.6 Some guiding questions for the lesson (cont.)

✓ scattering indicates to the size of the particles.	
✓ Why there is an increase in the turbidity of solution on adding the base? ✓ The intensity of scattering increases on adding the base. What is happening to the size of the particles?	To understand the condensation process where the addition of base initiates gel formation by linking small particles of silica sol to large network structure.
✓ In the formation of silica gel what is happening to the size of the particles as indicated by your observation on turbidity and scattering of light.	Relate the process formation of silica sol and silica gel through observation and scattering of light by emphasizing on the size of the particles.

Activity 3 teacher demonstration: For further understanding and assess their understanding at the individual level about the relationship of the scattering of light with the size of the particle using different wavelengths of light, the red and green laser, the teacher exhibits a brief demonstration. Students voluntarily try to answer the questions that are asked during the demonstration. Worksheet is provided to each individual to record their observation and difference (Appendix I). The description of demonstration is given in the table 3.7.

Table 3.7 Some guiding questions used for demonstration

Demonstration	Guiding questions	Objective
1. The teacher takes a colloidal solution in a beaker and point the laser	1. What is the difference between the scattering of red laser and green laser?	1. To assess students understanding about the difference between

Table 3.7 Some guiding questions used for demonstration (cont.)

pointer both red and green towards the solution. Students record their observations and reason the difference.	2. Why do you think the green laser scatter light more than red laser? 3. What do you conclude from the observation the relationship between the size of the particles and the nature of light?	different light based on wavelength and color. 2. Relate wavelength of light with scattering of light considering the size of colloidal particles same.
2. Now the teacher takes a a distilled water in a beaker and point the laser pointer like in first demonstration. Students record their observations in the worksheet provided and reason the difference.	1. The red laser does not show the Tyndall effect, but the green laser shows the effect? Why? 2. Distilled water contains water molecules, which are less than 1nm. It is a pure solvent yet light is scattered faintly by a green laser. Why?	The Student should realize the reality of the situation that it is very difficult to get a pure of water, 0 % impurities. The mixture is inevitable.

Activity 4: the follow-up (debriefing): With the understanding of the experiment and demonstration regarding the relationship between the scattering of light, the size of the particles and different wavelength of light in the visible spectrum, the class discusses about some natural phenomenon like the blue sky, reddish yellow sunrise and sunset; and white cloud. The discussion is followed by each student's summarizing their understanding and findings from the demonstration (Appendix I c). The class concludes by teacher summarizing the lesson in the PowerPoint. The presentation includes formation of silica sol and silica gel in molecular level and relationship of scattering of light with the size of particles and the wavelength of light.

3.2 Implementation of learning unit

The implementation of learning unit contains two lesson plans about 3 hours each. The lesson was implemented during the normal schedule of school, with each period of class lasting for 55 minutes. The chemistry class of grade 11 science consists of 7 periods a week. Since the learning unit is based on the lab based inquiry approach, the activities were carried out in the laboratory setting. There are 43 participants, so implementation was carried out in two phases based on the group distribution due to lack of space in the chemistry lab. So the implementation was carried in the morning session and afternoon session. The 10 groups were randomly divided into two phases, so that each session contains 5 groups each. The details of implementation of learning unit are given in the table 3.8 for guided inquiry lesson and table 3.10 for structured inquiry lesson.

Table 3.8 Guided Inquiry Lesson *"Distinguish between solution, colloids and suspension"*

Stage	**Activity**	**Duration (minutes)**
Pre Lab	Debriefing and prior knowledge	15
During Lab	Designing procedures, data collection and interpretation	105
Post Lab	Presentation, discussion, and conclusion	60
Total		**180**

Table 3.9 Structured Inquiry Lesson "*Preparation of colloidal silica sol and silica gel"*

Stage	**Activity**	**Duration (minutes)**
1	Lab work	60

Table 3.9 Structured Inquiry Lesson "*Preparation of colloidal silica sol and silica gel"* (cont.)

2	Comparison of results and discussion	45
3	Teacher demonstration of scattering of light in colloids using green and red lasers	30
4	The follow up (debriefing)	45
Total		**180**

3.3 Research Design

One group pre-post experimental design was carried out using mix research methodology framed on sequential dominant status design emphasizing more on quantitative data than qualitative data. The whole design contains four stages.

Stage 1: Familiarization

In this stage, meeting with participants; introduction and explanation about the aims and objectives of the study are done. The filling of informed consent and volunteers for participation was carried out. The students are familiarized with the research work, about the implementation of learning unit and also about the data collection. The students were briefed about each stage of implementation. The familiarization intended in helping students feel comfortable of the research activity too.

Stage 2: Pre-stage of the study

The whole participants conduct the pre-test (colloidal achievement test) before the implementation of the learning unit. Next, group distribution was carried out. The class was divided randomly into 10 groups (Group A − Group J) to carry out the activities. 43 students are divided into 10 groups. 3 groups contain 5 students each while 7 groups contain 4 students each. The distribution was also based on students' comfort. The reason for dividing students into group is in view of constructivist approach as hands-on activities represented a strategy of teaching in which the students usually work in groups, interact with peers to manipulate various objects, ask questions that focus observations, collect data and attempt to explain natural phenomena (Satterthwait, 2010).

Stage 3: Implementation stage

The learning unit includes two hands-on activity lesson plans of 6 hour class. The first lesson involves distinguishing the difference of suspension, colloids, and solution using lab based guided inquiry. The second lesson is the preparation of colloidal solution of silica sol and silica gel using the Sol-Gel process. The lesson is based on lab based structured inquiry. In each lesson, the worksheets are provided and at the end of each activity students write reflections. Since the learning unit is based on the lab based inquiry approach, the entire activities were carried out in chemistry lab. Due to limited space in the lab, the implementation was carried out in two sessions, morning (9am-12pm) and afternoon (1pm-4pm) for two consecutive days to complete both lesson.

1. Guided inquiry lesson → Differences between true solution, suspension, and colloids (3hrs)

2. Structured Inquiry lesson → Preparation of colloids through sol-gel process (3hrs)

Stage 4:Post-stage of the study

It is the final stage of the study and students are involved mainly in assessment part. All the students perform a post-test (colloidal achievement test). The questionnaire was distributed after the post-test. Finally 6 students were randomly selected based on their grade report, two students each from high achieving, medium achieving and low achieving. The selection was strictly carried out discreetly. 2 additional students were selected as they voluntarily came forward for interview making number of 8 students. The framework of the design is given in the figure 3.11.

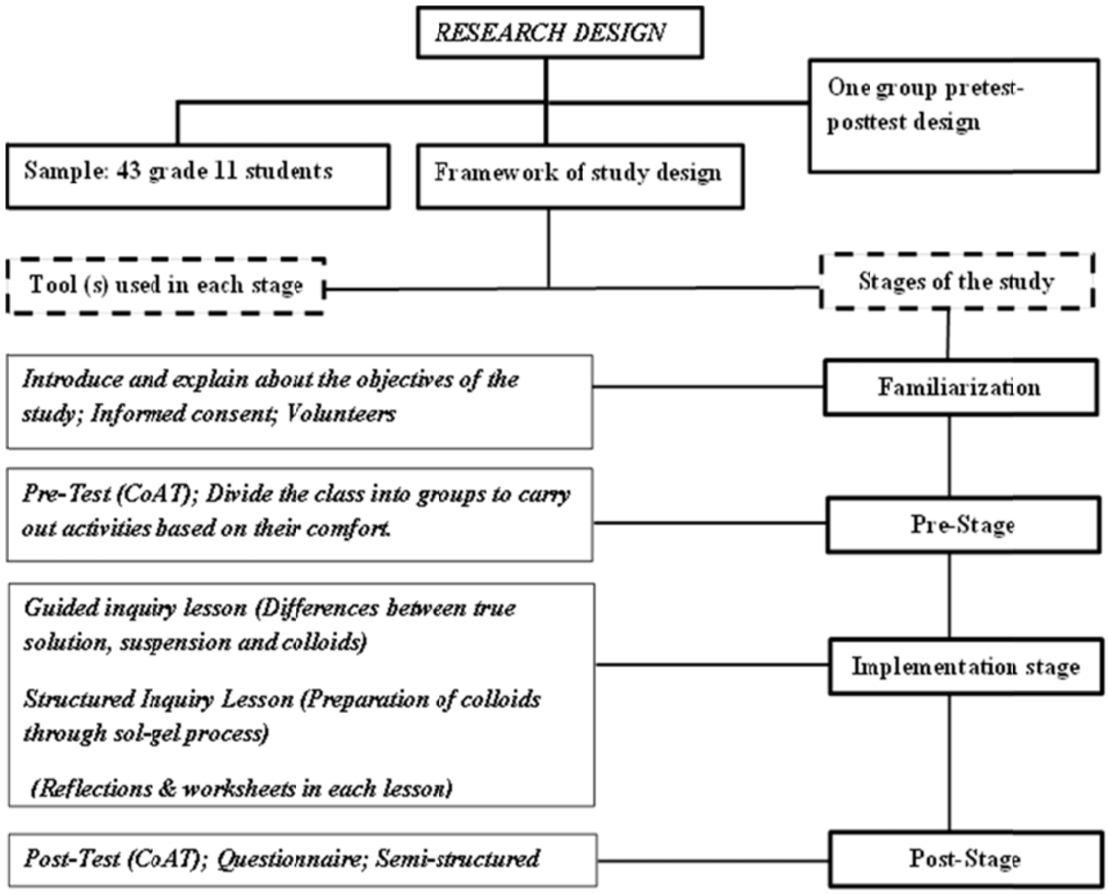


Figure 3.11 Outline of study design

3.4 Research Participants

Purposive sampling of 43 grade eleven students of the schools located in the southeastern part of Bhutan majoring in science participated in the study. All the schools in Bhutan are Co-educational institutionalized and are taught with the same curriculum and syllabus and English as the medium of instruction. So, every school in the country is guided by the same education framework and all the subjects have the required information. The study was carried out around 2 months before the end of academic session in 2014. The school had only one section of grade 11 science containing 43 students. All the students in the class took part in the studies.

3.5 Data collecting tools

There are five data collecting tools to answer the research questions. The tools are validated by five experts and are piloted prior to its implementation.

3.5.1 Colloidal achievement test

20 items of the two-tier multiple choice questions (MCQ) are administered as pre-test and post-test. The two-tier questions include conceptual part and reasoning part. Both parts have four choices. The student has to choose both the options correctly to obtain full marks. 5 experts validated the test and pilot testing was carried out for reliability.

Many tools are used to assess students' understanding. Every tool has its own strength and limitation so it is important to know test type procedures as different types of tests should be prepared considering the characteristics of the topic and the student to be implemented on (Temel, Özgür, & Yılmaz, 2012). The 20 items of the two-tier MCQ questions are developed considering the topic colloids that are studied in the class 11 chemistry syllabus under the science curriculum in Bhutan. The 20 items are divided into four construct to measure students’ understanding as given in the table 3.10.

Table 3.10 The construct to measure students’ understanding.

Construct	Objective	Question Number
Types of dispersion system	Distinguish between the properties of suspension, colloids and a solution (true solution)	Q1, Q2, Q3, Q4, Q5, Q6, Q7 & Q8
Types of colloidal system	Compare different types of colloids based on dispersed phase and dispersed medium	Q9, Q10 & Q11,
Preparation of colloids	Prepare colloids using dispersion and condensation method through preparation of silica sol-gel by	Q12, Q13, Q14 & Q15

Table 3.10 The construct to measure students' understanding (cont.)

	relating to scattering of light and size of particles.	
Effect of particle size	Relate the relationship with size of the particles, wavelength of light and scattering of light by particles in natural phenomenon.	Q16, Q17, Q18, Q19 & Q20

The two-tier multiple choice questions are considered as an effective way of assessing meaningful learning of students as well serves as diagnostic tools (Chandrasegaran, Treagust, & Mocerino, 2007). It is useful in detecting students' conception and underlying reasons for the conception (Akkus, Kadayifci, & Atasoy, 2011; Kılıç & Sağlam, 2009a). It has benefits over conventional one tier as it reduces measurement error and is easy to plan, rate and apply (Akkus et al., 2011; Kılıç & Sağlam, 2009b; Tüysüz, 2009).

3.5.2 Learning unit perception questionnaire

The 22 items of 5 point Likert-scale questionnaires with 3 open-ended questions was administered to find out students perception towards the learning unit. The question items are based on four constructs; interest in science class activities, perception towards the concept in science class activities, learning environment in the class, and role of instructor as given in the table 3.11. All items are scored from maximum (5) to a minimum (1) while the point for negative item is reversed. The questions were validated by 5 experts.

The 5 point Likert-scale questionnaire is used because of its likely to produce a highly reliable scale and easy to read and complete for participants (Bertram, 2007).

Table 3.11 Constructs of perception questionnaire

Construct	Description	Item
Perception towards Interest in science class activities	To check the students perception towards the activities in the class	1-10
Perception towards the concept in science class activities	To see students view of concept with the activities in the class	11-14
Perception towards Learning environment in the class	To see students' preference of cooperative work while doing activities.	15-18
Perception towards Instructor	To see the students' view of the instructors' role in the activities	19-22

3.5.3 Semi-structured interview

Semi-structured interview was carried out at the end of the implementation. The interview protocol was followed for selection of participants for the interview. 6 students were selected based on their academic grade in chemistry. The academic record was used to classify the students into high achievement, medium achievement and low achievement. The grouping was done very confidentially and secretly to avoid physical grouping thereby avoiding embarrassment and humiliation. Two students from each group were selected randomly. The concerned students were first asked for their consensus and the interviewees are told that they were selected randomly. The whole process was done discreetly. Two more students were interviewed as they volunteered making the number of interviewee to 8 students.

The interview questions contain 19 items to check their understanding as well as their perception towards the learning unit. The interview protocol was used as a guide. The participation was strictly based on selection protocol. The appropriateness of question item was checked by 3 experts.

3.5.4 Reflective journal

A journal is a rich resource for studying student thinking and valuable tool for students as a planning resource for exams. It provides opportunities for learners to understand their own learning process and take ownership of their learning (Dianovsky & Wink, 2012). The journals provide information about students' academic development, their personal and affective sides that provide students to reflect on their scientific understandings and express their views and feelings about the learning process (Avci & Karaca, 2012).

The reflective journal here uses the student reflection format of Lingua Folio training modules, North Carolina Department of Public Instruction and National Council of State Supervisors for Languages. It contains guiding phrases to help students to reflect and contains reflections on the topic and lessons. The appropriateness of phrases was checked by 3 experts.

3.5.5 Student documents

The worksheet used in the entire lesson was used to support the quantitative analysis and interpretation of the research. The worksheets and lab report from students are used to supplement mostly the quantitative data analysis.
(*Find the tools in the appendix.)

3.6 Data analysis

To answer the two research questions, data analysis was carried out both quantitatively and qualitatively. The summary of data analysis technique is given in the figure 3.11.

3.6.1 Quantitative data analysis

Quantitative data were analyzed using the SPSS package 16.0 software. The colloidal achievement test is piloted and tested for its reliability. The paired sample t-test is used to compare the pre-test and post-test to find out significance difference. The data are interpreted both through mean and standard deviation (SD). Furthermore, the data are also analyzed by frequency and percentage distribution for insight understanding of each item under each construct. The scale of interpretation of two-tier MCQ is based on assessment criteria given by Bayrak (2013) where each item or questions carry one mark. The question contains two parts; the 1st tier is conceptual and the 2nd tier is reasoning part. Each part contains 4 options with one correct answer. The assessment criteria are given in the table 3.12.

Table 3.12 The assessment criteria of two tiers MCQ

Assessment criteria	Points of the response
Not mark answer	0 point
Only choice of one tier is correct	0 point
Both the tiers are correct	1

The learning unit attitude questionnaire is analyzed using the four construct: interest in science class activities, concept in science class activities, learning environment in the class and role of instructor. The data were analyzed by frequency and percentage distribution. The scale of the interpretation is based on assessment criteria given by Pitafi & Farooq (2012), given in the table 3.13. Students' documents (students' worksheet and lab report) were analyzed by content analysis to support students' understanding.

Table 3.13 Interpretation of mean scale of questionnaire

Scale	Interpretation
Below 3.0	Negative
At 3	Neutral
3.1 to 3.5	Slightly positive
3.6 to 4.5	Moderately positive
4.6 to 5	Highly positive

3.6.2 Qualitative data

Qualitative data like semi-structured interview was audio taped and transcribed. The data were analyzed with predetermined categories using thematic coding. The predetermined categories are given in the table 3.14 the reflective journal was analyzed using descriptive analysis using frequency and percentage distribution. Open-ended questions of the questionnaire were grouped and coded.

Table 3.14 Predetermined categories of semi-structured interview

Conceptual understanding	**Perception**
Types of dispersion system	Perception towards changes in learning environments
Classification of colloids	Students' difficulties and challenges
Preparation of colloids from silica sol to silica gel by relating to scattering of light	Perception towards learning activities
Relationship with size of particles with scattering of light	Perception towards role of instructor
Relationship of size of particles, wavelength of light and scattering of light in natural phenomenon	Suggestion and overall feeling

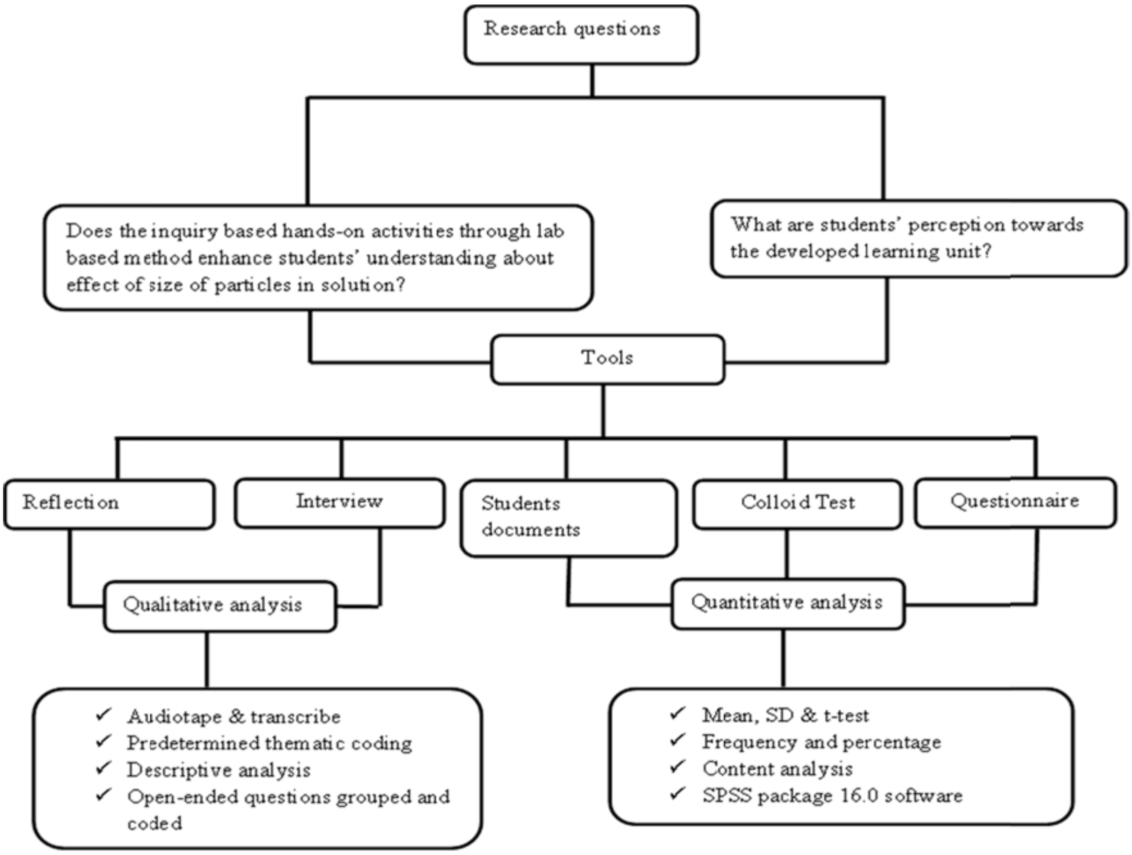


Figure 3.12 Overview of data analysis

3.7 Validity and Reliability

The learning unit and the tools are validated by 5 experts. The content validation test using the Index of Item-Objective Congruence (IOC) by Rovinenelli & Hambleton (1976) and Turner & Carlson (2003) was used. The IOC index was calculated by the formula:

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

Where

IOC_k	is the Index of the Item-Objective Congruence of item k
$\sum R$	is the total score of item k from the content experts, and
N	is the number of content experts

The experts consist of one associate professor, two lecturers holding PhD degree, one PhD teacher student and a master teacher. All the experts have a minimum experience in the teaching field for more than 5 years and have sound knowledge doing research about colloids. Each expert assessed by giving (+1 point) for agreeing, (0 point) for not sure and (-1 point) for disagreeing, by assessing the correlation of item with objective. The acceptable IOC for the agreement is at least 75% equivalent or more (IOC = ≥ 0.75). The average IOC for the conceptual test was 0.84 and for questionnaire is 0.93.

The colloidal achievement test was piloted in one of the schools in the western part of Bhutan. The students have already learned the concept of colloids in their previous year. It involves 40 students of grade 12 science class from one of the schools in the western part of Bhutan. Since they have already learned the topic, and do not involve any implementation of research, it does not possess any risk as their name, status and also the school is kept confidential. The item analysis was carried out. The scale of interpretation is based on (Pande, Pande, Parate, Nikam, & Agrekar, 2013) where:

a. Difficulty Index (P) $= h + \frac{1}{n} \times 100$

b. Discrimination Index (D) $= h - \frac{1}{n} \times 2$ where,

h = Number of students answering correctly in high achievers group

l = Number of students answering correctly in the low achievers group

n = Total number of students in two groups, including non-responders

The internal consistency was checked by Cornbach's alpha on the benchmark mentioned by (Tavakol & Dennick, 2011). The table 3.13 shows the scale of interpretation

Table 3.15 Scale of interpretation item analysis and reliability

Scale	**Range**	**Interpretation**
Item Difficulty (P)	>0.7 (70 %)	Easy
	0.3 (30%) – 0.7 (70%)	Acceptable
	< 0.3 (30%)	Difficult

Table 3.15 Scale of interpretation item analysis and reliability (cont.)

Item Discrimination (D)	> 0.4	Excellent
	0.3 – 0.39	Good
	0.2 – 0.29	Acceptable
	< 0 – 0.19	Poor
	= negative	Defective item
Reliability coefficient (Cronbach's alpha)	> 0.7	Acceptable range

The result of the pilot test of colloidal achievement test is given in the table 3.14. The overall item is quite difficult but some researchers consider the range of above 0.2 as acceptable (Boopathiraj & Chellamani, 2013; Sabri, 2013). The average item difficulty is good and with acceptable reliability of 0.74. Some of the items with low difficulty index and low discriminating index were checked and necessary reform were taken before the actual implementation

Table 3.16 Item analysis of the colloidal achievement test

Scale	**Range**	**Interpretation**
Item Difficulty (P)	Average = 0.27	Difficult item
Item Discrimination (D)	Average = 0.39	Good
Reliability coefficient (Cronbach's alpha)	0.74	Acceptable range

CHAPTER IV
RESULTS

Overview

The results of implementation of inquiry based, hands-on activity through lab based approach learning unit are reported in this chapter. The implementation used 5 tools; colloidal achievement test, questionnaire, students' reflection, semi-structured interview, and students documents to answer the two research questions that are 1) does the inquiry based hands-on activities through lab based method enhance students' understanding of the effect of size of particles in solution? And 2) what is students' perception towards the developed learning unit? The data were analyzed both quantitatively and qualitatively to answer the research questions. The results of each tool are described.

4.1 Colloidal Achievement Test

The quantitative analysis was carried out using mean, standard deviation, t-test, frequency and percentage distribution. The normality test was carried out in a colloidal achievement test before *t*-test was conducted. The SPSS software, version 16.0 was used for statistical analysis. The colloidal achievement test was conducted to 43 of grade 11 students both as pre-test and post-test. It contains 20 items of two-tier multiple choice questions to answer the first research question. The first tier is conceptual part and contains four options while the second tier is the reasoning part and also contains four options. Each item or questions carry one mark. The students receive score 1 (one) if they selected the correct answer in both the tiers and 0 (zero) if they selected incorrect answer in either one or both of the tier (Bayrak, 2013). The total score of whole item is 20. The normality test was conducted using Shapiro-Wilk test of normality as shown in table 4.1.

Table 4.1 Shapiro-Wilk test of normality for pre-test and post-test

	Shapiro-Wilk		
	Statistic	**df**	**Sig.**
difference	0.962	43	0.17

The p-value 0.17 from the table indicates that the data are normally distributed. Therefore, the normally distributed data were dealt with using paired sample *t* test.

4.1.1 Paired sample *t* test result of pre-test and post-test

Statistical analysis of pair sample *t* test was carried out upon the normal distribution of the data. The result of paired sample *t* test is given in table 4.2

Table 4.2 Pair sample *t* test results of students' performance of pre-test and post-test scores

Paired Samples Statistics							
Test	**N**	**Max. Score**	**Mean**	**Std. Deviation**	***t***	**df**	**Sig. (2-tailed)**
Pre-test	43	20	3.74	1.56	16.06	42	.000*
Post- test	43	20	10.23	3.15			

**Significant level at 0.05*

The mean score of pre-test was 3.74 (SD = 1.56) and the post-test mean was 10.23 (SD = 3.15) from the total score of 20. There was a mean difference of 6.49 (SD = 2.65). The result signifies that students' performance increased in post-test compared to pre-test (*t* = 16.06, p = 0.000) after the intervention. However, the mean difference was not that high. So for further analysis of each item and construct was analyzed through frequency and percentage distribution to look at item and construct level.

4.1.2 Percentage of students' result of pre-test and post-test

The percentage of students' result of pre-test and post-test was analyzed for the first tier (conceptual part) and both tier (conceptual and reasoning part) of the pre-test and post-test. The percentage of students of the pre-test score is given in the table 4.3.

Table 4.3 The percentage of students who scored correctly in the first tier and both tiers of the items in pre-test (N = 43)

Item number	**% of students who correctly answered**		Item number	**% of students who correctly answered**	
	First tier	Both tiers		First tier	Both tiers
1	74	70	**11**	30	9
2	72	53	**12**	21	9
3	30	12	**13**	7	2
4	33	9	**14**	35	2
5	81	37	**15**	44	26
6	7	5	**16**	35	16
7	49	28	**17**	79	9
8	12	12	**18**	33	14
9	21	9	**19**	37	26
10	72	16	**20**	63	9

The pre-test data from the table shows that students scored higher in first tier compared to both the tier. For example, the percentage of correct answers in the first tier of question 10 is 72%, whereas the percentage of correct answers for both tiers of question 10 is 16%. Likewise, all the items have more percentage of correct answers in the first tier than the both the tiers except for item 8 in which the score is equal. Total mean percentage scores of students in the first tier are 42 while that of both the tier is 19.

Table 4.4 The percentage of students who scored correctly in the first tier and both tiers of the items in post-test ($N = 43$)

Item number	% of students who correctly answered		Item number	% of students who correctly answered	
	First tier	Both tiers		First tier	Both tiers
1	98	77	**11**	49	33
2	98	79	**12**	9	9
3	56	37	**13**	65	49
4	72	58	**14**	26	16
5	88	67	**15**	93	77
6	51	42	**16**	95	88
7	77	63	**17**	100	28
8	53	47	**18**	67	58
9	65	28	**19**	77	70
10	77	53	**20**	86	44

The post-test data from the table 4.4 also shows the same trend where students scored higher in first tier compared to both the tiers. All the items have more score in the first tier than the both the tiers except for item number 12. Total mean percentage scores of students in the first tier are 70 while that of both the tier is 51.

The data from both pre-test and post-test indicates that students are able to score higher in first tier that is in conceptual part. But, students have scored less when it comes to both the tiers where students, besides their conceptual understanding, they have to give the underlying reason also. It is interesting to point out that in item number 17 students have scored 100% in the 1st tier, but only 28% in both tiers. This result shows that students' conceptual understanding lacks of scientific reasoning. In short, students may have learned most of the concept without understanding or knowing the underlying reason.

4.1.3 Comparison of percentage of students' result of pre-test and post-test

The first tier (conceptual) percentage of students and both tiers (conceptual and reasoning) percentage of students are compared to see the effect of implementation of learning unit. The table 4.5 shows the comparison of the first tier (conceptual) of the pre-test and post-test.

Table 4.5 Comparison of the percentage of students who scored correctly in the first tier in the pre-test and post-test (N = 43)

Item number	% of students who correctly answered first tier		Item number	% of students who correctly answered first tier	
	Pre-test	Post-test		Pre-test	Post-test
1	74	98	**11**	30	49
2	72	98	**12**	21	9
3	30	56	**13**	7	65
4	33	72	**14**	35	26
5	81	88	**15**	44	93
6	7	51	**16**	35	95
7	49	77	**17**	79	100
8	12	53	**18**	33	67
9	21	65	**19**	37	77
10	72	77	**20**	63	86

Mean percentage of students of pre-test = 42; post-test = 70

The data from the table shows that students have higher post-test score than the pre-test except for the item number 12 and 14. The mean percentage of students of pre-test has increased from 42 to 70. This indicates that the implementation of learning unit has increased their conceptual understanding of the concept under study. The pre-test score ranges from 7% − 81%, while the post-test score ranges 9% − 100%. The post-test score of item 12 is 9%, while that of item 14 is 26%. All other items have scored more than 50 %. The result indicates that though most of the items have increased score, there are two items where the post-test score has decreased compared to pre-test. The anomaly is further investigated in the later part of the chapter. Overall, the result of the pre-test and post-test shows that the learning unit has enhanced students' conceptual understanding as indicated by the mean percentage of students' score.

Table 4.6 Comparison of the percentage of students who scored correctly in the both tiers in pre-test and post-test ($N = 43$)

Item number	**% of students who correctly answered both tiers**		Item number	**% of students who correctly answered both tiers**	
	Pre-test	Post-test		Pre-test	Post-test
1	70	77	**11**	9	33
2	53	79	**12**	9	9
3	12	37	**13**	2	49
4	9	58	**14**	2	16
5	37	67	**15**	26	77
6	5	42	**16**	16	88
7	28	63	**17**	9	28
8	12	47	**18**	14	58
9	9	28	**19**	26	70
10	16	53	**20**	9	44

Mean percentage of students of pre-test = 19; post-test = 51

The data from the table 4.6 shows the mean score of the colloidal achievement test as the mark was allotted only if both the tiers were correct. The mean percentage of students score has increased from 19 % in pre-test to 51 % in post-test indicating that the learning unit has helped enhance students' understanding about the concept with proper reasoning. Some items data show a very high gain in score like item number 2, 15, 16 & 19 while some showed a medium increase in scores like item number 4, 7, 10, 13 & 18. However, the items like 3, 9, 11, 12, 14 & 17, though their post-test score increased from pre-test except item 12, the increase in score falls below 40%, which is the required pass percentage as standardized by the Bhutan Council for School Examination and Assessment (BCSEA), 2015.

The result is further explored through the construct because 20 item colloidal achievement questions measure under four construct. All construct are investigated individually and compared to response the differences in score and anomaly of some items shown by the data.

4.1.4 Comparison of mean percentage of students' result of pre-test and post-test of each construct.

The 20 items are divided into four constructs to measure students' understanding about the concept under study. The objective of the first constructs, types of dispersion system is to measure whether students are able to distinguish between solution, colloids, and suspension based on physical properties. It contains 8 items (item number 1-8). The objective of second constructs, types of colloidal system is to compare different types of colloids based on dispersed phase and dispersed medium. The items are item number 9, 10 & 11. Third constructs, preparation of colloids is to prepare colloids using dispersion and condensation method through preparation of the silica sol and silica gel though the sol-gel process by relating to scattering of light and size of particles. The item numbers are 12, 13, 14 & 15. And, the fourth construct study the effect of size of particles, to relate the relationship with the size of the particles, wavelength of light and scattering of light by particles in natural phenomenon. The item numbers are 16, 17, 18, 19 & 20. The mean percentage of students of each construct is given in the table 4.7.

Table 4.7 The mean percentage of students of each construct of students who scored correctly in the first tier and both tiers of the items in the pre-test and post-test (*N* = 43)

	Mean percentage of students of pre-test		**Mean percentage sudents of post-test**	
Construct	First tier	Both tiers	First tier	Both tiers
Types of dispersion system *(item no. 1-8)*	45	28	74	59
Types of colloidal system *(item no. 9-11)*	41	12	64	38
Preparation of colloids *(item no. 12-15)*	27	10	48	38
Effect of size of particles *(item no. 16-20)*	49	15	85	58

The differences in mean percentage students for 1st tier and both tiers for both pre-test and post-test are compared using graphs in figure 4.1.

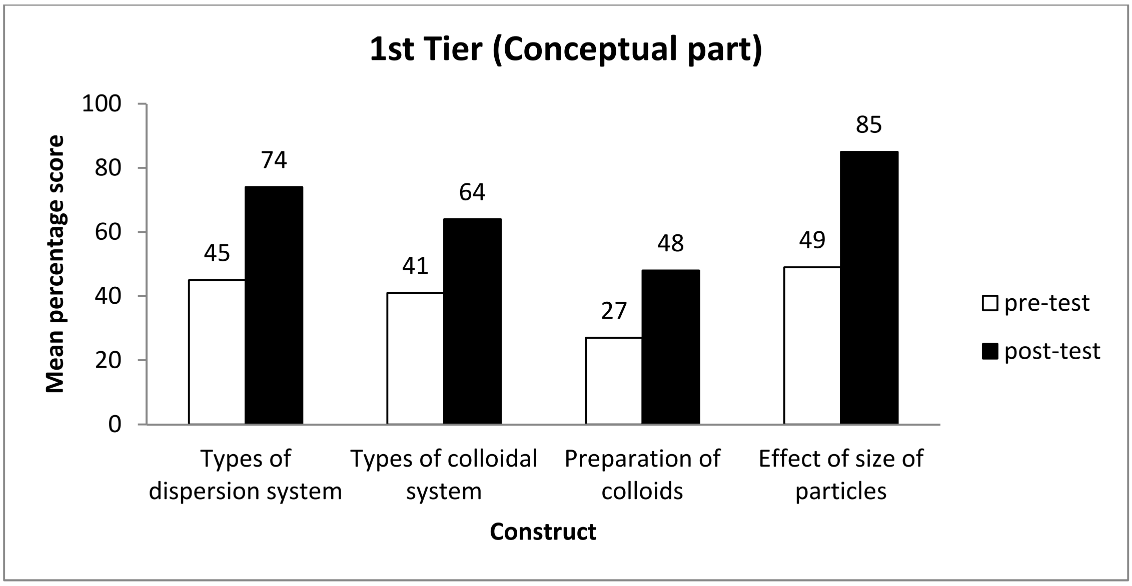


Figure 4.1 The mean percentage of students of 1st tier (conceptual part) of pre-test and post-test

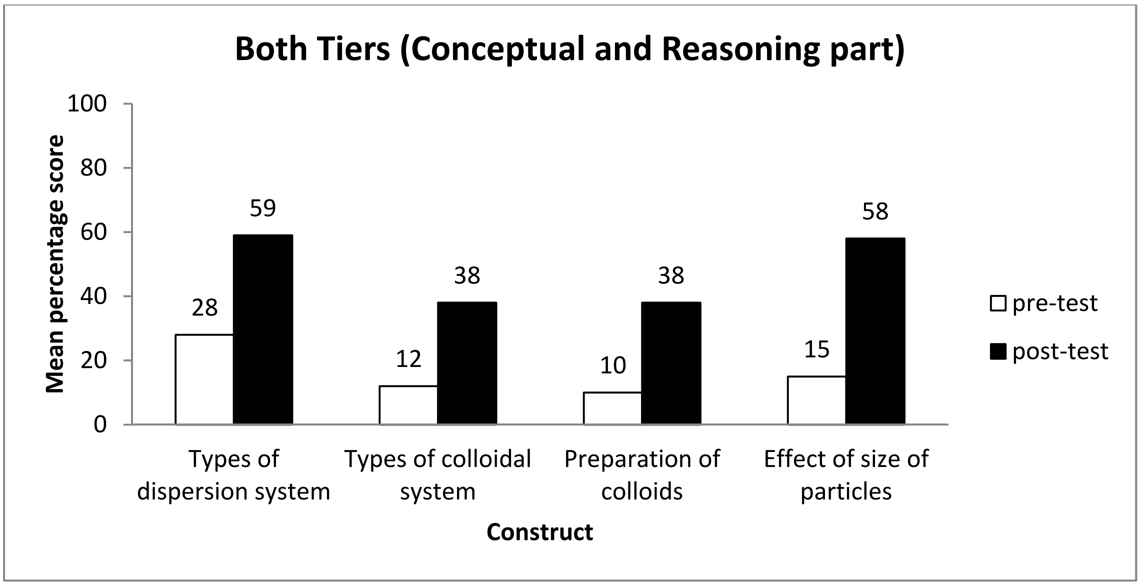


Figure 4.2 The mean percentage of students of both tiers (conceptual part & reasoning part) of pre-test and post-test.

The data from the figure 4.1 and figure 4.2 both shows that there was gain in post-test score of the entire construct than the pre-test score, in 1st tier (conceptual) and both tier (conceptual and reasoning). The earlier result already indicated that the percentage of students who scored correctly in both tiers question was less than the 1st tier. The mean percentage of students who correctly scored in both tiers of four constructs was also found less than the 1st tier. This designates that students lack to diagnose the underlying reason for the concept.

Students have performed better in two constructs, effect of size of particles and types of dispersion system as indicated by high score in both 1st tier (figure 4.1) and both tiers (figure 4.2). The result indicates that the learning unit was more effective on two constructs. This shows that students were able to distinguish between solution, colloids, and suspension; and able to relate the relationship of the size of particles and the different wavelength of light and scattering of light by particles in natural phenomenon after the implementation of learning unit.

From the figure 4.1 the students show high conceptual understanding (1st tier) for the construct, classification of colloids (post-test score of 64) but the data from figure 4.2 show post-test score of only 38 %. The result points out that students were able to perform well in conceptual but not well in underlying the reason. In case of the construct, preparation of colloids, the students have lowest performance compared to other construct both in 1st tier (post-test = 48) and both tiers (post-test = 38). The result indicates that students were not able to understand properly or have difficulty in the preparation of colloids, which involve preparing silica sol and silica gel using a sol-gel process through the method of dispersion and condensation.

The data from the figure indicates that post-test score (1st tier & both tiers) was more than pre-test score. It shows that learning unit has enhanced their understanding. Nevertheless, the result indicates that the learning unit was more effective in some construct while in the other the score is very less, despite its gain in post-test. The analysis of first tier described in the table 4.5 shows that item number 12 shows post-test score less than pre-test (pre-test = 21, post-test = 9) and item 14 (pre-test = 35, post-test = 26) falls under the construct of preparation of colloids. Furthermore, the analysis of both tiers described in the table 4.6, comparing both tiers of pre-test and post-test, item number 12 did not have any change in score (pre-test = 9; post-test = 9). And item number 14, has a pretest score of 2 and post-test score of 16. Both items are further analyzed and discussed further as they probably have contributed to low mean percentage of students score. Item number 3 under the construct types of dispersion system, item number 9 & 11 under the construct, types of colloidal system; and item number 17 of construct, effect of size of particles have all score less than 40 %. The score of this item has also probably contributed to low mean percentage of students score. These items are further discussed in later chapters.

4.2 Students' perception of the learning unit

The questionnaire was administered to 43 students after the implementation of learning unit. It contains 22 item questionnaire and 3 open-ended questions, total 25. The 22 items measure four construct, perception towards interests in science class activities, perception towards the concept in science class activities, perception towards a learning environment in the class and perception towards the instructor. The objectives of the construct are already described in chapter 3 (see table 3.12). The open-ended questions include a) what did you learn overall from the activities in the learning unit? b) What do you think you want to learn more about the activities in the learning unit? And c) comments/suggestions.

4.2.1 Questionnaires

The construct wise, frequency distribution of each item with mean and SD are given in table 4.8; table 4.9; table 4.10 and table 4.11. The 5-point Likert scale *(5 = strongly agree; 4 = agree; 3 = neither agree nor disagree; 2 = disagree and 1 = strongly disagree)* is used.

Table 4.8 Students' response to perception towards interests in science class activities

Sl. no	**Items**	**1**	**2**	**3**	**4**	**5**	**Mean**	**SD**	**Reverse code**
1	The activities were interesting.	0	0	0	4	39	4.91	0.29	
2	Doing activity made me uncomfortable	23	16	1	2	1	1.65	0.92	4.35
3	I learn better when I work through the activities.	0	0	1	3	39	4.88	0.39	
4	The activities motivated me to learn	0	0	1	5	37	4.84	0.43	
5	The activities made me curious	0	0	2	14	27	4.58	0.59	
6	I think that teaching something related to the activities to my group mates is a waste of time	29	11	2	1	0	1.40	0.69	4.60
7	Learning from the book is much better than doing activities	21	18	2	0	2	1.77	0.92	4.23

Table 4.8 Students' response to perception towards interests in science class activities (cont.)

8	The activities took too long	2	6	3	22	10	3.74	1.11	2.26
9	I look forward to learn from such kind of activities in the future	0	0	0	6	37	4.86	0.35	
10	I prefer learning from other approaches than such learning activities.	3	19	8	11	2	2.77	1.07	3.23
Average mean score							**4.27**	**0.68**	

***** *The negative statements were reversed coded.*

Table 4.8 shows students' perception toward interests in science class activities. All the students found the activities interesting. 3 students found the activity uncomfortable while remaining students were comfortable. 42 students (1 remaining neutral) responded they learned better through activities and it has motivated them to learn. Most of the students disagree that activities were a waste to their friends and responded that learning from such activities is better than learning from the book. However, one student agrees that it was a waste of time for friends and 2 students still find learning from book is better than the doing activities. The Majority of students finds that activity was time consuming. While all students strongly agree that they look forward to learn from such activities in future, there were mixed responses of students' preference to learn from other approaches than such learning activities. Overall, the mean score of 4.27 indicates that students have the moderately positive perception with regards of learning from such science class activities.

Table 4.9 Students' response to perception towards the concept in science class activities

Sl. no	**Items**	**1**	**2**	**3**	**4**	**5**	**Mean**	**SD**	**Reverse code**
11	I learned to differentiate different types of mixtures through learning activities	0	0	1	8	34	4.77	0.48	
12	Activities made it easier to understand the effect of particle size in different solutions.	0	0	0	7	36	4.84	0.37	
13	Activities made it easier to understand the effect of particles size and wavelength of light	0	0	0	9	34	4.79	0.41	
14	Activities made me realize the importance of the role played by particle size.	0	0	0	11	32	4.72	0.45	
Average mean score							**4.78**	**0.43**	

***** *The negative statements were reversed coded.*

The value reflected in table 4.9 indicates that the activities helped them to learn about the concept. Almost all of the students strongly agree that activities made it easier to understand the effect of the particle size, distinguish mixtures and made them realize the importance of the role played by particle size. The mean value 4.78 implies that the activities facilitated students in understanding the concept. It shows highly positive perception towards learning unit, which enable them to understand the concept.

Table 4.10 Students' response to perception towards the learning environment in the class

Sl. no	Items	1	2	3	4	5	Mean	SD	Reverse code
15	I feel better myself when I contribute more to the activities in my group.	24	16	2	1	0	4.58	0.59	
16	Doing Activities in group encouraged me to think well	23	18	1	1	0	4.47	0.70	
17	The questions asked by the teacher helped me to clear my doubt	38	5	0	0	0	4.88	0.32	
18	I don't like to work in groups	0	3	3	17	20	1.79	0.94	4.26
Average mean score							**4.55**	**0.64**	

***** *The negative statements were reversed coded.*

The table 4.10 shows students perception towards working in groups as the implementation of the whole lesson involves group work. The value from the table indicate that students like working in groups as it encouraged them to think better, contribute and clarify their doubts. The mean value 4.55 reflects that students prefer working in the group, yet there are few, 3 students who don't like working in groups, 3 being neutral. This reflects that despite students favor to work in groups, there are still some students who prefer learning individually. It shows highly positive perception towards the learning environment that is to work in groups.

Table 4.11 Students' response to perception towards the role of instructor

Sl. no	**Items**	**1**	**2**	**3**	**4**	**5**	**Mean**	**SD**	**Reverse code**
19	The teacher was enthusiastic in teaching the topic	37	6	0	0	0	4.86	0.35	
20	The Teacher was friendly	35	8	0	0	0	4.81	0.39	
21	The Teacher was well prepared and organized	32	11	0	0	0	4.74	0.44	
22	I feel free to tell the teacher about anything that stop me from learning	16	19	7	1	0	4.16	0.78	
Average mean score							**4.64**	**0.49**	

* *The negative statements were reversed coded.*

In the table 4.11, students' response indicates a satisfactory role played by the instructor. However, 7 students are neutral about the last item and one student doesn't, feel free to tell the teacher about anything that stop them from learning. It shows some reluctance about approaching to teacher when they have a problem. The mean score of 4.64 indicates highly positive perception towards the role of instructor.

4.2.2 Open-ended questions

The three open-ended questions, have lots of different responses from the students. The responses were looked for a pattern.

a) ***What did you learn overall from the activities in the learning unit?***

The response of the students was grouped into categories and the frequency of students' response was considered. The 2 categories, content and perception were deemed most appropriate by regarding the students' response. The content categories include the pattern of students' response that includes mainly the concept while perception includes response other than conceptual answer.

Table 4.12 Frequency of students' response based on content

	Content	**Frequency**
1	Suspension, Colloids and Solution (distinguish)	17
2	Classify colloids	8
3.	Preparation of colloids	7
4.	Effect of size of particles (scattering of light)	31

Looking into the frequency response mentioned by the students in table 4.12, it seems the effect of size of particles, scattering of light, where they also relate the relationship of size of particle with different wavelength of light seems to have more impact on their learning. The differences between suspension, colloids, and solution were 2nd frequent response. The classification of colloids and the preparation of colloids were least responded. Some of the responses of students include:

i) "I learned the particles are fundamental factors in solution which affect the scattering of different light".

ii) "I learned to distinguish among the colloids, solution and suspension. I also learned their characteristics. Not only that I also learned the relation between the scattering of light and size of particles and wavelength".

iii) "I learn that the types of solution and their differences. And I came to understand that main mechanism that makes a difference is the size of the particles. And scattering of light depends upon wavelength of different light. And I learn about the ways of preparing solution and usage of different solution".

iv) "Overall I learned that colloids, suspension and solution are distinguished based on the size of the particles. And shorter the wavelength of light, more frequency will be there and it scatter more due to more energy".

The response of the students indicates that students learned better in relating the effect of size of particles with a scattering of light and also able to make relationship in distinguishing dispersion system based on particle size.

According to students' response, other than content, students mentioned that they learn to work and cooperate in groups. They also mentioned that learning through activities (practical) is much better than learning from the book and in concluding the answer. This response indicates that students' preference for activity based learning and impression of working and cooperating in group is a whole new experience. Some of the responses are worth mentioning are

i) "I learned how to work and cooperate with my group members".

ii) "I learned how to work and keep the group spirit to work in future too".

iii) "I learned to work in group (i.e., to cope with group members)".

iv) "I learned how to work in group and to give cooperation to the group members".

v) "I learned doing of activities (practical) is much better way of understanding and is best way to help in our day to day life activities".

Vi) "From the activities I learned that to know better and to make us comfortable with a lesson, doing such activities (practical) is much better than what ever written in the book".

b) ***What do you think you want to learn more about the activities in the learning unit?***

From the various responses given by the students, two patterns came up where student mentioned more about it. Firstly, students mentioned they wanted to learn more about the scattering of light. They want to learn scattering by a different source of light; and scattering in different solution and colloids. They wrote

i) "I want to learn more about the form of colloidal solution and see scattering of light through each solution".

ii) "Learn more on scattering of many lights".

iii) "I think we need to learn more on Tyndall effect (scattering of light) and even movement of particles".

Students seem more interested in learning about scattering of light using different sources of light and in different solution. The students seem to be amused and interested in using light scattering techniques used in relating the size of the particles with a scattering of light.

Another pattern observed in students' response is that they mentioned about using a microscope to see the differences in size of the particles. They wrote

i) "I thought I could learn about particle size of colloids by viewing the particles under the microscope".

ii) "I could have used microscope to see particle size differences".

iii) "We could learn more on size of particles in the solution under microscope and could learn more on scattering of light for better understanding".

iv) "If I could have seen the particle size under microscope and compare the sizes to assure that there are differences in size".

It is interesting to note that maybe the student lacks the mental picture of nanoscale and capability of lab-equipment (simple microscope) in school. They perhaps think that it is possible to see the particle size using the microscope available in the school and can be used to compare at particulate level. Another plausible reason could be students are skeptical about the result of the experiment as stated in the last statement above. They want to confirm it by seeing it under the microscope. Some of them asked like

i) "I want to know how the particles of sodium silicate break into smaller units".

ii) "I want to know if adding more base that is more than 10ml of NaOH in the solution, whether we would obtain the same result or not".

iii) "I thought of learning about particles and what exactly is going on in the mixture solution".

However, from the statement above, students asking questions reveal that students wanted to learn more and go deeper in understanding at the microscopic level. It also shows curiosity build with students.

c) *Comments and Suggestion*

Most of the students commented positively, saying that

i) "Helpful, clearly understand, activity was awesome and everything went well".

ii) "Learnt more from practical session than theory. I like the asking of questions with every experiment masking us think critically".

iii) "I expect in future of such chance to learn such activities".

iv) "Always better to learn practically".

v) "I really like such research as we able to put abstract into concrete, visible to eye (practical) than being done theoretically. (appreciate)".

From the comments, it is clear that student like learning from the activity. They regard learning by doing. They like asking of questions and looks for opportunities to learn from such an environment. However, there were a few suggestions that students mentioned. One of them wrote *"shorten the experiment duration of time"* while few of them mentioned above for conducting the activities individually and not in a group. They wrote

i) "It could be better if we could do experiment individually not in group'.

ii) "Since exam are undergone through self-exploration and abilities it will be effective if the experiments are done on individual basis"

iii) "It could be better if we get a chance to conduct the experiment individually".

iv) "Instead of doing in group, individual is much better to learn".

From the suggestion, despite the students' positive impression of working in groups, there are few who suggested working individually. Some of them reason out from examination point of view, saying that performance in the exam is done on an individual basis, so it is better to learn individually while another mentioned that the individual is better to learn.

4.3 Students Reflection

Students' reflection as described in chapter 3 uses the format of Lingua Folio training modules, North Carolina Department of Public Instruction and National Council of State Supervisors for Languages, University of Texas, USA. It contains guiding phrases to help student reflect and divided into two sections, Topic and Lesson. Students write the reflection at the end of each lesson. So the data are reflected separately for each lesson.

4.3.1 ***Guided inquiry lesson: Distinguish between solution, colloids and suspension***

The responses from the students were looked for patterns and grouped into a common category. The frequency of response was then calculated under each category.

Table 4.13 Frequency of students' response about topic

Guiding phrases	Category	Frequency
I have learned…	Suspension, Colloids and Solution (distinguish)	40
	Setting up of apparatus and procedures	8
	Effect of size of particles (scattering of light)	9
I can…	Differentiate between mixtures	25
	Perform the experiment with confidence	11
	Replicate the experiment	7
	Explain the properties	7
I am good at…	Cooperating in the group	6
	Setting up the experiment	15
	Observing and recording data	3
	Differentiating the mixture	14
I haven't managed to….	Complete on time	11
	Get clear result	5
	Use cellophane paper to filter	8
	Use and handling of apparatus	4
	Observing clearly	7
I don't understand…	Scattering of light mechanism	15
	Filtration by cellophane paper	8
	Handling equipment	6
I have difficulty in…	Observing the result	15
	Use of cellophane paper	9
	Designing and setting procedure	6
	Handling apparatus	9

From the table 4.13, students mentioned besides learning how to distinguish between the dispersion system and the effect of particle size, they also learned how to set up experiment and procedures. It is interesting to find that students can replicate and perform the experiment with confidence and they are good at differentiating mixtures and setting up experiments. However, they had difficulty completing the experiment on time and in handling laboratory apparatus. The concept of scattering and use of cellophane paper was another challenge that students faced in this lesson.

Table 4.14 Frequency of students' response about lesson

Guiding phrases	Category	Frequency
I like best…	Observing scattering of light using laser	18
	Filtration	4
	Doing an experiment (activities)	9
	Preparing a solution	11
The most interesting thing is…	Observing scattering of light using laser	16
	Filtration	6
	Doing experiment	7
	Others (group work/setting up experiment/discussion/presentation/designing)	9
I don't like…	Waiting for results	11
	Slow mechanism (time consuming)	12
	Use of fragile apparatus (glass) and chemicals	6
The most boring thing is…	Slow mechanism (time consuming)	6
	Waiting for results	7
	Redo the activity when experiments fails	7
Any suggestion…	More time	7
	Individual chance	5
	Help in doing experiments	4

From table 4.14, students like doing activities which involve all the process like preparing, filtering, observing, discussion, presentation and they find observing scattering of light using laser the most interesting. Nevertheless, students don't like using glass apparatus, chemicals and redo the experiment when they fail to get the result. Students don't like waiting for the result, usually when the process is slow and time consuming. Therefore, they suggested, for more time to do experiments and also seek help in doing the experiment. Some of them suggested working individually rather than in a group.

4.3.2 *Structured inquiry lesson: preparation of colloids through sol-gel process*

The responses from the students were looked for patterns and grouped into a common category. The frequency of response was then calculated under each category.

Table 4.15 Frequency of students' response about topic

Guiding phrases	Category	Frequency
I have learned…	Scattering of light	6
	Preparation of colloids (sol and gel)	10
	Classification of colloids	17
	Relationship of particle size, wavelength and scattering of light.	5
I can…	Differentiate/identify/classify colloids	21
	Explain and reason the properties of scattering	7
	Replicate and perform the experiment	11
I am good at…	Preparing a solution	14
	Observing scattering of light	14
	Measuring and handling of equipment	6
	Helping friends	3

Table 4.15 Frequency of students' response about topic (cont.)

I haven't managed to….	Use and handling of apparatus/observing	5
	Conduct experiment on time	11
I don't understand…	Difference in scattering of different light	9
	Gel formation	9
I have difficulty in…	Observing the difference (scattering/appearance)	9
	Differentiating intensity of different light	5
	Handling apparatus (fragile materials)	5
	Differentiating dispersed phase and dispersed medium	5

From table 4.15, most of the students have mentioned about learning classification of colloids and the preparation of colloids beside scattering of light and the effect of particle size. They mentioned that they could differentiate, classify or identify colloids, explain the properties of scattering and replicate and perform the experiment. They also mentioned they are good at preparing solution and observing the scattering of light. Conducting experiment on time and handling of apparatus is still a problem. Students found difficulty in observing the difference in scattering of different light and the appearance of the solution. Differentiating colloids on the basis of dispersed phase and dispersed medium and how gel is formed is the difficulty students faced with the concept.

Table 4.16 Frequency of students' response about lesson

Guiding phrases	Category	Frequency
I like best…	Formation of gel	17
	Doing an experiment (using chemicals)	10
	Scattering of light	7

Table 4.16 Frequency of students' response about lesson (cont.)

The most interesting thing is…	Formation of gel	12
	Using laser beams through solution and observing(scattering)	12
	Questioning	3
I don't like…	Waiting for results (time consuming)	13
	Redo experiment when fails to get results	5
	Handling fragile(glass) apparatus/chemicals	3
The most boring thing is…	Waiting for results (patience)	24
Any suggestion…	Familiar with lab apparatus	3
	Individual work	3

From the table 4.16, students like the activity formation of gel and doing experiment by using chemical besides scattering of light. And they found gel formed as the result at the end of the experiment the most interesting thing. They also found interesting using laser beam to observe scattering of light in solution. However, time consuming, again, students don't like waiting for the result when it takes long time to get the result. They also do not like to handle apparatus made of glass and using chemicals. And also redo the experiment when they fail to get the result. Some of the suggestions include individual work rather than group work and familiarization with lab apparatus or equipment.

Summary from reflection

From students' reflection on the topic as well as on lesson from two lesson plans, it is evident that students really like doing activities. They find interesting to work with new materials like laser to observe scattering of light; cellophane paper in filtering; preparing solution and process involved in various stages of the experiment. They were very happy to prepare and get gel at the end of 2^{nd} lesson. Though they like doing experiments with new materials, they also found difficulty in using it like cellophane paper and observing the scattering of light by different laser.

Some of the problems that students faced usually were handling the laboratory apparatus. The lab apparatus has been simple equipment usually found in the lab like a test tube, beaker, conical flask etc., it is clear from the response that students are hesitant in using fragile (glass) apparatus and chemicals. They also do not like to redo the experiment when they fail to get the result. It shows they are not use to failure and experimental error. They expect a perfect result at the first instance only. They had a problem in observing the difference and they really do not like waiting for the result (lack of patience). Time was another factor. Most of them mentioned that they were not able to complete the experiment on time. The logic points out that students lack experience working in the lab. The measurement error, uneasiness in using lab materials, time factor could be attributed to their inexperience. Probably that is why they suggested familiarization with lab apparatus; more lab time and ask for help in doing the experiment. Few of them suggested individual work rather than group work.

4.4 Semi-structured Interview

Semi-structured interview questions consist of two parts. The first part contains 9 questions to assess students' understanding about the concept and the 2nd part, contain 10 questions to see their perception towards the learning unit. Data from 8 students are interpreted in two separate parts.

4.4.1 Conceptual part

Students' understandings are assessed in the following field:

Types of dispersion system.

All the students seem to have a very good understanding about dispersion system; solution, colloids and suspension. They were able to distinguish the properties among them in detail by emphasizing on the size of the particle.

i) "In suspension, particles sizes are bigger than 1,000 nm. Particles settle down and are heterogeneous. Colloidal solution, particle size ranges from 1-1,000 nm and it is homogenous. In solution, we cannot see particle, it is homogenous and size is less than 1 nm. Solution does not scatter light while colloidal solution and suspension scatter light. Particle of suspension settle down because particle are bigger in size so they settle down. Solution cannot be separated by semi-permeable membrane because particle sizes are smaller than pores of semi-permeable membrane".

ii) "First solution, the particle size is below 1 nm, it's smaller. Colloids the size is between 1-1,000 nm and suspension is above 1,000 nm. Regarding scattering, solution does not scatter light while suspension and colloids scatter light. Suspension is like heterogeneous solution where we can see particles settle down whereas in colloids we cannot see, it is translucent. Particles settle down in suspension because the particle sizes are more than 1,000 nm and are large so it settles down. The solution can be differentiated from colloids as solution are homogeneous while colloids, there is not much clarity. Colloid is translucent while true solution is transparent. Colloids can be separated by semi-permeable membrane while solution cannot because the particle size of solution is too small".

From the response, students could distinguish three dispersion system based on the properties of homogeneity, filterability, optical activity, gravitational effect and appearance. They distinguish them by relating to the size of the particles and all of them mentioned the size of the particles as fundamental differences behind all this property. One of them said *"the main difference is particle size and one thing is ability to undergo Tyndall effect"*. They were able to even explain about the Tyndall effect and relate the materials used and could differentiate them on the basis of size. One of them said "*Tyndall effect is scattering of light. I think it happen because when the light rays passes through solution the particles are blocking the way. So when it blocks, it is diverted from its path. So there are lots of particles, each particle are been hit with a beam of light so the light has to go up in zigzag motion so because of it the whole solution is scattered"*

Classification of colloids

Students' explanation to the classification of colloids includes like *i) "There are 8 types of colloids. Aerosol is one where dispersed phase is liquid and dispersed medium is gas. Cloud is an example. Gel is one type. Example is sodium hydroxide and sodium silicate soln. it can be hair gel and sometime it may be wax also".*

ii) "As per I have seen colloids like aerosol, sol, foam and all. There are 8 types based on dispersion phase and dispersion medium. So accordingly they are being classified. For e.g. like if dispersion phase is gas and dispersion medium is liquid, it is called foam".

Students were able to explain and classify colloids with an example, but the explanation does not cover full detail about the classification. They were able to give types and examples, but not able to fully relate the phase system.

Preparation of colloids of silica sol and silica gel by relating to scattering of light

Most of the students were able to give detailed procedure about how they prepare colloids, silica sol and silica gel. They remembered the steps. They were able to relate the process under two methods on the basis of particle size and narrate with their observation. This indicates those students had a sound understanding about the process of preparing colloids and were able to relate with their observation. For example;

i) "We prepared gel. First in 3 test tubes, we added 20ml of sodium silicate. After pouring we add vinegar and after we add base that is sodium hydroxide. Then we got gel. T here are two method in preparation of colloids, the dispersion method and condensation method. In the sodium silicate, we add vinegar is dispersion method because before sodium silicate was little foggy. When we add vinegar, the particle size decrease because it becomes clearer. And the scattering of light was also less. Condensation occurs when we add sodium hydroxide, it condenses and forms gel. In this particles are coming together and forming large".

"Firstly we pour 20ml of sodium silicate in beaker. Then we add vinegar. It became clearer compared to sodium silicate which indicates decrease in size of the particles. We call it Dispersion because there is disintegration of particles into smaller size. There is less scattering of light. Then we add sodium hydroxide and we

got gel. We prepared two types of colloids, sols and gels. Two methods are involved, dispersion and condensation. Dispersion means disintegration, breaking of particles into small one and condensation, small particles aggregate together to form big particles".

Relationship of size of the particles with scattering of light

7 students responded to the question while one did not respond. Students from their response indicate that they understood the relationship of the size of the particles. For example;

i) "More size, more scattering, smaller the size, less scattering. From the color spectrum red has longer wavelength so less scattering so orange will scatter more compared to red. Suspension has bigger in size and scatters more. Colloids scatter light, is bigger than true solution. Green light will scatter more than red light due to shorter wavelength".

ii) "Scattering of light is directly proportional to size of the particles. Which means if size of the particles is big scattering increases and vice versa. The difference between blue laser and green laser, beside all voltage and current are same, wavelength is only difference. Blue has shorter wavelength than green. So according blue will scatter more than green because shorter wavelength has high frequency and high frequency is associated with high energy. So scattering of light is all because of the energy of the laser"

Students are able to relate the scattering of light with the size of the particle by comparing different sources of light and also with a different solution. It shows those students understood about its relationship and are able to relate to the activities.

Relationship of size of the particles, wavelength of light and scattering of light in natural phenomenon.

The natural phenomenon includes like blue sky, reddish yellow sunset and white cloud. This phenomenon was discussed exclusively through questioning and letting students to analyze after both the lessons were complete. To assess their understanding, students mentioned *i) "Sky is blue because blue color is scattered more while all other colors are absorbed. Violet and indigo has shorter wavelength yet we see blue because of sensitivity of our eye. Violet and indigo are less sensitive to our eye".*

ii) "Sky is blue because it has high frequency with shorter wavelength and it reaches our eyes because our eyes contain cones. Blue are scattered more by dust particles, carbon dioxide, gases. Red has longer wavelength and reaches our eye. Blue is scattered. Cloud is white because the particle size is big, all the light are scattered equally. It does not depend on wavelength. Actually shorter wavelength it scatters more but in cloud the light are scattered equally because it contain big particle size in cloud".

Students are able to reason with the size of the particles, scattering of light with different wavelength of light and also with sensitivity of our eyes. They relate with spectrum of light, composition of earth's atmosphere and even compared the Rayleigh scattering and the Mie scattering. One of them mentioned

"Scattering of light is directly proportional to size of the particles but inversely proportion to wavelength of light. The size of the particle in cloud is bigger than the air. The cloud is white in color which is also due to scattering of light and contains mixtures of all the color. Though the particle size in cloud are bigger and it is white, Sir Rayleigh could not even answered that but later Mie, said that as particle size become bigger and bigger, the scattering of light become independent of size of the particle so that is the reason why cloud are white".

Finally, students were asked to relate some examples in their daily life where the size of particles has played a very important role. All the students said the size of the particles play an important role in their life. But when relating, only few could justify with appropriate examples like

"I have come across a glove when immersed in the sticky or adhesive substance like grease or oil; it was not sticking so I later on found that it is because of nanotechnology. And I learned that nanotechnology has all to do with size of the particles because it changes its properties like if aluminum can is reduced to size of 1-100nm, it says that can be used to shoot a rocket to the space so in that way, it plays a very important role in our life".

"Like in home we use to part the grain and stone. Grain is smaller in size than stone so to separate it is much easier".

Some students were familiar with such idea and some students could relate with their daily life activities like separating technique. However, students were not able to relate the effect of particle size in microscopic level. There are few students, whose concept of particle size and surface area are in contradiction with each other. Examples are

"Bigger size of the particles, they occupy large surface area. For eg. large stone will cover more surface area and small stone will occupy small area".

"Bigger the size more efficient. Food item like loaf of bread, if it is the size, if it is bigger the size, we can feed more but if it is less, we can only feed less number".

It's interesting to know that the meaning of particle size is not implied at the microscopic level but in macroscopic level. Students seem to misunderstand about surface area and occupying space. They take the measurement in the aspect of observable volume (qualitative aspect) but not in quantitative aspect. They relate the size as macroscopic entity, but not as microscopic. In short, students are not able to link scientifically the term "particle" though they show understanding about the size.

4.4.2 Perception part

The perception parts of interview are divided into 5 categories. Response of students are looked for patterns and grouped into each category.

Students' perception towards changes in environment

In this category to find the differences from other classes, students find it interesting and easy to work in groups. They show teamwork, cooperation and group management. Students mentioned

"Everything is new. It is interesting to work in group because we got more interactive, we get to know more about them. I learned how to manage with my group friends. It is much easier to do in the group in practical".

They say it was a new experience and found it very engaging, satisfying and got opportunity to work with lab equipment. Students mentioned

"By doing practical, we know how it takes place and can see with our eyes".

"In theory most of the student they sleep but in practical we are engaged in doing something in our hand we are not feeling sleepy and it makes us learn more. New thing that we learn like handling of things".

Students' perception towards difficulties and challenges

Students found difficulty in use and handling of simple lab materials. They say that they are inexperience due to lack of opportunity to work in the lab and are unfamiliar with materials and how to use it. They said

i) "Not that much difficulty as such but with handling of materials and apparatus because it is first time and bit nervous. No experience learning like this. We visit lab but didn't get chance to experiment by our own".

ii) "Since the class was first practical class in chemistry so most probably for us was nervous. It maybe nature of it that some of the reaction were slow for doing for the first time and I didn't have the patience to wait also".

iii) "I had difficulty in differentiating test tube and measuring cylinder and in recognizing apparatus".

Students' lack of experience of working in the lab was one major challenge as they faced difficulties in handling of lab apparatus. They were nervous and impatient. The time constraint is another challenge that almost all students mentioned. It made them feel hesitant about their work and make them impatient and doubtful. One of them stated "*It takes longer time and I feel hesitant because I thought this might be wrong result*".

Students' perception towards the learning activities

Students realize it is always better to learn by doing. They found it, interesting, fun, useful, interactive, confident and comfortable. They pointed out it was hands-on experience and can able to do and experience themselves. They show positive relationship with friends by working in groups. Students really like learning through activities. They said *i) "We did practical in group so more interaction and we had fun. We helped each other and it was interesting".*

ii) "I like it because we are able to do and experience ourselves. Doing practical is interesting and we like to have another opportunity".

iii) "We were able to enjoy with our friends by working together. We had better concept while doing practical. In theory class we are told about things which we cannot see with our own eyes but in practical we can do it with our own hands and see it. We don't see the size of the particles but we are able to see how it is important".

iv) "We are able to do and experience our self. It is interesting because we can do it practically. It is more like in class it is difficult in understanding so practical give us more knowledge. We are able to see, in class we just hear so by doing practically we learn more".

However, their lack of experience and time constraint was some negative aspects.

Students' perception towards the instructor

The Student found the instructor role as facilitator and is organized and prepared. They expressed positively towards the questions asked by the instructor and said it enabled them to think, analyze and clarify their doubts. In short, the guidance through question served the purpose of directing students towards the learning goals and objectives.

i) "When we were not able to do, sir ask question and we came to know. It helped us by asking us question as question was related to experiment and we thought, and it helped us think and find answer".

ii) "During the preparation, at first moment, when materials were provided, we don't know what to do and teacher helped us to do it indirectly by asking questions which helped us to do the work".

iii) "Help us to analyze to think about answer by indirectly asking question".

Suggestion and overall feeling

For the improvement, student pointed out individual work rather than group work for better performance. They express it from examination view point. The need of job distribution, individual responsibility to work within the group was raised by student as it gives confusion over who is going to do what. They also suggested smaller group member of 2-3 students. The Student said

"Instructor could have given chance to do individual as exam are done on individual basis".

"If there are more materials, we can have fewer members like two members. Less is better because all the students can involve in the activity".

"Doing individually is quite better. When we do in group it is confusion because like who will say some question and who will do the work. By doing individual, if we have question we can ask teacher but in group we are hesitant".

Overall the students found it a better learning experience, satisfaction and confidence, active, enjoyable and better understanding. It was completely new experience of learning for the students and they expressed their appreciation.

"It was new experience because till now, 12 years of learning what we did was sit in the class and just listen to the lecture. Where as in this class we could explore our self, go about how to do practical. When things are done with our self we learn better. Not just listening and seeing but by doing and feeling the subject makes us understand better. So I found it very informative and I could get lots of knowledge and if question are asked about colloids, now I feel I am confident".

"I feel satisfied, interesting and enjoyable. When we work in group, we are known to each other so it is interesting doing all new things".

4.5 Students' document

The whole class was divided into 10 groups of 4-5 students in each group. Students worked in groups. The group activities involve some activity sheet where they make necessary observations throughout the process. Some of the activities were used to assess individual understanding of the concept under study. The results of the question (appendix G), out of 43 students, 43 of them answered correctly the matching question while 42 of them have stated size of the particle as the fundamental difference between the solution. This conclusion from the students indicates that students understood the materials under the study and were able to classify them appropriately with the dispersion system. They also understood the size of the particles as fundamental differences behind the properties of suspension, colloids and a solution.

Students' summary after the demonstration (appendix I) were analyzed to assess their understanding about the scattering of light by different source of light in order to check the relationship between different wavelength of light in colloids. The responses from the students were looking for three things: 1. Students state only the difference 2. Students state the difference with valid reason and 3. Students state the difference with reason as well as able to relate to reality of the situation, like the scattering in distilled water. The Frequency of each student is found in the table 4.17.

Table 4.17 Frequency of students' response to the relationship of scattering of light by different source of light (red laser and green laser)

	Students are able to state	Frequency
1	The difference between different source of light only	13
2	The difference with valid reason	10
3	The difference, reason and relationship	9

From the table, out of 43 students, 13 students were able to state the difference between scatterings of different light only while 10 of them could state the difference with reason. Only 9 of them stated the difference with reason by relating to the size of the particles and scattering in distilled water. 11 of the students did not mention about the scattering of light. Rather, their summary involved other aspect about preparation of colloids, classification of colloids and difference between the dispersion systems. So sum up, students' knowledge about scattering of light and wavelength is worthy in understanding the effect of the size of the particles in the activities. It seems, students are able to relate the scattering of light with activities to understand the effect of particle size in preparation of colloids, distinguish between dispersion system, and in understanding some natural phenomenon.

CHAPTER V
DISCUSSION

Overview

This chapter presents the discussion of research findings based on the developed hands-on activities using lab-based inquiry learning unit to enhance students’ understanding of the effect of size of particles and to find the students’ perception towards the learning unit. The discussion is emphasized on these two sessions and the discussions covers a wider perspective of findings from the results and are conceivably argued or supported in lights of finding from previous researchers. The discussion is divided into two broad topics conceptual understanding and perception towards the learning unit.

5.1 Conceptual understanding

The 20 items two-tier colloidal achievement test was administered as pre-test and post-test and was analyzed using both statistical and descriptive analysis. The results were then triangulated with finding from other tools and discussed. The normality test significance value of 0.17 indicates normal distribution of data; therefore paired sample t-test was used for statistical analysis. The *t*-test results of pre-test and post-test shows p value of 0.000 at the significance value ($p < 0.05$). The result signifies that students' performance increased in post-test compared to pre-test, thereby indicating that hands-on activity lab-based inquiry learning unit has enhanced students’ understanding about the effect of the size of the particle in solution. The effectiveness of the hands-on inquiry-based laboratory is consistent with other findings (Sesen & Tarhan, 2013; Blanchard et al., 2010; Wolf & Fraser, 2008).

Even though the statistical analysis showed significant difference, the mean difference of the pre-test (mean = 3.74) and post-test (10.23) was only 6.49. That means, from the total score of 20, the impact of only around 51 % was observed which is not high. So to further analyze, descriptive analysis was carried out in the colloidal achievement test. The 20 items were analyzed based on the conceptual (1st tier) and both conceptual and reasoning (both tier) parts as done usually by many researcher like Hanson (2015); Lin (2004); Sia, Treagust, & Chandrasegaran (2012); Tan, Goh, Chia, & Treagust (2002). The two-tiers multiple choice question is effective way of assessing meaningful learning of students as well serves as diagnostic tools (Chandrasegaran, Treagust, & Mocerino, 2007). But it should be noted that the two-tiers multiple choice question used here is not implemented as diagnostic test, rather it is developed and used to assess their meaningful learning. The test was further analyzed on construct basis finally touching some parts of items which probably have contributed to low score in the statistics.

The pre-test score and post-test score of both 1st tiers (conceptual) and both ties (conceptual and reasoning) parts shows a similar trend. The score of both tiers were found less than the 1st tier. It implies that student did better in conceptual understanding but when it comes to scientific reasoning along with conceptual understanding, students had some difficulties. The result is similar to the one seen by researcher who used two-tiers multiple choices like Sia et al., (2012) on understanding of basic concept of electrolysis. Chandrasegaran et al., (2007) to evaluate students' ability to describe and explain chemical reactions says that students must have memorized certain facts without sufficient understanding of concept involved. Tan et al., (2002) studied high school students' understanding about inorganic chemistry also state that students may have learned facts without an adequate understanding of propositions and concept involved. However, Chou, Chan, & Wu (2007) found out that students spent more time in choosing the 2nd tier stating that students are able to sense right or wrong answer in given situation but were unable to give the exact reason. Sesli & Kara (2012) studied on diagnosing students' understanding of the cell division and reproduction saw students lack of reasoning skills. Their results indicate some confusion and incoherence between students' conception and scientific conception due to the abstract nature of topics. The result of researcher provides various reasons on the use of two-tiers multiple choice questions. It is clear that the use of two-tiers questions is difficult to score compared to normal MCQ. If only conceptual part (1st tier) is considered, the post-test score is 70% which is high and when both tiers (both conceptual and reasoning) is considered, the score is only 51%. Temel, Özgür, & Yılmaz, (2012) discussed that different assessment tools in evaluating the students would lead to differences in their achievement. Their study on the effect of different types of test on pre-service teacher showed that open-ended questions and two-tier MCQ were difficult to score compared to correct/incorrect test and MCQ test. The students who participated in this study are also not familiar with the two-tiers MCQ as such test are not used in the assessment and examination part according to website of Bhutan Council for School Examinations and Assessment, 2015. Therefore, the use of two-tiers MCQ test is probably one of the reasons behind the low score in the statistical analysis. Different types of test are recommended and be prepared considering the characteristics of topics and students to implement on (Temel et al., 2012).

The construct comparison of mean percentage of students score of the pre-test and post-test for both 1st tier and both tier shows that students performed well in the construct, types of dispersion system and effect of size of particles, followed by types of colloidal system, and preparation of colloids. The result showed that some anomaly of items and items which are scored less are found to be under the construct where students have performed less. The result clearly indicates that those items are responsible for contributing in low score of statistical analysis. From the open-ended questionnaire, what did you learn overall from the learning unit, the response of students supports the finding of colloidal achievement test. 31 students mentioned about learning effect of size particles, 17 mentioned about distinguishing solution, suspension and colloids, just 8 mentioned about classifying colloids and 7 students about preparation of colloids. It seems the dispersion system and effect of size of particles had more impact on students' learning. But from the students' reflection data, table 4.16, most students mentioned about learning classification of colloids followed by preparation of colloids.

The data from interview shows that students were able to relate the process of preparation of colloids through dispersion method and condensation method in detail indicating reflection of procedural knowledge which represents first hand students' knowledge (Peker & Wallace, 2011) about the process of preparing colloids. But regarding the classification of colloids, the explanation of students does not cover full details about the classification indicating that students are not able to fully relate the phase system with examples. Regarding the classification of colloids, students learn about it during the discussion part only. The lesson does not involve any activities focusing on classification of colloids rather the concept is picked up during the debriefing session and discussion part as it forms one of the important aspects of colloids. Therefore, further focus is needed in this field to address the problem. The present study is limited to this construct. The result of these tools shows that the learning unit is more focused towards the dispersion system and the effect of the size of the particles. The findings take into consideration of the learning unit developed with the sole purpose to enhance students understanding about the effect of the size of the particles in solution through teaching colloids which is achieved here. Hence, it is expected that students score is not higher in those construct that students have scored less. And another point is the preparation of colloids involves the Sol-Gel process, which is a complete new concept to students. The difficulty of students in comprehending this new idea in preparing colloids can also be attributed to low score in that construct.

The anomaly of some items and items contributing to low score were analyzed individually. The table 5.1 shows items having a low score having less than 40 and with anomalies.

Table 5.1 Items having a low score (< 40%) and anomaly. (N=43)

Construct number	Item number	**% of students who correctly answered first tier**		**% of students who correctly answered both tiers**	
		Pre-test	Post-test	Pre-test	Post-test
1	**3**	30	56	12	37
2	**9**	21	65	9	28
	11	30	49	9	33
3	**12**	21	9	9	9
	14	35	26	2	16
4	**17**	79	100	9	28

** Refer appendix A for questions items*

Item number 3 in construct, distinguishing between dispersion systems and score of the post-test in both the tiers is 37 which is less than required 40 % standard of BCSEA. The question for the first tier of question number 3;

Each mixture below has particles dispersed in water. Which list has particles, increasing in size?

1. Salt + water; 2. Sand + water; 3. Starch + water

(1) $1 < 2 < 3$;

(2) $2 < 3 < 1$;

(3) $3 < 2 < 1$;

(4) $1 < 3 < 2$).

Seven students chose option 1, 7 chose option 2, 5 chose option 3 and 24 of them chose option 4 which is the correct choice. From the choice, most of the students have an idea about size of the particles of given mixture but in the reasoning part: 10 students chose (a) (1 = colloids), (2 = suspension), and (3 = True solution); 9 students chose (b) (1 = colloids) (2 = true solution), and (3 = suspension); 8 students chose (c) (1 = suspension) (2 = colloids), and (3 = True solution); and 16 students chose the correct answer (d) (1 = true solution) (2 = suspension), and (3 = colloids).

From the response students are not able to link the mixtures under the particular dispersion system, though many of them have an idea about particle size of the given mixture. This probably can be attributed to students' lack of idea about examples of the mixtures given in the questions like starch solution and salt solution because students used milk powder and sugar in the activities instead. The process of designing the experiment and inferring it to distinguish as dispersion system is limited to examples provided to them. There is high possibility of students considering the materials used in the activity as only know examples. This shows that students making inference from only first-hand data instead of constructing generalization (Peker & Wallace, 2011). So linking of new information with preliminary information during teaching and learning is deemed important (Tosun & Taskesenligil, 2013). However, the average mean percentage score in this construct has seen increased from 45% in pre-test to 74% in post-test of the 1st tier (conceptual part) and 28% in pre-test to 59% in post-test of both tiers (conceptual and reasoning). The data from other tools also support that students' understanding in this construct is high.

The low score of item 9 and 11 in the 2nd construct an analysis shows that students' confusion about the classification of colloids based on dispersed medium and dispersed phase. The item 9: *What kind of colloids do you think our cloud is?*

In the 1st tier (conceptual part) post-test, *28 students* chose correctly that cloud is an (*1) aerosol* while *15* of them chose option *(3) Foam*. In the reasoning part, *23 students* chose *(a) dispersed phase is gas and dispersed medium is liquid*; *1 student* chose option *(b) dispersed phase is liquid and dispersed medium is liquid*; and *19* chose the correct response *(c) dispersed phase is liquid and dispersed medium is gas*. From the response, students seem to have confusion between aerosol and foam especially when they differentiate them based on dispersed phase and dispersed medium of liquid and gas. It is clear from the choice of the option, student's choice shift between aerosol and foam in conceptual part and between phase system of liquid and gas. Both aerosol and foam are differentiated on the phase system of liquid and gas. Aerosol is a liquid dispersed in the air while foam is air dispersed in liquid (aerosol = dispersed phase is a liquid while dispersed medium is a gas; and foam, dispersed phase is a gas while dispersed medium is liquid).

The item 11: *Which of the following example of colloids is not correctly matched with different types of colloids?*

21 students chose correct option *(3) Smoke-foam*; *11 students* of them chose option *(4) Starch solution-sol*; *7 students* chose *(1) Butter-gel* and *4 students* chose *(2) Milk-emulsion*. In the reasoning part, students' option of the choice is equally distributed. 8 students chose *a) Dispersed phase is gas and Dispersed medium is solid*; 10 chose *b) Dispersed phase is liquid and Dispersed medium is solid*; 14 chose the correct option *c) Dispersed phase is solid and Dispersed medium is gas*; and 11 chose the option *d) Dispersed phase solid and Dispersed medium is liquid*. The choice of students indicates that some of the students are not able to relate the examples and classify them. The result of item 9 shows students' confusion in the phase system of liquid and gas state of the cloud. Students have mixed up aerosol and foam while relating to cloud. The item number 11 indicates that inability of students to classify colloids on the basis of dispersed phase and dispersed medium is also can be related to students' unfamiliarity of materials. Like it is evident from item number 3 also shows the possibility that students were not able to classify a starch solution as colloids, solution or suspension as the materials was not used in the activity. In the item number 11 also, 11 students do not think starch is a sol or colloids. This shows that students unfamiliarity with examples taken some students do not have idea about starch at all. It is assumed that students' unfamiliarity with the examples could be one of the reasons of their difficulty in answering correct answer. The interview result also shows that only a few students were able to classify with some examples and their explanation was also too brief or short.

The classification error of mixture was discussed by Kingir, Geban, & Gunel (2012) as they found that students were not able to classify solution and mixture scientifically; Awan, Khan, & Aslam (2012) found that students had difficulty in classifying mixture of solution, suspension and colloids with logical reasoning; and Purtadi & Sari (2007) states that students do not use the information of colloids characteristics to explain the matter they faced as they assume that students conception about milk is liquid and the students assume it as solution. So the difficulty in classification is a problem seen in other research also and the current result also points out the unfamiliarity of materials used in the question may also have resulted in choosing wrong answer. So ensuring students learning with stated goals for learning demand, decision of laboratory, topics, materials, and teaching strategies should be explicitly linked (Hofstein, Kipnis, & Abrahams, 2013). Separate studies need its attention as the current learning unit does not focus too much on this construct thereby students' ability to classify colloids is not expected to have high score, thus affecting the score of statistical result.

The construct, preparation of colloids introduce students to complete new dimension of ideas of preparing colloids as it uses the Sol-Gel process to help student understand about its preparation through dispersion method (top-down process) and condensation method (bottom up process). From interview result, students' show good understanding about the preparation and also students were able to relate with size of the particles through process of scattering of light. However, the two items 12 and 14 showed some anomaly and low score in in the construct. The anomaly of item 12, where student post-test score of the 1st tier is less than pre-test and no change in the score of both pre-test and post-test score of both tier is interesting: *What happen to the* *turbidity (clarity) and intensity of scattered light when an acid is added to sodium silicate solution?*

The response of the option of the 1st tier in post-test shows that *23 students* chose option *(4) turbidity increases but intensity of scattered light decreases*; *11 students* chose (1) *both turbidity and intensity of scattering increases* while *5 students* chose (3) *Turbidity decreases, but the intensity of scattered light increases* and only 4 students chose the correct option (2) *Both turbidity and intensity of scattering decreases*. In the reasoning part *27 students* chose correct response (a) *acid causes particle size to decrease due to breaking down of particles*; *7 students* chose (b) *The Acid causes the particle size to increase due to aggregation of particles*, *4 students* chose (c) *The Acid causes the particle size to decrease and then increase due to breaking down and aggregation of particles respectively* and *5 students* chose (d) *The Acid causes the particle size to increase and then decrease due to aggregation and breaking down of particles respectively*. The students answer to this item is based on their observations during the lab activities. The students in the group collect the data by carrying out the lab activity following the procedure provided to them. The data collection is based on their observation on the changes in turbidity or clarity; and increase and decrease in scattering of light on adding acid (acetic acid) and base (NaOH). According to activity, students see the changes like during the formation of silica sol on adding of acid (acetic acid), the solution becomes clear and the scattering of light decreases due to breaking down of silica particles. But the opposite observation is made when the base (NaOH) is added, resulting in formation of silica gel. The results indicate that students either lacked the observation skill or they are not able to link their observation with the result during the whole process of data collection. They show confusion about turbidity and scattering of light during the dispersion process when acid is added to sodium silicate, thus unable to properly relate the effect.

Item number 14 is quite thought-provoking as actual answer already contradicts the option. The activity is based on dispersion and condensation process that is narrowed to the students to understand the concept through the top-down and bottom-up process. In reality, the preparation of sol can be done through both the process, but the activity confines students to answer based on the activity. And based on the activity, students' response to the item is expected to be an option *(3) dispersion method* and *18* of the students answered correctly. But in reality it can be done through a process, option (1*) both dispersion and condensation*, where *11 students* opted. In the reasoning, the expected answer, according to the activity is option (b) *the large silica particles of sodium silicate are converted into small particle*; *18 students* opted while the real answer (d) is chosen by *7 students*. Most of them, 17 students chose option (a). The inconsistency of response indicates students' confusion of condensation and dispersion in preparation of silica sol. From item 12 and 14 under the same construct, it shows students' face some difficulties in preparation of colloids. The result shows students' difficulty in linking the process with their observation or difficulty in relating their observations with the result. The result after analysis assumes that students' difficulty in relating observation with the result during the learning process could be one of the reasons as the students' answer to these items are based on their observation result during lab activities. The other reason could be attributed to their lack of basic laboratory skills due to their limited experience in the lab as mentioned by many students that it is the first time working in the laboratory. The lack of experience may have hindered the collection of data and in inference by students.

Högström, Ottander, & Benckert (2010) states that for laboratory to be a learning experience, it is important for students to develop observation skills. The results from other tools show sufficient evidence to link it to their lack of observation skills due to introduction of new process. From students' reflection, table 4.14, fifteen students had difficulty in observing the result and also from table 4.16; nine students had difficulty in observing the difference of scattering. The scattering of light using different laser (red and green) is new and students shared it as interesting as well as difficult to understand. Many state that they were not able to recognize the action of scattering of light and observing scattering of light through a solution. It is clear that students may have faced difficulty in observing the difference in scattering of different light and appearance of the solution. The students also show confusion about turbidity and scattering of light during the dispersion process. The lack of observation skill can be attributed to students' lack of experience working in lab as mentioned by almost all the students. The observation skills are very important as teaching chemistry involves interplay between ideas and observation (Hofstein et al., 2013). The item 14 however, contradict the options of students answer with the activities, nevertheless, inconsistency of students' response shows students difficulty in linking the process with their observation or relating to their observation with the result.

Finally the item number 17 under the construct of the effect of size of particle, shows 100% score in the 1st tier, but 28% in both tiers indicating 72% of the students got the reasoning part wrong. The analysis of the reasoning part shifts between two options. 26 students chose *c) light with longer wavelengths are scattered more over the great distance, leaving the shorter wavelength of light in the visible spectrum* While 12 students chose *d) Light with shorter wavelength are scattered more over the longer distance, leaving the longer wavelength of light in the visible spectrum.* 3 chose option a) and 2 chose option b). It probably indicates that students were either confused about the use of terms or language of scattering shorter and longer wavelength over great distance or students have misunderstood about the relationship of scattering by different wavelength of light. Data from other tools were used to shed light on this issue. From students' documents, they were able to state the difference between different sources of light with reason and also relate between them. The interview data also show, students were able to relate scattering of light with the size of the particles by comparing the different source of light and also with a different solution. It is also evident from open-ended questionnaires that students were able to relate the relationship of particle with different wavelength of light and had more impact on their learning. So the students' choice of the answer in the reasoning part cannot be accounted for their misunderstanding or lack of understanding of relationship between scatterings of light by different wavelength.

Therefore, it seems the confusion probably may have evolved due to language, sentence structure or their inability to read and understand the meaning of the sentence by the students. The assumption can be supported in light of some reviews. Schurmeier, Atwood, Shepler, & Lautenschlager (2010) found that question difficulty and misunderstanding sometimes are derived from the wording of questions. They say it may unintentionally lead students away from the correct answer or requiring skills that the questions was not intended to assess. Wang, Wang, Tai, & Chen (2010) found that students with high prior reading ability showed significantly higher gain as compared to those with low reading ability. Sia et al., (2012) reviewed and discussed about the difficulties experienced by the students in following the specific language used in chemistry and distinguishing it from everyday meaning of identical or similar terms. Peker & Wallace (2011) discuss about role of language in the teaching and learning and state that the language of scientific explanation is not straight forward but rather an interpretations of the authors' idea linked to experiences and context. The review indicates the possibility of confusing student is high due to language or words used and also due to reading ability. Therefore, the need to assess the choice and use of words or language is very important as it plays a vital role in learning and in making meaning of the statements. Even though, students' data reveal that the particular construct shows high understanding as it is evident from all the tools. The mean percentage score has increased from 49% in pre-test to 85% in post-test in 1st tier while in both tiers; the score has increased from 15% in pre-test to 58% in post-test indicating highest mean percentage score change of 36% in 1st tier and 43% in both tiers. From students' document also, 100 % of students got the matching correctly and 97.8% of students state the size of the particles as fundamental differences in distinguishing the dispersion system (Appendix G).

In summary, from the construct, students show enhancement in their understanding about the effect of the size of the particles as the data from all the tools show enough evidence. Beside the construct, effect of size of particle, the understanding of 1st construct is completely based on the concept of size of particles where students need that understanding to infer their conclusion that distinguishing the property of solution, suspension and colloids is based on the fundamental differences of size of particles. And students' show sound understanding about that inference. However, classification of colloids tends to be less problematic for the students but nevertheless, the objective of the study is based on the effect of particle size. Likewise, in preparation of colloids, though statistical analysis show low score, the data from other tools contradict with the issue as students were able to show their understanding in preparing that is evident from interview, students' reflection and open-ended questionnaire. The low score perhaps can be attributed to many other fallacies as discussed and shown by low scoring items. In short, overall, the data show enough evidence that students learning about the effect of size of particle have enhanced due to implementation of the learning unit which is developed using hands-on activity and inquiry-based laboratory approach

5.2 Students' Perception towards the Learning Unit

The research study has shown that inquiry-based laboratory is very effective with students learning of concept, skills development, cooperative learning and provides a whole new experience of learning environment. Students in this study worked with a group of 4-5. The students were actively involved in designing, collecting data, interpreting, presentating, manipulating materials, discussion and coming to the same conclusion. The response of students was overwhelming that the approach or technique has helped them gain knowledge and experience even though the learning unit was quite demanding as students did not have much experience in learning from such approach. The findings acknowledge that the use of inquiry-based laboratory instruction has the effect of making the laboratory experience more valuable for students, and as such increased their perseverance in the course (Scott & Pentecost, 2014).

The data from questionnaire, student refection, and interview indicate that students found the activity interesting and it is evident that students like learning by doing. They find it useful, engaging, interactive and satisfying. They mentioned that it provided them with opportunity to work in group, learn to design their own procedures, use and handle laboratory apparatus, and it was hands-on experience and can able to do and experience in real situation. They mentioned that doing activities in laboratory, it enable them to observe the effect themselves and do not feel sleepy as they are fully engaged in the activities. They mentioned that it benefited them as they can see and do the things in real while in class they just listen and learn from the book. They also mentioned that they learned and understood the concept by learning through activities and urge for more of such activities in the future. The findings are in agreement with the previous researchers as the increased interest and fun of learning from inquiry based lab as advantage is pointed by Deters (2005) where better learning of chemistry concept, learning about the scientific process, increased in communication skills was observed. Sesen & Tarhan (2013) in their study found that instruction based on inquiry-based laboratory caused significantly better acquisition of scientific concept and higher positive attitude towards chemistry and laboratory. Kilinc (2007) in the study, students found inquiry-based laboratory more permanent, more enjoyable, more pupil centered, satisfied with their teacher guidance and positive increase in their attitude. It was also shown by increase in students' self-confidence as students expressed that self-centered learning and self-designed mechanism was useful. It is justifiable to point out students' self-confidence as students mentioned about it in the data. From students' reflection, from table 4.14, 11 students' mentioned that they can perform the experiment with confidence while 7 of them think they can replicate the experiment. From table 4.16 also, 11 students mentioned they can replicate the experiment. It is also clear from the interview data, students expressed that such learning activities has given them confidence. So students' confidence is acknowledged in the present study as Brownell, Kloser, Fukami, & Shavelson (2012) saw increase in self-confidence in performing lab tasks as a result of taking introductory lab course.

It is interesting to discuss that from the open-end question, students seem to be amused with light scattering technique used in relating size of particle and some of the students mentioned about using microscope to see the differences in size of particles. Some of them mentioned using microscope in order to learn more while one of them mentioned that they want to see in order to compare the size of the particle to assure or confirm that there is really a difference in size. It seems that students are skeptical with their result or they lack mental picture of nanoscale and also the capability of lab equipment (simple microscope) available in the school. They think it is possible to compare the size of particles (solution and colloids) under the microscope that is found in the school. The interview result also shows that students' interpretation of measurement is considered only in terms of observable aspect while failing to consider the microscopic entity. They show misunderstanding about term surface area. One of them relate that large stone will cover more surface area because the student think that bigger the size of particle, it occupy large surface area. Another one state that bigger the size, more efficient. He give examples of loaf of bread and justify that if the size of the loaf is big, we can feed more but if size is less, we can feed less. It seems students lack to view "particle" as microscopic entity while they take the understanding of meaning of what “size” is. This shows that students fail to view in microscopic level and are unable to link with macroscopic entity. The view of complexity of nature of chemistry is inability to link micro, macro and symbolic, what we know as threefold representation of matter or Johnstone triplet (Gabel, 1999; Taber, 2013). It is clear that students are having some misconception about the terms used and are unable to view the particles in microscopic entity.

Another plausible explanation of using microscope can be given on the basis of students’ skepticism where students might have built curiosities that enable them to explore further. It can be supported in view of students’ questions or statements from interview and students’ reflection like, they want to know how the big particles break into smaller units upon dispersion (top-down process); some comments that they want to know what exactly is going in the mixtures and see it under the microscope; and some even asked whether the addition of more base or acid than the required amount stated in the procedure would give same result or not. It should be noted that students started asking questions which is avery healthy indication of learning according to constructivist learning involving inquiry approach. The questions of the students depict some curiosity and motivation to learn more. Hofstein, Shore, & Kipnis (2004) suggests that asking questions is central tenet to learning by inquiry approach as effective learning environment create an opportunity for students to ask questions; Dkeidek, Mamlok-Naaman, & Hofstein (2011) states that questioning ability is integral part of meaningful learning and scientific inquiry and Hofstein et al., (2013) discussed students who learn science, their questions help them self-evaluate and monitor their understanding and increase their motivation and interest in a topic by arousing their epistemic curiosity. The above view can be interpreted in terms of hands-on activity involving inquiry based-laboratory as the driving force of learning behind students’ ability to ask question and search for different means of finding the answer. The finding is in consistent with finding of Shamsudin, Abdullah, & Yaamat, (2013) where their findings revealed that inquiry-based teaching strategies were able to stimulate excitement among students while learning science and such strategies has benefits of enhancing interest, curiosity and liking for the subject.

Result from studies on students' perception towards lab-based inquiry approach showed that students enjoyed working in group and provided opportunities for cooperative learning. The result from students' perception questionnaire, the mean value of 4.55 reflect students like working in group as it encouraged them to think better, contribute and clarify their doubt. The data from open-ended questions, students' reflection and interview reveals that students enjoy working in group. They found it interesting, fun, and interactive. Students state that such activities and approach help them to learn how to work and cooperate with fellow group members; learned to work and keep group spirit in future work too. The benefit of group or collaborative work for students had an impression of working in group as a whole new level of experience for them. Hofstein & Lunetta (2004) states that such laboratory setting provides a unique learning environment, setting in which students can work cooperatively in small groups to investigate scientific phenomenon. Hofstein & Kind, (2012) states that such setting provides opportunities for more constructive interaction between students, students and teachers, promote social interaction and create positive learning environment. The benefits of working in group are well acknowledged by previous researcher where inquiry-based lab promotes cooperative learning which helps students construct knowledge (Brownell et al., 2012; Hofstein et al., 2013, 2004; Kilinc, 2007).

Though the students showed strong and positive opinion towards working in group, few students suggested working individually. It seems from the data, students attribute the importance of working or learning whether in classroom or in laboratory, they are strongly driven by the fact that their performance is measured and reflected by exam scores. The data from interview and students' reflection shows that they believe that they can perform better in exam if they are given opportunity to do work on individual basis. Wallace & Kang (2004) in their study put such aspect as influence of culturally based beliefs of exam preparation which differs from school, curriculum, and society and education system of a country as a whole. The National Education Framework of Bhutan (Royal Education Council, 2012) states that the teaching and learning process are founded on enabling students to pass examinations rather than fostering the skills of rational inquiry, learning how to learn, effective problem solving, etc., The findings indicate that despite the positive aspects of working in group or acquisition of knowledge and skills, passing the exam is regarded by some students as their important priority. Few students point out lack of work delegation in the groups and need of fewer members for better involvement. Xu & Talanquer (2013) discuss about group domination and lack of individual accountability. They suggested organizing activities to ensure interdependence, co-regulation, and individual accountability like assigning rotational managerial (e.g., facilitator, monitor, manager) and cognitive (e.g., clarifier, questioner, explainer) roles.

Högström et al., (2010) found out importance of learning perceived by students during the lab-work is influenced by teacher-student interaction. They pointed out that teachers' action is also very important in order to help students understand what to learn from a laboratory exercise. The role of teacher in this study requires the act of facilitator which is fulfilled from the students' response. Students responded positively towards teachers' probing questions that helped them to find answer for themselves. Students feel such activities were very helpful in building teacher-student relationship as evident from questionnaire and interview data. Therefore the learning unit is built on the principle that constructivist learning supports inquiry by placing the focus of learning on students and not teacher by delivering of contents (Eick & Reed, 2002).

Though the implementation of lab-based inquiry in schools showed positive impact on their understanding as well as in their attitudes, there have been some confining issues and challenges in its implementation especially the laboratory works. Kim & Tan (2011) discussed and mentioned limited time, large number of students, availability of resources, low proficiency of teachers and the absence of trained laboratory assistance as some issues, while Kilinc (2007) outlined lack of materials and longer time duration. Lack of time and content overload (practical classes sometimes take place after school); lack of expert technical support; and lack of teacher expertise and withdrawal of the practical exam in class 10 are some of the issues raised in Bhutan (Childs et al., 2012)**.** Such challenges have resulted in wide range of students' experience in laboratory activity.

Time is one of the issues students' repeatedly mentioned in the data. Most of students demanded more time to do the experiment as they were unable to complete the work on time. On other hand, students suggested in reducing the time as it take long time to complete. Basey, Sackett and Robinson (2008) say that students are genetically adapted to want labs that are time efficient. The current study acknowledges the issue of time factor raised by the students. The two lab-based instructions were of 3 hours each that were implemented separately in two lab sessions. The activities and the result of chemical reaction can be obtained within 10-15 minutes maximum. One logical explanation could be to their lack of experience working for such hours in the lab as they are accustomed to 45-55 minutes of regular class instruction. The activities involves planning, designing, data collecting, interpreting and concluding which consumes more effort and time than the regular class. Use of more class time as disadvantage is mentioned by Deters (2005) in his study. So Bruck and Towns (2009) suggested modifying pedagogical strategies of transition students gradually to inquiry-based activities. The need for more time for such approach were also seen by Gormally et al., (2011) especially those depended on collaborative group efforts. They suggested beginning with simpler activities with students unfamiliar with inquiry, first introducing the approach and then gradually increasing the level of difficulty. It is clear that the nature of inquiry itself is time demanding. Lau, Foong, Kadir, & Wong (2011) found that students took too long to do the PbI (Physics by Inquiry) activities due to materials, resulting in some groups failing to obtain the required experimental data. Likewise Winter, Lemons, Bookman, & Hoese (2012) mentioned that nature of material being covered may be difficult for students to grasp within limited amount of time, and mentioned that keeping the design of curriculum within constrained time-some students will struggle to achieve the learning goal. Toplis & Allen (2012) reported time constraint as one of the restriction to practical investigative course work and Bowen (1999) found that time anxiety was high as affective dimension like anxiety affect learning and performance in laboratory situation.

The current study on the issue of time cohere with the previous researcher but it is also important to point out that from the data, one of the factor contributing to time constraint can also be seen from students lack of experience in laboratory. The data from interview, students’ reflection and open-ended questionnaires show enough evidence that students had difficulty in use and handling of simple laboratory equipment; show hesitation towards use of chemicals and glass materials; lack of patience; experimental errors; unfamiliarity of materials. Hodson (2014) mentioned of students making errors in observing, measuring or recording, mishandling apparatus and failure to finish data collection in the time available. It is interesting to find out from the data that students' inability to recognize simple lab-equipment and their function like basic measuring cylinder, burette, conical flask etc., are of concern; and students' reluctance in using glass equipment, fear of chemicals probably have resulted in hesitation and extra caution.

The connection between time factors as an issue with nature of lab-based inquiry is clearer from the previous research but the lack of hands-on experience with simple laboratory equipment may possess a challenge in its use and implementation of such approach. In this study, such challenges and difficulties of students may have originated due to lack of experience and low knowledge on laboratory work which are the outcome of practice and a system. It is because as stated by Kim and Tan (2011) it is not just the issues of background, materials or time but also the complex schema of experiences, values and traditions of knowledge and teaching in our society. Students could not use prior knowledge in the laboratory as they lack experience of working in the laboratory. Therefore, lack of experience with experimental techniques points the beginner to emphasis fully on the skills necessary to complete task (Southam et al., 2013).

The study points out "time factor" as an issue not only attributes to nature of inquiry approach but also with the experiences of students working in the laboratory. The lack of experience or little experience in laboratory in the implementation of lab-based inquiry approach is confronted by students' lack of knowledge about laboratory materials and its usage. Fear of chemical and to handle fragile glass apparatus may have resulted in hesitation and extra caution. The logic says that such problems might have led to experimental error resulting in slow mechanism, incorrect result and repetition of procedures all over again may have contributed to time consumption. Probably, due to these issues, students do not like waiting for results; showed frustrations when they fail to get result. But expression of such frustration is indication of success as truly engaging students with course content and offering a realistic view of what it means to "do science" (Gormally et al., 2011).

It is found that introductory students experience to experimental error on observable basis for learning and understanding the nature of experimental error is important (Prilliman, 2012). As suggested by Bruck and Towns (2009), it is very important to assess students' conceptual knowledge and skills prior to undertaking the inquiry activities. The study suggests the need of students' experiences and knowledge in laboratory work, especially in handling basic laboratory equipment and its uses. The students should be provided with more opportunity for such basic field to avoid such problems and also to develop their experimental skills including observation. Such remedies are important to overcome time limitation and efficiency.

However, the implementation of hands-on activity inquiry approach in the present study has seen students learning the process skills. It helps in acquainting them with nature of practical work; recognize that trial and error are integral part of learning in the laboratory. It also familiarize them with uses and handling of laboratory apparatus; getting them more comfortable with uses of chemicals and fragile equipment and above all providing a platform for students to experience in real the benefit, challenges and difficulties of working in such a learning environment. The students found it very enriching as they could learn many things and states that it was very important learning experience for them. The use of such learning approach provides a wide area of opportunities to students, where, besides acquiring conceptual knowledge or fostering a positive attitude, it also provides the students to accustom and adapt to learning from such situation where the students learn by doing. Hofstein & Lunetta (2004) indeed states that laboratory play a distinctive role in science education as rich benefits of learning accrue from using laboratory activities. The finding are in agreement with the previous researcher that hands-on activity permit wide arena of application in terms of role of experiment as it provides hands-on experience by "learning by doing" (Haury & Rillero, 1992; Jodl & Eckert, 1998; Lee & Fortune, 2013; Wen-jin, Chia-ju, & Shi-an, 2012).

CHAPTER VI
CONCLUSION

Overview

This chapter presents the interpretation of the research findings and discussion to answer the research questions. It also presents implication of the studies along with limitation and provides recommendation for the future studies.

6.1 Conclusion

The lab based inquiry, hands-on activity learning unit is developed with an aim to enhance students' understanding of the effect of size of particles in solution through the teaching of colloids. The learning unit is designed and developed in perspective to the science curriculum in Bhutan with a syllabus of grade 11-12 chemistry, surface chemistry. The study was implemented to 43 grade 11 students in one of the schools in the southeastern part of Bhutan. The particular school had just one section of students who majored in science. All the students participated in the study. A total of five tools was used to collect data and interpreted both qualitatively and quantitatively. The results from both qualitative and quantitative data gave some insight into the use and implementation of the learning unit. The results were then discussed with findings from students' data and also findings and reviews from previous studies. The result and discussion finally try to answer the two research questions given below

6.1.1 Research question 1

Does the inquiry-based hands-on activity through lab based method enhance students' understanding about effect of size of particles in solution?

To answer this research question, the following data are used to interpret the result.

a) The statistical analysis shows the mean score in the post-test (M = 10.23, SD = 3.15) and the pre-test (M = 3.74, SD = 1.56). The mean difference shows a significant difference of (t = 16.06, p = 0.000) at a significant level of <0.05. The significant difference in mean score indicates that students' understanding about effect of size of particles is enhanced due to implementation of hands-on learning unit based on inquiry-based lab.

b) The descriptive analysis shows high score in the effect of size of particles construct. The mean percentage score has increased from 49% in pre-test to 85% in the post-test of the 1st tier while in both tiers; the score has increased from 15% in pre-test to 58% in post-test indicating highest mean percentage score change of 36% in 1st tier and 43% in both tiers. The construct to distinguish solution, colloids and suspension whose difference in properties is due to the size of particles saw an average mean percentage score increase from 45% in pre-test to 74% in post-test for 1st tier (conceptual part) and 28% in pre-test to 59% in post-test of both tiers (conceptual and reasoning). The result indicates that students understanding about the size of the particles has enhanced.

c) From students' document also, 100 % of students got the matching correctly and 97.8% of students state the size of the particles as fundamental differences in distinguishing the dispersion system.

d) From the questionnaire (table 4.10), the mean value of 4.78 implies that the hands-on activity learning unit based on inquiry-based lab has helped them learn about the effect of the size of the particles.

e) The open-ended questionnaire, students' reflection and interview data which are found in result and discussion chapter holds enough evidence to show that students' understanding about effect of size of particles is high. They are able to distinguish dispersion system based on the size of the particles; they can relate the size of the particles with a scattering of light; they can relate scattering of light with different wavelength of light and different size particles; able to explain natural phenomenon like blue sky, reddish yellow sunset, white cloud based on scattering of light with the size of the particles found in the atmosphere and water droplets in the cloud. They show understanding about preparation of colloids by relating scattering of light, whether the size is decreasing or increasing and states that the size of the particles play an important role in our lives.

The result from all this tool provides enough support to affirm that students' understanding about the effect of the size of the particles is enhanced and students express high understanding of the knowledge particularly in the field of particle size. So it can be concluded that the hands-on activity using inquiry approach based on the lab method has enhanced students' understanding of the effect of the size of particles in solution.

6.1.2 Research question 2

What is students' perception towards the developed learning unit?

As expected, students' perception towards the learning unit show positive expressions and students' comments are quite overwhelming and encouraging. There are different views of students' perception. It is wide and varied on individual level. The result and discussion in the previous chapter are done on the basis of similar pattern that are obtained from overall students' perception towards the learning unit. Those patterns of students' perceptions are given below

a) *New learning experience*: its' interesting to find that students mention about learning from such class or approach is new for them. It seems from students' comments, learning in the laboratory; learning in a group; doing activities involving designing, collecting data, observation, interpreting, presentation, etc., and working with materials, apparatus, chemicals and equipment, the whole implementation seems to be new to them. It reflects their experience, perhaps they never got the opportunity to work in this kind of learning environment, learning situation and learning approach. It indicates the strong prevalence of the traditional approach of learning in the system. Even though students found it a new learning experience, they mentioned that such experiences are very important as they can learn many things. They found it indeed very worthy and significant in their learning. They really like learning by doing and mentioned that they expect and want to learn from such kinds of activities. They were asking for more opportunities in the future to learn from such an approach.

b) *Interesting, engaging, interactive and satisfying*: students found the learning unit interesting to learn as they mentioned they can learn many things from designing of procedures to collecting data, observing, using materials, handling equipment and lab apparatus, discussion, question answer session between instructor and students, etc., They found activities were very engaging as they have to do the experiment and involve fully. They also mentioned working in the group was interactive as they get an opportunity to work in groups and work for a common goal. They show satisfaction of learning from such activities and approach.

c) *Real life hands—on experience*: students mentioned that learning from such activities they can experience in real and observe the phenomenon with their eyes. They mentioned that they do not feel sleepy as they are involved in doing the activities; they can see as well as touch and confirm from their own experience of working with activities. They mentioned, it provides them an opportunity where they can work and find their own result by working in real situations. They express their dislike of learning from a class where they have to listen to a teacher's lecture and books telling them about the concept. They mentioned by doing such activities, they can experience in real and make them believe rather than books and teacher simply telling them in the class.

d) *Motivating, confidence and curiosity*: The findings and students' comments reveal that learning unit has played important role in motivating them, giving confidence and arousing curiosity. They mentioned that such learning activities motivate them to learn more as they can experience in real. It helped them learn many things. They said they are now confident that they can work in the lab, handle apparatus, and carry out the practical without any difficulties. The questions that students mentioned revealed their urge to learn more. They mentioned they want to learn more about scattering of light, size of particles, colloids etc. They mentioned they want to learn beyond the topic and were curious to know what is happening at the particulate level. They want to confirm it by using a microscope. They also show skepticism and frustrations, which is positively indication of learning. Many of their questions include "what, how and why" about scattering, preparation of colloids, dispersion system as reflected in the result which shows students' motivation and curiosity to take a further step in learning.

e) *Like the questioning by instructor*: the whole approach involves inquiry through questioning by the instructor to guide the students with activities that enable them to think and find the answer by working in groups rather than telling them directly. The findings indicate that students showed positive looks towards the questions. They mentioned that they like the question answer session, especially when they had a problem, the questions provided by instructor instead of answer help them to think and by working in groups helped find answers. The students expressed that questioning is very important as it guide them with their work, let them to think and find the solution. They also mentioned it helps in building teacher-student relation as it involves more interaction.

f) *Group work beneficial and enjoyable yet some still prefer working individually*: one of the finding from the study is that working in a group is a whole new experience for students. They find it beneficial as they can help each other. They mentioned by working in a group, they can interact more with their friends and they enjoy working together. They learn better by helping each other and can also help know their group member better. It shows besides learning concept, it helps develop personal relationships. They mentioned they learned how to cooperate with their group members, to show group spirit and can learn to work in group in future. On the other hand, there are some students who suggested working individually though they enjoyed and benefitted working in groups. Most of the reason behind such suggestion is based on examination point of view where they feel if they work individually they can perform better in the exam. Other reasons involve lack of work distribution within the group leading to confusion about the responsibility of different work within the group members.

g) *Time still a challenge:* some students demanded more time to complete the work as it was not enough for them to get results on the specified period of time while some suggested that the activity time should be reduced as it take long time to get the result. The time issue is discussed explicitly in the discussion chapter, which shows various reasons for making the issue a concern. The issue of time in this study seems to stem out more from students' lack of experience working in the laboratory which make them hard to use basic laboratory equipment resulting in hesitation and error. That makes students to redo the experiment and wait for result thereby contributing to time issue. Despite many reasons, time is still a challenge and an issue that students found in the learning unit.

h) *Lack of experience*: students mentioned that since it is the first time they are learning in this kind of learning environment, the practical work or working in chemistry lab also seems to be new according to their comments. Some of them mentioned they go to the lab but did not get the opportunity to work with equipment and apparatus. They mentioned difficulty in recognizing basic laboratory apparatus. They mentioned their hesitation to use glass apparatus and chemicals. They mentioned about experimental error and show lack of patience in waiting for results. They show frustration when they do not get the desired result. They find it boring to repeat the experiment when it fails to give result and they really do not like to wait. They mentioned about learning unit providing them the opportunity to learn the use and handling of laboratory apparatus. They asked for more opportunity to work in the lab to help improve their skills and understanding. Students said that the difficulties and challenges they faced working in the lab was because it is the first time for them. Nevertheless, students mentioned they are satisfied learning from such approach as they expressed their appreciation and acknowledge the potential that inquiry lab with hands-on activity can provide. However, inexperience seems to be lots of discussion point behind the issues, challenges and success of the learning unit.

6.2 Implication and Limitation of the study

The teacher-designed inquiry-based learning unit involving hands-on activities and laboratory is developed to evaluate students' performance and perception on the suggestion and recommendation of previous studies and also based on the objectives and goals of science curriculum in Bhutan as a means to improve students' understanding and attitude. The learning unit is developed based on chemistry syllabus of grade 11 and 12, colloids chapter. But, the learning unit is not intended fully to cover the whole chapter, rather it infuses the idea of physics (scattering of light) in enabling students to understand the role played by size of the particle. The students learn most of the concept in the syllabus through such integration. The result of this study, although preliminary can be adapted to meet their needs, but it may require modification to implement in the class. The learning unit provides the possibility of infusing ideas from different subject as a means to help students meet a common objective and also thereby creating some awareness of some emerging field in science and technology. The use of such approach and design have the possibility of bringing students out of traditional way of teaching and making teaching and learning more interesting and meaningful. However, developing such learning unit is limited in scope of achieving all the goals and objectives of curriculum and syllabus, but nevertheless, it helps unveil some information about students' learning, thereby, can provide an area for improvement of learning for both students and teachers.

The learning unit achieves the study objective and found positive perception of students' towards learning unit, but it also addressed some challenges and issues in implementing. The issue to be concerned in developing and implementation of such learning unit is to come up with more innovative design to suit the classroom time based on particular topics and objectives. The design of two lessons of 6 hours in this study is too demanding in aspect of curriculum, syllabus and school culture because need of such implementation requires adjustment of extra class which is difficult in real classroom situations. So teachers can come up with activities with a particular objective and topic to address in time period allocated for a normal class.

However, the learning unit presented in this study show possibility and can provide ideas for teacher to design an appropriate program by infusing interdisciplinary knowledge that can, besides covering the concept in the syllabus, can also enable students to relate different ideas from different subject, thus integrating and become aware of some current issues. It provides teacher ideas about using possible tools in assessing the students; the issues and challenges that one can encounter through implementation of such design; feasibility of time, materials and students' learning style; students' achievement and interest and overall, through such practice and development, it provides opportunity in making the teaching and learning more meaningful. It has an ability to discover lots of knowledge, issues, challenges and problems which can be addressed and improved. Such remedy will be helpful in lifelong learning for students.

The use of constructivist approach of learning, using hands-on activities, inquiry and using laboratory was a success in this study and future works of design and implementation can be carried out more effectively with the use of the above approach. It should be noted that the current study found some difficulties of students using laboratory equipment due to their limited experience of working in the lab. This probably has implication on their learning as lack of experience demanded more effort and time. Students' struggled to cope up with the new environment. Nevertheless, students' found it very meaningful and worth experiencing. So the need of experiencing students with laboratory works is important and familiarizing with equipment and material is very important. Prior knowledge about students on such use and capability need to be checked. It should not be taken for granted that, students in such standard will be well equipped with use of basic laboratory equipment, handling and are comfortable working in lab as already stated by Wallace & Kang (2004) that studies of student response to inquiry should take place in classrooms where teachers are currently implementing inquiry within the constraints of school culture, rather than special camps, classes, or programs. Kim & Tan (2011) found that the complex schema of experiences, values and traditions of knowledge and teaching in our society is complex and differs from school to school, curriculum to curriculum and country as a whole. In short, to design and implement such design requires the need to find experience of students as the students in the particular environment is affected by particular school culture and believe. So, one should not be surprised to find students that have never gone to chemistry lab and never had hands-on experience in their 12 years as student in the school though it is a matter of great concern. Therefore, implementation require sound knowledge about students' experience so that development and design can be more suited and also to avoid problems in the implementation.

The overall result and finding of this study is just based on one school, the finding cannot be generalized and so more studies are required to further confirm it. Even then, the study gives some insight into the real class room situation which is explicitly discussed based on students' data and literature review. And, also due to limited study on colloids, requiring students understanding of effect of size of particle by integrating with scattering of light in education field, the learning unit can be useful for some teachers to adopt and adapt in their teaching and learning practice. But the implementation as mentioned earlier, require modification like teacher should work out with concentration of solution in preparing silica sol and silica gel prior to implementation to get the result within the time frame. The use of materials and tools need to be familiarized with students. Prior experience of students working in the lab should be checked and necessary remedies should follow. Since the constructivist approach firmly believes in constructing knowledge through student centered learning, hands-on activities, inquiry, etc.., the study find out that such teaching and learning experience is worthy of using in our everyday life.

The present study acknowledges the limitation based on students' background as design and implementation did not take account of experiences of students. The knowledge on how the concept was being taught before the implementation of the present learning unit resound the liability upon which the findings are based on. The background knowledge about how the concept being taught before in the system or school is felt important as the present participants are exposed to treatment and there is no control group to compare the result. The comparison will provide a validation of the effect of the treatment, thereby making the findings of the present study more resilient though the study was limited by the sample size, time, lab facilities, resource, etc., So the need of the control group in the study are felt important given the limited information about teaching and learning process in the particular system. This comparison will help in the unveiling important aspect of students' understanding and will make the present finding more accountable and clear. The finding and issues of effectiveness and limitation provided by the present study on the conceptual understanding will be made more valid and reliable by accounting the control group in the study.

6.3 Recommendation for further studies and development

The present study involves only 43 students, whole class in one of the schools in Bhutan. The study is limited by the number of samples so the findings are confined to particular schools. Similar studies with more sample is needed to generalize the findings in the future. The construct, classification of colloids needs further study to find out students' difficulty and misconception. The study can be done separately and requires enough examples of our daily life to relate and also to find students' confusion over differentiation based on dispersed phase and dispersed medium of solid, liquid and gas state.

The development of such learning unit needs to consider the experience of students working in the laboratory. The materials used should be familiar to students and careful consideration should be made in developing questions to avoid wrong answer due to the unfamiliarity use of the materials in the question. The use of tools (conceptual test) should be further reviewed and made strong both on choice of test used and reliability. The uses of tools need to be familiar with students as limited in this context and probably can be redesigned to find misconception of students on particular concept also. The lesson can be divided and made suitable to classroom time for better management. More focus can be given to science process skill for further insight and information. The study can be implemented with different groups of students with prior experience working in a lab, those with knowledge and skills of basic laboratory experience. The study can also be implemented by taking control group so that the result of the present study can be compared for further validation and meaningful insight.

REFERENCES

Acar Sesen, B., & Tarhan, L. (2013). Inquiry-based laboratory activities in electrochemistry: High school students' achievements and attitudes. *Research in Science Education*, *43*(1), 413–435. doi:10.1007/s11165-011-9275-9

Aegerter, M. A., Leventis, N., & Koebel, M. M. (Eds.). (2011). *Aerogels Handbook*. doi:10.1007/978-1-4419-7589-8

Ahn, H., & Whitten, J. E. (2005). Monitoring particle growth: Light scattering using red and violet diode lasers. *Journal of Chemical Education*, *82*(6), 909.

Akkus, H., Kadayifci, H., & Atasoy, B. (2011). Development and application of a two-tier diagnostic test to assess secondary students 'understanding of chemical equilibrium concepts. *Journal of Baltic Science Education*, *10*(3).

Aramrak, S., Flury, M., Harsh, J. B., Zollars, R. L., & Howard P. Davis. (2013). Does colloid shape affect detachment of colloids by a moving air− water interface? , *Langmuir, 29*, 5770−5780. doi:10.1021/la400252q

Avci, D. E., & Karaca, D. (2012). An investigation of students' academic development, views, and feelings through journals. *Eurasia Journal of Mathematics, Science & Technology Education*, *8*(3), 177–188.

Awan, A., Khan, T., & Aslam, T. (2012). Gender disparity in misconceptions about the concept of solution at secondary level students in Pakistan. *Journal of Elementary Education*, *22*(1), 65–79.

Ayyildiz, Y., & Tarhan, L. (2012). Effect of case studies on primary school teaching students'attitudes toward chemistry lesson. *Hacettepe Universitesi Egitim Fakultesi Dergisi-Hacettepe University Journal of Education*, *43*, 62–70.

Bächtold, M. (2013). What do students "construct" according to constructivism in science education? *Research in Science Education*, *43*(6), 2477–2496. doi:10.1007/s11165-013-9369-7

Basey, J., Sackett, L., & Robinson, N. (2008). Optimal science lab design: impacts of various components of lab design on students' attitudes toward lab. *International Journal for the Scholarship of Teaching and Learning*, *2*(1), 15.

Bayrak, B. K. (2013). Using two-tier test to identify primary students' conceptual understanding and alternative conceptions in acid base. *Mevlana International Journal of Education*, *3*(2), 19–26. doi:10.13054/mije.13.21.3.2

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, *72*(7), 30–33.

Berg, K. C. de. (2006). The status of constructivism in chemical education research and its relationship to the teaching and learning of the concept of idealization in chemistry. *Foundations of Chemistry*, *8*(2), 153–176. http://doi.org/10.1007/s10698-006-9010-1

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability? A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, *94*(4), 577–616. doi:10.1002/sce.20390

Boopathiraj, C., & Chellamani, K. (2013). Analysis of test items on difficulty level and discrimination index in the test for research in education. *International Journal of Social Science & Interdisciplinary Research*, *2*(2), 189–193.

Bowen, C. W. (1999). Development and score validation of a chemistry laboratory anxiety instrument (CLAI) for college chemistry students. *Educational and Psychological Measurement*, *59*(1), 171–185.

Brar, S. K., & Verma, M. (2011). Measurement of nanoparticles by light-scattering techniques. *TrAC Trends in Analytical Chemistry*, *30*(1), 4–17. doi:10.1016/j.trac.2010.08.008

Brownell, S. E., Kloser, M. J., Fukami, T., & Shavelson, R. (2012). Undergraduate biology lab courses: Comparing the impact of traditionally based "cookbook" and authentic research-based courses on student lab experiences. *Journal o College Science Teaching*, *41*, 18–27.

Bruck, L. B., & Towns, M. H. (2009). Preparing students to benefit from inquiry-based activities in the chemistry laboratory: Guidelines and suggestions. *Journal of Chemical Education*, *86*(7), 820.

Bryceson, K. (2007). The online learning environment—a new model using social constructivism and the concept of "Ba" as a theoretical framework. *Learning Environments Research*, *10*(3), 189–206. doi:10.1007/s10984-007-9028-x

Bulunuz, N., Bulunuz, M., & Peker, H. (2014). Effects of formative assessment probes integrated in extracurricular hands-on science: Middle school students' understanding. *Journal of Baltic Science Education*, *13*(2), 243–258.

Bulunuz, N., & Jarrett, O. S. (2010). The effects of hands-on learning stations on building American elementary teachers' understanding about earth and space science concepts. *Eurasia Journal of Mathematics, Science & Technology Education*, *6*(2), 85–99.

Bybee, R. W. (2002). *Learning science and the science of learning*. Virginia: National Science Teacher Association. Retrieved from http://www.nsta.com

CAPSD, & BBE. (2012). *Syllabus for class XI and XII*. Thimphu, Bhutan: Ministry of Education, Royal Government of Bhutan.

Chamely-Wiik, D. M., Haky, J. E., Louda, D. W., & Romance, N. (2014). SQER ^{3}: An instructional framework for using scientific inquiry to design classroom demonstrations. *Journal of Chemical Education*, *91*(3), 329–335. doi:10.1021/ed300689n

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. *Chemistry Education Research and Practice*, *8*(3), 293–307.

Childs, A., Tenzin, W., Johnson, D., & Ramachandran, K. (2012). Science education in Bhutan: Issues and challenges. *International Journal of Science Education*, *34*(3), 375–400. doi:10.1080/09500693.2011.626461

Chou, C., Chan, P.-S., & Wu, H.-C. (2007). Using a two-tier test to assess students' understanding and alternative conceptions of cyber copyright laws. *British*

Journal of Educational Technology, *38*(6), 1072–1084. doi:10.1111/j.1467-8535.2006.00695.x

Brinker, J.C., & Scherer, G.W. (1990). *Sol-Gel Science - The physics and chemistry of sol-gel process*. London: Academic Press.

Cloonan, C. A., Andrew, J. A., Nichol, C. A., & Hutchinson, J. S. (2011). A simple system for observing dynamic phase equilibrium via an inquiry-based laboratory or demonstration. *Journal of Chemical Education*, *88*(7), 975–978. doi:10.1021/ed100846k

Bertram, D. (2007). *Likert Scales*. Retrieved from http://poincare.matf.bg.ac.rs/~kristina/topic-dane-likert.pdf

Sederberg, D. (2009). *Middle and High School Teachers 'Development of Nanoscience and Engineering Subject Matter Knowledge*. Retrieved from http://web.ics.purdue.edu/~dsederbe/wp-content/uploads/2011/06/NARST-2009.pdf

DCRD. (2013). *Science Curriculum Framework: Classes PP-XII*. Thimphu, Bhutan: Royal Government of Bhutan.

Derry, J. (2007). Abstract rationality in education: From Vygotsky to Brandom. *Studies in Philosophy and Education*, *27*(1), 49–62. doi:10.1007/s11217-007-9047-1

Deters, K. M. (2005). Student opinions regarding inquiry-based labs. *Journal of Chemical Education*, *82*(8), 1178.

Dianovsky, M. T., & Wink, D. J. (2012). Student learning through journal writing in a general education chemistry course for pre-elementary education majors. *Science Education*, *96*(3), 543–565. doi:10.1002/sce.21010

Dkeidek, I., Mamlok-Naaman, R., & Hofstein, A. (2011). Effect of culture on high-school students'question-asking ability resulting from an inquiry-oriented chemistry laboratory. *International Journal of Science and Mathematics Education*, *9*(6), 1305–1331.

Duit, R., & Treagust, D.F. (1995). Students' conception and constructivist teaching approaches. In B.J. Fraser & H.J. Walberg (Eds.), *Improving Science Education*. (pp. 46-69). Chicago: The International Academy of Education.

Duncan, K. A., Johnson, C., McElhinny, K., Ng, S., Cadwell, K. D., Zenner Petersen, G. M., Crone, W. C. (2010). Art as an avenue to science literacy: Teaching nanotechnology through stained glass. *Journal of Chemical Education*, *87*(10), 1031–1038. doi:10.1021/ed1000922

Duvarci, D. (2010). Activity-based chemistry teaching: A case of "elements and compounds." *Procedia - Social and Behavioral Sciences*, *2*, 2506–2509. doi:10.1016/j.sbspro.2010.03.362

Education Sector Review Commission. (2008). *Education without compromise*. Retrieved from http://www.camb-ed.com/Portals/0/Documents/Bhutan-Education-Quality-Survey--Education-without-Compromise-jan2008.pdf

Eick, C. J., & Reed, C. J. (2002). What makes an inquiry-oriented science teacher? The influence of learning histories on student teacher role identity and practice. *Science Education*, *86*(3), 401–416. doi:10.1002/sce.10020

Eisen, L., Marano, N., & Glazier, S. (2014). Activity-based approach for teaching aqueous solubility, energy, and entropy. *Journal of Chemical Education*, *91*(4), 484–491. doi:10.1021/ed4005563

Rollings-Carter, F. (1997). *LinguaFolio training modules*. Retrieved from http://www.learnnc.org/lp/media/uploads/2010/06/lftraining_m3_a2.pdf

Flick, L. B. (1993). The meanings of hands-on science. *Journal of Science Teacher Education*, *4*(1), 1–8.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education*, *76*(4), 548.

Glinka, N. (1960). *Colloids and the Tyndall effect*. Retrieved from http://www.think-downloads.com/download/Technology/colloids-a-the-tyndall-effect.pdf

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2011). Lessons learned about implementing an inquiry-based curriculum in a college biology laboratory classroom. *Journal of College Science Teaching*, *40*(3), 45–51.

Hahn, D. W. (2009). *Light scattering theory*. Retrieved from http://plaza.ufl.edu/dwhahn/Rayleigh%20and%20Mie%20Light%20Scattering.pdf

Hanson, R. (2015). Identifying students' alternative concepts in basic chemical bonding–a case study of teacher trainees in the university of education, Winneba. *International Journal of Innovative Research and Development*, *4*(1), 115–122.

Haury, D. L., & Rillero, P. (1992). *Hand-on approach to science teaching: questions and answer from field of research*. Columbus, Ohio: ERIC clearing house for science, mathematics, and environmental education.

Hébert, Y. M., & Abdi, A. A. (Eds.). (2013). *Critical perspectives on international education*. Rotterdam: Sense.

Hodson, D. (2014). Learning science, learning about science, doing science: different goals demand different learning methods. *International Journal of Science Education*, *36*(15), 2534–2553. doi:10.1080/09500693.2014.899722

Hofstein, A. (2004). The laboratory in chemistry education: Thirty years of experience with developments, implementation, and research. *Chemistry Education Research and Practice*, *5*(3), 247–264. doi:10.1039/B4RP90027H

Hofstein, A., & Kind, P. M. (2012). Learning in and from science laboratories. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second International Handbook of Science Education* (pp. 189–207). doi:10.1007/978-1-4020-9041-7_15

Hofstein, A., Kipnis, M., & Abrahams, I. (2013). How to learn in and from the chemistry laboratory. In *Teaching chemistry–A study book* (pp. 153–182). doi:10.1007/978-94-6209-140-5_6

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, *88*(1), 28–54. doi:10.1002/sce.10106

Hofstein, A., Shore, R., & Kipnis, M. (2004). Research report: providing high school chemistry students with opportunities to develop learning skills in an inquiry-type laboratory: A case study. *International Journal of Science Education*, *26*(1), 47–62. doi:10.1080/0950069032000070342

Högström, P., Ottander, C., & Benckert, S. (2010). Lab work and learning in secondary school chemistry: The importance of teacher and student interaction. *Research in Science Education*, *40*(4), 505–523. doi:10.1007/s11165-009-9131-3

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students' interest. *Research in Science Education*, *40*(5), 743–757. doi:10.1007/s11165-009-9142-0

Bergna, H. E. (1994). *The colloid chemistry of silica*. Washington DC: American Chemical Society.

Jeong, U., Herricks, T., Shahar, E., & Xia, Y. (2005). Amorphous Se: A new platform for synthesizing super paramagnetic colloids with controllable surfaces. *Journal of the American Chemical Society*, *127*(4), 1098–1099. doi:10.1021/ja043847u

Jodl, H.-J. rg, & Eckert, B. (1998). Low-cost, high-tech experiments for educational physics. *Physics Education*, *33*(4), 226–235.

Gilbert, J.K., Jong, O.D., Justi, R., Treagust, D.F., & Van Driel, J.H. (2002). *Chemical education: Towards research -based practice*. Netherland: Kluwer Academic Publishers.

Kaya, E., & Geban, O. (2011). The effect of conceptual change based instruction on students' attitudes toward chemistry. *Procedia - Social and Behavioral Sciences*, *15*, 515–519. doi:10.1016/j.sbspro.2011.03.133

Kilinc, A. (2007). The opinions of Turkish high school pupils on inquiry based laboratory activities. *Online Submission*, *6*(4). Retrieved from http://eric.ed.gov/?id=ED499653

Kim, M., & Tan, A. (2011). Rethinking difficulties of teaching inquiry-based practical work: Stories from elementary pre-service teachers. *International Journal of Science Education*, *33*(4), 465–486. doi:10.1080/09500691003639913

Kingir, S., Geban, O., & Gunel, M. (2012). How does the science writing heuristic approach affect students' performances of different academic achievement levels? A case for high school chemistry. *Chemistry Education Research and Practice*, *13*(4), 428. doi:10.1039/c2rp20013a

Kılıç, D., & Sağlam, N. (2009). Development of a two-tier diagnostic test to determine students' understanding of concepts in genetics. *Eurasian Journal of Educational Research*, *36*, 227–244.

Kokhanovsky, A. A. (Ed.). (2013). *Light Scattering Reviews 8*. Berlin, Heidelberh: Springer

Kurt, S., & Ayas, A. (2012). Improving students understanding and explaining real life problems on concepts of reaction rate by using a four step constructivist approach. *Energy Education Science and Technology Part B: Social Educational Studies*, *4*(2), 979–992.

Kutzner, M. (2013). The laser level as an optics laboratory tool. *The Physics Teacher*, *51*(9), 532. doi:10.1119/1.4830064

Lapworth, D. J., Stolpe, B., Williams, P. J., Gooddy, D. C., & Lead, J. R. (2013). Characterization of suboxic groundwater colloids using a multi-method approach. *Environmental Science & Technology*, *47*(6), 2554–2561. doi:10.1021/es3045778

Lau, C. Y., Foong, S. K., Kadir, M. S., & Wong, D. J. S. (2011). PBI1@ SCHOOL: Developing and implementing an inquiry-based curriculum for speed and density. Retrieved from http://repository.nie.edu.sg/jspui/handle/10497/6818

Lee, M., & Fortune, A. E. (2013). Do we need more "doing" activities or "thinking" activities in the field practicum? *Journal of Social Work Education*, *49*, 646–660. doi:10.1080/10437797.2013.812851

Lee, V. S. (2012). What is inquiry-guided learning? *New Directions for Teaching and Learning*, *2012*(129), 5–14. doi:10.1002/tl.20002

Lin, S.-W. (2004). Development and application of a two-tier diagnostic test for high school students' understanding of flowering plant growth and development. *International Journal of Science and Mathematics Education*, *2*(2), 175–199.

Lurton, T., Renard, J.-B., Vignelles, D., Jeannot, M., Akiki, R., Mineau, J.-L., & Tonnelier, T. (2014). Light scattering at small angles by atmospheric irregular particles: Modelling and laboratory measurements. *Atmospheric Measurement Techniques*, *7*(4), 931–939. doi:10.5194/amt-7-931-2014

Madan, R. D., & Bisht, B. . (2013). *ISE Chemistry Book I for class XI*. New Delhi: S.Chand & Company Ltd.

Miller, L. S., Nakhleh, M. B., Nash, J. J., & Meyer, J. A. (2004). Students' attitudes toward and conceptual understanding of chemical instrumentation. *Journal of Chemical Education*, *81*(12), 1801.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction-what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.20347

Muñoz, O., & Hovenier, J. W. (2011). Laboratory measurements of single light scattering by ensembles of randomly oriented small irregular particles in air. A review. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *112*(11), 1646–1657. doi:10.1016/j.jqsrt.2011.02.005

Muñoz, O., Moreno, F., Guirado, D., Ramos, J. L., López, A., Girela, F., … Bustamante, I. (2010). Experimental determination of scattering matrices of dust particles at visible wavelengths: The IAA light scattering apparatus. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *111*(1), 187–196. doi:10.1016/j.jqsrt.2009.06.011

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education*, *69*(3), 191.

National Aeronautics and Space Administration. (2001). *Scattering: Seeing the microscopic among the giants*. Retrieved from http://saturn.jpl.nasa.gov/files/Scattering.pdf

National Education Policy. (2012, March). *Educating for GNH*. Thimphu, Bhutan: Ministry of Education, Royal Government of Bhutan.

Nordell, K. J., Boatman, E. M., & Lisensky, G. C. (2005). A safer, easier, faster synthesis for CdSe quantum dot Nano crystals. *Journal of Chemical Education*, *82*(11), 1697.

Ornstein, A. (2006). The frequency of hands-on experimentation and student attitudes toward science: A statistically significant relation (2005-51-Ornstein). *Journal of Science Education and Technology*, *15*(3-4), 285–297. doi:10.1007/s10956-006-9015-5

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049–1079. doi:10.1080/0950069032000032199

Pande, S. S., Pande, S. R., Parate, V. R., Nikam, A. P., & Agrekar, S. H. (2013). Correlation between difficulty and discrimination indices of MCQs in formative exam in physiology. *South East Asian Journal of Medical Education*, *7*, 45–50.

Paul A. Webb. (2000). *A primer on particle sizing by static laser light scattering*. Retrieved from http://www.particletesting.com/Repository/Files/A_Primer_on_Particle_Sizing_by_Static_Laser_Light_Scattering.pdf

Pecina, M. A., Smith, C. A., Johnson, K., & Snetsinger, P. (1999). A classroom demonstration of Rayleigh light scattering in optically active and inactive systems. *Journal of Chemical Education*, *76*(9), 1230.

Peker, D., & Wallace, C. S. (2011). Characterizing high school students' written explanations in biology laboratories. *Research in Science Education*, *41*(2), 169–191. doi:10.1007/s11165-009-9151-z

Petruševski, V. M., Monković, M., & Ivanovski, V. (2006). Laser pointers–a tool for better lecture experiments. *Journal of Turkish Science Education*, *3*, 43–51.

Philip Ball. (1994). *Designing the molecular world*. USA: Princeton University Press.

Piaget, J. (1977). *The development of thought: Equilibration of cognitive structures*. Oxford, England: Viking.

Pitafi, A. I., & Farooq, M. (2012). Measurement of scientific attitude of secondary school students in Pakistan. *Academic Research International*, *2*(2), 379–392.

Prilliman, S. G. (2012). An inquiry-based density laboratory for teaching experimental error. *Journal of Chemical Education*, *89*(10), 1305–1307. doi:10.1021/ed2006339

Purtadi, S., & Sari, R. L. P. (2007). *Using structured clock reaction demonstration to assess students understanding of solution and colloid concepts*. Retrieved from http://staff.uny.ac.id/sites/default/files/penelitian/Rr.%20Lis%20Permana%20Sari,%20Dra.%20M.Si./USING%20STRUCTURED%20CLOCK%20REACTION%20DEMONSTRATION.pdf

Hassan, P.A., Rana, S., & Verma, G. (2014). Making sense of Brownian motion: Colloid characterization by dynamic light scattering. *Langmuir*, 140731115652001. doi:10.1021/la501789z

Roduner, E. (2006). Size matters: Why nanomaterials are different. *Chemical Society Reviews*, *35*(7), 583. doi:10.1039/b502142c

Rovinelli, R. J., & Hambleton, R. K. (1976). *On the Use of Content Specialists in the Assessment of Criterion-Referenced Test Item Validity*. Retrieved from http://eric.ed.gov/?id=ED121845

Royal Education Council. (2012). *National Education Framework (NEF): Shaping Bhutan's Future*. Retrieved from http://www.ibe.unesco.org/curricula/bhutan/bt_alfw_2012_eng.pdf

Rushton, G. T., Lotter, C., & Singer, J. (2011). Chemistry teachers' emerging expertise in inquiry teaching: The effect of a professional development model on beliefs and practice. *Journal of Science Teacher Education*, *22*(1), 23–52. doi:10.1007/s10972-010-9224-x

Sabri, S. (2013). Item analysis of student comprehensive test for research in teaching beginner string ensemble using model based teaching among music students in public universities. *International Journal of Education and Research*, *1*(12), 14.

Satterthwait, D. (2010). Why are hands-on science activities so effective for student learning? *Teaching Science*, *56*(2), 7–10.

Schurmeier, K. D., Atwood, C. H., Shepler, C. G., & Lautenschlager, G. J. (2010). Using item response theory to assess changes in student performance based on changes in question wording. *Journal of Chemical Education*, *87*(11), 1268–1272. doi:10.1021/ed100422c

Scott, P., & Pentecost, T. C. (2014). *From Verification to Guided-Inquiry: What Happens When A Chemistry Laboratory Curriculum Changes?* Retrieved from http://scholarworks.gvsu.edu/theses/732/

Sesli, E., & Kara, Y. (2012). Development and application of a two-tier multiple-choice diagnostic test for high school students' understanding of cell division and reproduction. *Journal of Biological Education*, *46*(4), 214–225. doi:10.1080/00219266.2012.688849

Shamsudin, N. M., Abdullah, N., & Yaamat, N. (2013). Strategies of teaching science using an inquiry based science education (IBSE) by novice chemistry teachers. *Procedia - Social and Behavioral Sciences*, *90*, 583–592. doi:10.1016/j.sbspro.2013.07.129

Sia, D. T., Treagust, D. F., & Chandrasegaran, A. L. (2012). High school students' proficiency and confidence levels in displaying their understanding of basic electrolysis concepts. *International Journal of Science and Mathematics Education*, *10*(6), 1325–1345.

Sirokman, G. (2014). Synthesis, dehydration, and rehydration of calcium sulfate (gypsum, Plaster of Paris). *Journal of Chemical Education*, *91*(4), 557–559. doi:10.1021/ed400004b

Southam, D. C., Shand, B., Buntine, M. A., Kable, S. H., Read, J. R., & Morris, J. C. (2013). The timing of an experiment in the laboratory program is crucial for the student laboratory experience: Acylation of Ferrocene as a case study. *Chemistry Education Research and Practice*, *14*(4), 476. doi:10.1039/c3rp00011g

Seager, S.L., & Slabaugh, M.R. (2004). *Introductory chemistry for today* (Fifth edition). USA: Thomson Brooks/Cole.

Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice*, *14*(2), 156. doi.org/10.1039/c3rp00012e

Tanamatayarat, J., Arayathanitkul, K., Emarat, N., Chitaree, R., & Sujarittham, T. (2012). Surveying Thai freshmen science students' background knowledge of basic properties of laser beam. *Lat. Am. J. Phys. Educ. Vol*, *6*(2), 177.

Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2002). Development and application of a two-tier multiple choice diagnostic instrument to assess high school students' understanding of inorganic chemistry qualitative analysis. *Journal of Research in Science Teaching*, *39*(4), 283–301. doi.org/10.1002/tea.10023

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53–55. doi:org/10.5116/ijme.4dfb.8dfd

Temel, S., Özgür, S. D., & Yılmaz, A. (2012). The effect of different types of test on preservice chemistry teachers' achievement related to" chemical bonding.". *Problems of Education in the 21st Century*, *45,* 123–129.

Todebush, P. M., & Geiger, F. M. (2005). Sedimentation time measurements of soil particles by light scattering and determination of chromium, lead, and iron in soil samples via ICP. *Journal of Chemical Education*, *82*(10), 1542.

Toplis, R., & Allen, M. (2012). "I do and I understand?" Practical work and laboratory use in United Kingdom schools. *Eurasia Journal of Mathematics, Science & Technology Education*, *8*(1), 3–9.

Tosun, C., & Taskesenligil, Y. (2013). The effect of problem-based learning on undergraduate students' learning about solutions and their physical properties and scientific processing skills. *Chemistry Education. Research and Practice*, *14*(1), 36–50. doi:10.1039/C2RP20060K

Türk, F., Ayas, A., & Karslı, F. (2010). Effectiveness of analogy technique on students' achievement in general chemistry laboratory. *Procedia - Social and Behavioral Sciences*, *2*(2), 2717–2721. doi:10.1016/j.sbspro.2010.03.402

Turner, R. C., & Carlson, L. (2003). Indexes of Item-Objective Congruence for multidimensional items. *International Journal of Testing*, *3*(2), 163–171.

Tüysüz, C. (2009). Development of two-tier diagnostic instrument and assess students' understanding in chemistry. *Scientific Research and Essay*, *4*(6), 626–631.

Ultanir, E. (2012). An epistemological glance at the constructivist approach: Constructivist learning in Dewey, Piaget, and Montessori. *Online Submission*, *5*(2), 195–212.

Van Compernolle, R. A., & Williams, L. (2013). Sociocultural theory and second language pedagogy. *Language Teaching Research*, *17*(3), 277–281.

VanDorn, D., Ravalli, M. T., Small, M. M., Hillery, B., & Andreescu, S. (2011). Adsorption of arsenic by iron oxide nanoparticles: A versatile, inquiry-based laboratory for a high school or college science course. *Journal of Chemical Education*, *88*(8), 1119–1122. doi:10.1021/ed100010c

Vygotsky, L.S. (1978). *Mind in society: The Development of Higher Psychological Processes.* Cambridge, MA: Harvard University Press.

Walker, J. P., & Sampson, V. (2013). Learning to argue and arguing to learn: Argument-driven inquiry as a way to help undergraduate chemistry students learn how to construct arguments and engage in argumentation during a laboratory course. *Journal of Research in Science Teaching*, *50*(5), 561–596. doi:10.1002/tea.21082

Wallace, C. S., & Kang, N.-H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. *Journal of Research in Science Teaching*, *41*(9), 936–960. doi:10.1002/tea.20032

Wang, J.-R., Wang, Y.-C., Tai, H.-J., & Chen, W.-J. (2010). Investigating the effectiveness of inquiry-based instruction on students with different prior knowledge and reading abilities. *International Journal of Science and Mathematics Education*, *8*(5), 801–820.

Wen-jin, K., Chia-ju, L., & Shi-an, L. (2012). Promoting female students' learning motivation towards science by exercising hands-on activities. *Online Submission*. Retrieved from http://eric.ed.gov/?id=ED535489

Winter, D., Lemons, P., Bookman, J., & Hoese, W. (2012). Novice instructors and student-centered instruction: identifying and addressing obstacles to learning in the college science. *Journal of the Scholarship of Teaching and Learning*, *2*(1), 14–42.

Wolf, S. J., & Fraser, B. J. (2008). Learning environment, attitudes and achievement among middle-school science students using inquiry-based laboratory activities. *Research in Science Education*, *38*(3), 321–341. doi:10.1007/s11165-007-9052-y

Xu, H., & Talanquer, V. (2013). Effect of the level of inquiry on student interactions in chemistry laboratories. *Journal of Chemical Education*, *90*(1), 29–36. doi:10.1021/ed3002946

Yadigaroglu, M., & Demircioglu, G. (2012). The effect of activities based on 5e model on grade 10 students' understanding of the gas concept. *Procedia - Social and Behavioral Sciences*, *47*, 634–637. doi:10.1016/j.sbspro.2012.06.709

APPENDICES

APPENDIX A

COLLOIDAL ACHIEVEMENT TEST

Construct	Objective	Question Number
Types of dispersion system	Distinguish between the properties of suspension, colloids and a solution (true solution)	Q1, Q2, Q3, Q4, Q5, Q6, Q7 & Q8
Types of colloidal system	Compare different types of colloids based on dispersed phase and dispersed medium	Q9, Q10 & Q11,
Preparation of colloids	Prepare colloids using dispersion and condensation method through preparation of silica sol-gel by relating to scattering of light and size of particles.	Q12, Q13, Q14 & Q15
Effect of particle size	Relate, the relationship with the size of the particles, wavelength of light and scattering of light by particles in natural phenomenon.	Q16, Q17, Q18, Q19 & Q20

- ➢ The questions are randomly mixed before distributing to students during pre-test.
- ➢ The questions are again randomly mixed during posttest.

Please provide your information in the following parts by tick marking [√] in the box provided.
CODE: ………….. **Gender**: ☐ Male ☐ Female
Age: ☐ < 16 ☐ 17 ☐ 18 ☐ 19 ☐ > 20

Direction:

This assessment consists of 20 questions that examine your knowledge of colloids with size of the particles and scattering of light. Each question has two parts: a multiple-choice conceptual part followed a multiple-choice reasoning part. Please circle one answer from both the response and reason sections of each question. The questions contain total score of 20 marks, each question carrying one mark. You must answer both the parts in a question to obtain one mark.

1. What is the property of a suspension that is different from that of a solution or colloid?
   1. Particles of suspension cannot scatter light
   2. Suspension are colorless
   3. Suspension are transparent
   4. Most of the particles of a suspension will settle out if left to rest.

The reason for your answer is
   a. The Size of the suspension particles is large and most of the particles settle down.
   b. The Size of the suspension particles is small and homogenous.
   c. The Size of the suspension particles is in a range to scatter light.
   d. The Size of the suspension particles is heterogeneous.

2. The main difference between solution, colloids and suspension is that of

1. Particle concentration
2. Particle composition
3. Particle electrical conductivity
4. Particle size

The reason for your answer is

a. They can be differentiated by their filterability property.
b. They are either homogeneous or heterogeneous.
c. They are either heavy or light.
d. They are either positively charged or negatively charged.

3. Each mixture below has particles dispersed in water. Which list has particles, increasing in size?

1. Salt + water 2. Sand + water 3. Starch + water

1. 1 < 2 < 3
2. 2 < 3 <1
3. 3 < 2 < 1
4. 1 < 3 <2

The reason for your answer is

a. (1 = colloids) (2 = suspension) & (3 = true solution)
b. (1 = colloids) (2 = true solution) & (3 = suspension)
c. (1 = suspension) (2 = colloids) & (3 = true solution)
d. (1 = true solution) (2 = suspension) & (3 = colloids)

4. What happened when a laser is pointed towards the milk powder solution?

1. Observes particles in zigzag motion (Brownian motion)
2. Observes the trace of light beam through the solution (Tyndall effect)
3. Observes attraction of molecules and ions dissolved on their surface (Adsorption)
4. The Precipitate is formed (Coagulation)

The reason for your answer is

a. Due to movement of the particles
b. Due to opposite charge of the particles
c. Due to repulsion of particles
d. Due to scattering of light

5. The Milk powder solution can be separated by using

1. Chromatography paper
2. Filter paper
3. Semi-permeable membrane
4. All of the above

The reason for your answer is

a. The size of particles is smaller than the pore size of the semi-permeable membrane
b. The size of particles is bigger than the pore size of the semi-permeable membrane
c. The size of particles is equal to the pore size of the semi-permeable membrane
d. The size of particles has some interaction force between particles and the semi-permeable membrane

6. Which one of the following exhibit the Tyndall effect?

1. Colloids
2. Solution
3. Suspension
4. Both colloids and suspension

The reason for your answer is

a. The size of the particles is more than 1nm so scattering can occur
b. The size of particles is less than 1nm so scattering can occur
c. The size of particles is 1nm so scattering can occur
d. The size of particles is very large, so scattering can occur

7. An unknown sample scatters light and is separated through filter paper. The sample is likely to be a

1. Colloids
2. Solution
3. Suspension
4. Both colloids and suspension

The reason for your answer is

a. The size of particles is Less than 1nm
b. The size of particles is Between 1-1000nm
c. The size of particles is Between 100-1000 nm
d. The size of particles is more than 1000 nm

8. Which of the following represents a correct set of observation for colloids?

	Tyndall effect	*Transparency*	*Precipitation*
1.	Yes	Transparent	Precipitate
2.	Yes	Translucent	Precipitate
3.	Yes	Transparent	Precipitate on long standing
4.	Yes	Translucent	Precipitate on long standing

The reason for your answer is

a. The particles in a colloidal dispersion are intermediate between the true solution and suspension so to exhibit the above observations.
b. The particles in a colloidal dispersion are larger than suspension so to exhibit above observations
c. The particles in a colloidal dispersion are smaller than true solution so to exhibit above observations
d. Particles in a colloidal dispersion are smaller than true solution and some larger than suspensions so to exhibit the above observations

9. What kind of colloids do you think our cloud is?

1. Aerosol
2. Gel
3. Foam
4. Sol

The reason for your answer is

a. Dispersed phase is the gas and dispersed medium is liquid
b. Dispersed phase is liquid and dispersed medium is liquid
c. Dispersed phase is liquid and dispersed medium is gas
d. Dispersed phase is solid and dispersed medium is liquid

10. Milk is a colloid in which a

1. Liquid is dispersed in liquid
2. Liquid is dispersed in solid
3. Solid is dispersed in liquid
4. Solid is dispersed in gas

The reason for your answer is

a. Milk contains less of water and more of proteins and fats which are in liquid form.
b. Milk contains more of water and less of proteins and fats which are in liquid form.
c. Milk contains less of water and more of proteins and fats which are in solid form.
d. Milk contains more of water and less of proteins and fats which are in solid form.

11. Which of the following example of colloids is not correctly matched with different types of colloids?

1. Butter – Gel
2. Milk – Emulsion
3. Smoke – Foam
4. Starch solution – Sol

The reason for your answer is

a. Dispersed phase is the gas and dispersed medium is solid.
b. Dispersed phase is liquid and dispersed medium is solid.
c. Dispersed phase is solid and dispersed medium is gas.
d. Dispersed phase is solid and dispersed medium is liquid.

12. What happen to the turbidity (clarity) and intensity of scattered light when an acid is added to sodium silicate solution?

1. Both turbidity and intensity of scattering increases
2. Both turbidity and intensity of scattering decreases
3. Turbidity decreases, but the intensity of scattered light increases
4. Turbidity increases, but the intensity of scattered light decreases

The reason for your answer is

a. The Acid causes the particle size to decrease due to breaking down of particles.
b. The Acid causes the particle size to increase due to aggregation of particles.
c. The Acid causes the particle size to decrease and then increase due to breaking down and aggregation of particles respectively.
d. The Acid causes the particle size to increase and then decrease due to aggregation and breaking down of particles respectively.

13. During sol-gel preparation, the addition of sodium hydroxide solution to silica sol results in

1. Decrease in the intensity of scattering of particles by laser beam
2. First the intensity of scattering of particles increases, then it decreases
3. First the intensity of scattering of particles decreases, then it increases
4. Increase in the intensity of scattering of particles by laser beam.

The reason for your answer is

a) Condensation of sodium silicate so more scattering of particles.
b) Condensation of sodium silicate so less scattering of particles.
c) Dispersion of sodium silicate so more scattering of particles.
d) Dispersion of sodium silicate so less scattering of particles

14. The silica sol in the colloids is prepared by the process

1. Both dispersion and condensation
2. Condensation method
3. Dispersion method
4. Neither condensation nor dispersion

The reason for your answer is

a. The small silica particles of sodium silicate solution are converted into larger particles.
b. The larger silica particles of sodium silicate solution are converted into smaller particles.
c. The size silica particles of sodium silicate solution remain same.
d. The silica particles of sodium silicate solution decrease in size, then increases or vice versa.

15. The increase in intensity of light from a laser pointer during gel formation indicates

1. To both increase and decrease in size of particles
2. Decrease in size of particles
3. Increase in size of particles
4. The Size of the particles remains same.

The reason for your answer is

a. Silica particles combine together to form large networks of particles due to condensation
b. Silica particles disintegrate into small particles due to condensation
c. Silica particles combine together to form large networks of particles due to condensation and dispersion simultaneously
d. Neither condensation nor dispersion occurs

16. The sky is blue during the daytime because

1. More scattering of blue light and also color perceived by our eyes
2. Less scattering of blue light and also color perceived by our eyes
3. Due to more scattering of blue light
4. Due to less scattering of blue light

The reason for your answer is

a. Longer wavelength = more scattering of particles
b. Longer wavelength = less scattering of particles
c. Shorter wavelength = more scattering of particles
d. Shorter wavelength = less scattering of particles

17. The sky is yellowish to reddish orange during the sunrise and sunset because of

a. The atmosphere is humid during sunset and sunrise
b. The intensity of light from the sun is maximum during sunset and sunrise
c. Mostly the light with longer wavelengths reaches us as the light from the sun has to pass a long distance
d. The sun is reddish orange in color

The reason for your answer is due to

1. Less scattering of red light

2. More scattering of red light
3. Light with longer wavelength are scattered more over the great distance, leaving shorter wavelength of light in the visible spectrum
4. Light with shorter wavelength are scattered more over the great distance, leaving longer wavelength of light in the visible spectrum

18. Though the sky is blue during the clear day and reddish orange during sunset and sunrise yet the clouds are white or dark gray and not blue or reddish orange. Why?

1. The water droplets in the cloud are very small to scatter light.
2. The water droplets in the cloud are very large to scatter light.
3. The water droplets in the cloud scatter all the color of the light.
4. The water droplets in the cloud do not scatter light.

The reason for your answer is

a. The Size of the water droplets in the cloud is big, so, it becomes independent of the wavelength of light.
b. The Size of the water droplets in the cloud is big, so, it becomes completely dependent on the wavelength of light
c. The Size of the water droplets in the cloud is big, so, it becomes partially dependent on the wavelength of light
d. The Size of the water droplets in the cloud is big, so, it becomes partially independent of the wavelength of light

19. Which wavelength of light has the ability to scatter more light?

1. Green light
2. Red light
3. Blue
4. All have the same ability

The reason for your answer is

a. Has equal wavelength hence more scattering
b. Has longer wavelength hence more scattering.
c. Has shorter wavelength hence more scattering.
d. Has all the wavelength of light, hence more scattering

20. The intensity of scattered light depends on

1. Both sizes of the particles and the wavelength of the light
2. Neither on the sizes of the particles nor on the wavelength of light.
3. Size of the particles
4. Wavelength of the light

The reason for your answer is

a. Intensity of scattering is directly proportional to the size of the particles and the wavelength of the light.
b. Intensity of scattering is inversely proportional to the size of the particles and the wavelength of the light.
c. Intensity of scattering is directly proportional to the size of the particles, but inversely proportional to the wavelength of the light.
d. Intensity of scattering is inversely proportional to the size of the particles, but directly proportional to the wavelength of the light.

APPENDIX B

LEARNING UNIT PERCEPTION QUESTIONNAIRE

Construct	**Description**	**Item**
Perception towards Interest in science class activities	To check the students perception towards the activities in the class	1-10
Perception towards the concept in science class activities	To see students view of concept with the activities in the class	11-14
Perception towards Learning environment in the class	To see students' preference of cooperative work while doing activities.	15-18
Perception towards Instructor	To see the students' view of the instructors' role in the activities	19-22

1. Please provide your information in the following parts by tick marking [√] in the box provided.

Code:…………………… **Gender**: ☐ Male ☐ Female

Age: ☐ < 16 ☐ 17 ☐ 18 ☐ 19 ☐ > 20

2. Please tick the most appropriate option

Direction: There are 25 statements. Tick one of the scales in each statement that best describes your opinion on activities in learning unit. Try not to think too deeply about each response; there are no correct or incorrect answers. Please respond to all of the statements.

Items	S A (5)	A (4)	ND (3)	D (2)	SD (1)
1. The activities were interesting.					
2. Doing activity made me uncomfortable					
3. I learn better when I work through the activities.					
4. The activities motivated me to learn					
5. The activities made me curious					
6. I think that teaching something related to the activities to my group mates is a waste of time					
7. Learning from the book is much better than doing activities					
8. The activities took too long					
9. I look forward to learn from such kind of activities in the future					
10. I prefer learning from other approaches than such learning activities.					
11. I learned to differentiate different types of mixtures through learning activities					
12. Activities made it easier to understand the effect of particle size in different solutions.					
13. Activities made it easier to understand the effect of particles size and wavelength of light					
14. Activities made me realize the importance of role played by particle size.					
15. I feel better myself when I contribute more to the activities in my group.					
16. Doing Activities in group encouraged me to think well					
17. The questions asked by the teacher helped me to clear my doubt					
18. I don’t like to work in groups					

Items	S A (5)	A (4)	ND (3)	D (2)	SD (1)
19. The teacher was enthusiastic in teaching the topic					
20. The teacher was friendly					
21. The teacher was well prepared and organized					
22. I feel free to tell the teacher about anything that stop me from learning					

SA= Strongly Agree, A= Agree, ND = Neither Agree Nor Disagree**,** DA=Disagree, SD Strongly Disagree

Open- ended Questions

23. What did you learn in overall from the activities in the learning unit?

…………………………………………………………………………………………

24. What did you think you want to learn more about the activities in the learning unit?

…………………………………………………………………………………………

25. Any Comments or Suggestions

…………………………………………………………………………………………

…………………………………………………………………………………………

APPENDIX C
REFLECTION

Please provide your information in the following parts by tick marking [√] in the box provided.

Code:………… **Time: 15 mins**

Gender: ☐ Male ☐ Female

Age: ☐ < 16 ☐ 17 ☐ 18 ☐ 19 ☐ > 20

Direction:

There are two parts of writing your reflection. The first part is about the topic of the lesson and the second part is about the whole lesson that you have learned. The following structure will help you to start with but not necessary to follow. So please feel free to genuinely express yourself.

Topic: ___________________

1. I have learned…
2. I can…
3. I am good at…
4. I haven’t managed to…
5. I don’t understand…
6. I have difficulty in…

About the lessons

I. I like best…
II. The most interesting thing is…
III. I don’t like…
IV. The most boring thing is…

Any suggestions:

APPENDIX D
SEMI-STRUCTURED INTERVIEW

Objective: To obtain information regarding the students

1. about their understanding of different types of dispersion system.
2. on their understanding of relationship of size of particles with the properties of mixtures.
3. on their understanding of the relationship of the size of the particle and wavelength of light in understanding the natural phenomenon like why the sky is blue?
4. on their perception towards the developed learning unit.

Interview Questions

1) Please tell me about yourself?

Prompt: Name, favorite subject, hobbies and so on.

Conceptual Part

2) Explain your understanding of true solution, suspension and colloids?

Prompt: *state the differences in their properties? *Why do you think so?

3) What is the main reason behind the different properties of these mixtures?

Prompt: * try to conclude from the activities. Why suspensions settle down? Why true solution cannot be separated by semi-permeable membrane?

4) What is Tyndall effect?

Prompt: *how does it happen? Why?

5) Explain different types of colloids?

6) Explain your understanding of the preparation of colloids?

Prompt: * what processes are involved? How did you prepare silica sol and silica gel?

7) Explain your understanding of the relationship of the size of the particles with a scattering of light?

Prompt: * Compare the scattering of red and green laser? What is the difference between these two lasers?

8) Why do think our sky is blue?

Prompt: * Why is the sky during sunset and sunrise reddish yellow? Why the cloud is white?

9) Explain the relationship of the above phenomenon with colloids, wavelength of light and size of particles?

Prompt: * what is the difference between the size of particles present in the air and size of water particles in clouds?

10) Does the size of the particles play an important role in our lives? How?

Prompt: * Give some examples from your experience or daily life where the size has played an important part.

Perception Part

11) In what way did you learn in the class?

Prompt: * what did you do in the class? Any activities?

12) Does the learning in this class different from other classes? How?

Prompt: * What new things did you do in this class?

13) What challenges did you face from learning in this class?

Prompt: * Did you face any difficulties? How?

14) Are activities in this class interesting? How?

15) What activity did you like the most? Why?

16) Does the teacher support you in learning? How?

Prompt: * how did teacher help you?

17) Would you like to learn in this kind of class? Why?

18) Do you think the class can be improved? Why and How?

Prompt: *how can it be made more interesting? Please suggest the way you can learn better.

19) Overall tell me how did you feel about learning in this class?

Prompt: *Share your feelings like, dislike, interesting, hard,…

20) If you rate this class out of 10 points, what point would you give? Why?

APPENDIX E
LAB REPORT

Group Number: **No. of Students:**

Topic:

"Distinguish between three different types of mixtures (sand + water; sugar + water; milk powder + water)"

Materials:

…………………………………………………..………………………………………

…………………………………………………..………………………………………

Procedures:

…………………………………………………..………………………………………

…………………………………………………..………………………………………

Observation

…………………………………………………..………………………………………

…………………………………………………..………………………………………

Results

…………………………………………………..………………………………………

Discussion and Conclusion

…………………………………………………..………………………………………

…………………………………………………..………………………………………

…………………………………………………..………………………………………

…………………………………………………..………………………………………

APPENDIX F
WORKSHEET

Group No:

Properties		**Sand + water**	**Sugar + water**	**Milk Powder + water**
Particles settle at bottom(sedimentation)				
Scatter light:	Red laser			
	Green laser			
Can be filtered with filter paper				
Can be filtered with semi-permeable membrane				
Homogenous/heterogeneous				

APPENDIX G
WORKSHEET

CODE: …………..

Conclusion:

1. *Match the following*

Types of solution

Examples

1. Solution (true solution)	a. Salt and water
2. Suspension	b. Milk powder and water
3. Colloidal solution	c. Sand and water

2. What do you think is the fundamental differences between solution, colloidal solution and suspension?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

APPENDIX H
WORKSHEET

Group number: **Total students:**

CODE:

Compare your result

<table>
<tr><th colspan="2"></th><th>Only 20ml sodium silicate</th><th>Addition of 40ml Acid (vinegar)</th><th>Addition of base 0.5M NaOH (10ml)</th></tr>
<tr><td colspan="2">Observation1. (Turbidity)</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Observation 2.
(Scattering)</td><td>Red Laser</td><td></td><td></td><td></td></tr>
<tr><td>Green Laser</td><td></td><td></td><td></td></tr>
</table>

APPENDIX I
WORKSHEET

Group number: **Total students:**

CODE:

A) Demonstration of a colloidal solution by scattering of light using lasers

Light source	**Observation**	**Differences**
Red Laser		
Green Laser		

B) Demonstration on pure distill water by scattering of light using lasers

Light source	**Observation**	**Differences**
Red Laser		
Green Laser		

c) Summarize your findings and understanding from the demonstrations.

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BIOGRAPHY

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