EXPLORATION AND CATEGORIZATION OF PRE-SERVICE PHYSICS TEACHERS' ALTERNATIVE CONCEPTIONS IN SUPERCONDUCTIVITY AND NANOTECHNOLOGY

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Declaration

Student number: 55757952

I declare that an exploration and categorization of pre-service teachers' alternative conceptions of superconductivity and nanotechnology is my own work and that all the sources that I have used are indicated and acknowledged by means of complete references.

SIGNATURE **DATE:** 18TH JANUARY, 2019

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The last expression of appreciation goes to my family: My wife Celestyn, my children Purity, Jeremy, Gloria and Juda. I value their patience, love, sacrifice, encouragement during the entire study and work period. Their happiness is the driving force behind my further studies.

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Acronyms

B.Ed.: Bachelor of Education

B.Sc.: Bachelor of Science

BCS: Bardeen, Cooper and Schrieffer

CNNS: Conceptual Survey of Superconductivity and Nanotechnology

DNA: Deoxyribonucleic acid

GER: Global Educational Report

HEP: High Energy Physics

HTS: High Temperature Superconductors

LTS: Low Temperature Superconductors

MEG: Magnetoencephalography

MER: Model of Educational Reconstructions

MRI: Magnetic Resonance and Imaging

NUST: Nizwa University of Science and Technology

NST: Nanoscience and Technology

PCK: Pedagogical Content Knowledge

SQU: Sultan Qaboos University

SQUID: Superconducting Quantum Interference Device

PSTs: Pre-service Physics Teachers

Abstract

An exploratory case study research design was followed to explore and categorize 23 pre-service physics teachers' understanding in the fields of superconductivity and nanotechnology at the Sultan Qaboos University in Oman. To elicit their responses, a five-stage categorical framework analysis was used. The five stages included identification of the thematic framework, familiarization, coding, placing the categories on a chart and finally, interpretation. A conceptual survey test (Conceptual Survey of Superconductivity and Nanotechnology) was administered to the pre-service physics teachers to form four independently homogenous ability focus groups. This was followed by focus group discussions whose data were analyzed to group their conceptions in both the epistemological as well as ontological categories. From the focus group discussions, six categories were considered from previous studies, namely; lateral alternative conceptions, ontological conceptions, naïve physics, Ohm's p-primes, mixed conceptions and loose ideas. Since this was a pre-instructional study, naïve physics ideas and lateral alternative conceptions were dominant. Naïve physics refers to the untrained student or human perception of various physical phenomena while lateral alternative conception refers the misconceptions individuals have on ideas that may be inconsistent with scientifically acceptable facts. Findings indicate that the pre-service teachers' conceptions deviated from canonical scientific concepts, are diversified and inconsistent. The knowledge on pre-instructional conceptions will influence the development of evidence-based pedagogy, which is fundamental to the development of an effective physics education curriculum.

Key words: superconductivity, nanotechnology, pre-instructional conceptions, focus group discussions.

CHAPTER 1: INTRODUCTION

1.0 Background

From the last quarter of the twentieth century, there has been an international consensus on the need to introduce contemporary physics topics in the high school syllabus (Ostermann & Moreira, 2004; Petri & Niedderer, 1998; Cuppari, Rinaudo, Robutti, and Violino, 1997; Lawrence, 1996; Gil & Solbes, 1993; Fischler & Lichtfieldt, 1992; Jones, 1991; Stannard, 1990). Physics education researchers, high school physics teachers and physicists are those who were at the forefront of this movement (Ostermann & Moreira, 2004). Such an initiative is justified in the sense that there is a need to awaken these young people's curiosity and enlighten them to identify physics as a human innovativeness by making it familiar to them. Ostermann and Moreira (2004) reiterated the benefits of possessing sound scientific knowledge to advance economy and society.

What's more, there is an intense revision of high school curricula to include contemporary physics (Ireson, 2000; Barlow1992; Swinbank1992) as new books have been published as well as other materials prepared on this topic (e.g. Fermi National Laboratory, 2002; Contemporary Physics Education Project, 2002; Ireson; 2000;). Therefore, the inclusion of some new subjects on contemporary physics is proposed in high school curricula to introduce the students to the more recent developments in physics. Contributing to the updating of physics curriculum in Brazilian schools, Ostermann (2000) suggested that in Brazil and other universities around the world, superconductivity as a contemporary physics field has received little attention in terms of research for use in the teaching of high school students. Despite the importance of certain topics in physics such as superconductivity, there is paucity of literature when it comes to the study of superconductivity and how it's taught in schools worldwide (Ostermann & Moreira, 2004). This is because superconductivity has been part of the technological and industrial revolution that has been going on from the beginning of this century and therefore forms a platform to explain to the students some of the potentially motivating applications like magnetic levitation of a superconducting tablet (Ostermann & Moreira, 2004). On the other hand, it is important to note that this topic requires prerequisite knowledge of classical physics especially electromagnetism and thermodynamics as well as basic concepts of quantum physics and solid-state physics that are not taught at the high school level. Thus, superconductivity provides a link between the topics already included in the secondary school curriculum and the ones to be incorporated to update it.

On the other hand, superconductivity is closely linked to nanotechnology, a term used to describe manipulation of materials to the scale of 10^{-9} of a metre to fabricate materials with other properties different from their macroscale properties. For example, the properties of nanotubes are observed to improve conductivity, optical and mechanical properties of carbon (Chico, Crespi, Benedict, Louise & Cohen 1996; Eatemadi et al. 2014).

Whereas several studies have been conducted in these two subjects, superconductivity and nanotechnology, however, when a literature search using Google scholar, JSTOR, springerlink, ERIC, WorldWideScience and Ebsco, no study was identified on pre-service teachers' conceptions on superconductivity and nanotechnology. Thus, there is a gap in research which the findings of this research could address. This research will explore and categorize the pre-service physics teachers' conceptions in two areas of contemporary physics namely, superconductivity and nanotechnology. The study was done with the third year

Bachelor of Education (Physics) students, referred to as *pre-service teachers* at the Sultan Qaboos University in Oman.

Although students come to the classroom with pre-conceptions or mental processes on how the world works and are referred to as pre-instructional or alternative conceptions, such conceptions are described as theory-like ideas (Ioannides &Vosniadou 2002) and are often inconsistent with the sound scientific concepts delivered during instructions. Other researchers (Chi 2008; Chi & Slotta 1993) also describe them as miscalculation of concepts across or within the ontological category while others, (diSessa 1993; diSessa et al. 2004) call them fragmented knowledge 'pieces'. The differences in the definition of either theory-like ideas or miscalculations of concepts arises because of the antagonizing perspectives on pre-instructional conceptions namely; epistemological and ontological perspectives (Dega, Kriek & Mogese 2012; Treagust & Duit 2008).

While ontological perspective views the alternative conceptions as the incorrect categorization of scientific concepts (e.g. Duschi & Gitomer 1991, Posner et al. 1982), the epistemological perspectives view the same as theory-like and inconsistent pieces of ideas (Chi Slotta & deLeeuw 1994; Chi 2008). So far, researches on epistemological perspectives on conceptual change are dominating over the researches on ontological perspectives (Kivunja & Kuyini 2017).

Whereas there were two earlier perspectives on pre-instructional conceptions namely theory-like ideas and misclassification of ontological concepts, Gardner and Brown (2013) adds the third perspective - misconception. He further describes misconceptions as regular things and unitary entities that exist in the mind and gives some examples that are familiar to the physics teachers like; “molecules expand when heated”, “a bowling ball of a larger mass exerts more force on a smaller pin during collision”, and “mass is not conserved during the burning process” (Brown, 2013 pp. 1467). Therefore, these misconceptions, when viewed as wrong chunks of conceptual knowledge that are wrong need to be replaced by sound and accepted scientific conceptual knowledge (Brown 2013).

1.1 Study context

In Oman, (a country bordering Saudi Arabia, United Arab Emirates and Yemen) the students are admitted to institutions of higher learning after attaining a high school diploma at grade 12. Accordingly, the admission criteria for all the public universities in the country follows a cut-off system which depends on the number of students’ spaces that are available in each faculty. The students are admitted to a course, based on their choices and the subject cluster aggregate performance. For example, to qualify for Bachelor’s degree in Physics Education, the subjects’ clusters include English, mathematics, physics and social studies in which the percentage average score is set for qualification into the degree. This is the second criteria after the student has qualified for the university admission (cut-off mean grade which is calculated from the average of all the subjects done in high school diploma). This is done across the board for all the seven public universities, Sultan Qaboos, being one of them. This activity is a sole responsibility of the Ministry of Education.

Consequently, at the Sultan Qaboos University, the pre-service teachers undergo a four-year undergraduate training programme in which some units run parallel to the BSc. Physics, another four-year course which prepares prospective future physicists. The pre-service teachers who successfully complete this course should be ready to teach the high school students between the ages of 14 to 17 who are studying in their last four years of secondary education. The department of physics, offers physics units for both the B.Ed. (Physics) and B.Sc. students. However, the pre-service teachers do additional pedagogical courses from the faculty of education so, they share core physics units and some electives with the BSc students. It is expected of the pre-service physics teachers to do a supervised teaching practice in the last semester of their final year in one of the bilingual high schools.

Superconductivity, a unit in solid state physics forms part of the curriculum offered by the department of physics but forms part of the B.Ed. (physics) degree in the universities in Oman. Solid state physics is part of the third-year physics curriculum and considered a core unit. This study focusses on the 3rd year pre-service physics teachers who are enrolled in physics modules such as; classical physics II, quantum mechanics, nuclear and particle physics, mathematical methods of Physics II, thermal physics, practical physics III and condensed matter and other units. Superconductivity and nanotechnology form part of the condensed matter module which is part of the solid-state core unit. This particular module has practical sessions on levitating magnets to demonstrate superconductivity. The students take this unit after the completion of units in classical physics I, quantum physics, and nuclear physics. Therefore, conceptions such as electron flow, kinetic energy and resistance has been dealt with prior to solid state physics instruction.

1.2 Problem Statement

There is a drive to be exposed to recent developments in science (Laherto 2012), and the best way to start is to introduce it into the school curriculum (Michelini & Viola 2011). The introduction into developments such as superconductivity and nanotechnology is therefore a good start. However, the teachers who need to be teaching these concepts perhaps have alternative conceptions not necessarily compatible with the scientific views. Alternative conceptions, which are not aligned with the scientific views, can be a hindrance to the effective instruction in superconductivity and nanotechnology. Research is therefore needed to explore and categorize pre-service physics teachers' conceptions in the areas of superconductivity and nanotechnology in order to facilitate the effective teaching and learning of physics at school level.

1.3 Rationale of the Study

The approach to the learning and teaching of physics need improvement in both high schools and universities in Oman and the world at large. The training of teachers, also regarded as pre-service teachers, not only has to address the development of conceptual understanding of their subject matter knowledge but also be able to transfer their understanding to everyday life experiences. Therefore, it is the concern of the Sultan Qaboos University to address pre-service physics teachers' alternative conceptions to enable them to be effective teachers in high schools. This problem, if not addressed, will result into a detrimental effect on physics education in the whole of Oman.

Furthermore, the investigation into pre-service physics teachers' conceptions will influence curriculum designers to design a curriculum to assist physics educationists improve the teaching of physics especially contemporary physics units like superconductivity and nanotechnology (Duit, Gropengießer & Kattmann 2005).

Therefore, this dissertation seeks to explore pre-service teachers understanding of superconductivity and nanotechnology in order to address their alternative conceptions. By categorizing their alternative conceptions and offering suggestions, a curriculum can be developed to specifically address these misconceptions.

1.4 Significance of the study

The findings of this research will play a very beneficial role to the universities and high schools because of the improvement in teaching, considering the leading roles superconductivity plays in industrialisation since the beginning of this century. The greater demand for the nanoscientists and nanotechnologists as well as solid-state superconductivity researchers with sound physics background justifies the need for learners who have a complete understanding of physics concepts. Furthermore, the In-Service Educational Trainers (INSETs) will be guided on what categories of alternative conceptions the pre-service physics teachers possess and possibly suggest what framework to apply for effective instruction. For the researchers, this study will help to reveal critical areas in pre-service physics teachers that have not been explored by previous researchers.

1.5 Objectives and Research Questions

The main objective of this study is to explore and categorise undergraduate pre-service physics teachers' alternative conceptions in superconductivity and nanotechnology. Therefore, the study seeks to answer the following research questions:

1. How do pre-service physics teachers depict basic concepts of superconductivity and nanotechnology?

2. What are the differences (if any) of pre-service teachers' depictions when compared to what is scientifically accepted conceptions of superconductivity and nanotechnology?

3. How extensive are categories of the pre-service physics teachers' alternative conceptions?

4. How consistent/inconsistent are the pre-service teachers' alternative conceptions in the categories that exist?

1.6 Operational Definitions of Key Terms

Classical mechanics: The branch of physics that deals with the motion of objects based on Newton's laws of motion.

Quantum mechanics: The branch of mechanics, based on the quantum theory used for interpreting the behaviour of elementary particles and atoms, which do not obey Newtonian mechanics.

Superconductivity: The flow of current through a conductor without any resistance. This happens in alloys and metals at near absolute zero temperature.

Critical temperature: The lowest temperature at which a material becomes a superconductor.

Type I Superconductors: These are materials which become superconducting at near absolute zero temperature.

Type II Superconductors: The materials which become superconducting at higher temperatures far from absolute zero but below ambient temperatures.

Diamagnetism: This is the creating of a magnetic field which opposes external magnetic field.

Nanotechnology: The name given to new methods of exploring and manipulating the molecular behaviour and physical shape of matter down to the atomic and molecular level.

Pre-service teacher: Bachelor of education student training to become a teacher.

Perspectives of pre-service teachers' conceptions: Classification of pre-instructional conceptions into two categories; ontological and epistemological.

Conceptions: The mental formations of a learner on how the world works.

Model of Educational Reconstructions: A model which integrates both the learners' and the science instructors' perspectives to design a suitable learning environment.

1.7 Limitation of the Study

The study analyzes data from the Focus Group Discussions (FGD), which was obtained from the pre-service physics teachers' responses to the open-ended questions. This implies that the students were interacting and there were some changes in conceptions due to group dynamics. Consequently, there were some pre-service physics teachers whose views might have been overlooked thus slightly descriptively interfering with the study. Therefore, for a more usefulness of this study on pre-service teachers' conceptions on superconductivity and nanotechnology concepts, a study that investigates the individual alternative conceptions is recommended for further studies.

Finally, the study was only done in one University in Oman and therefore the findings cannot be generalized. This research should be extended to students majoring in physics in order to explore and categorize their conceptions in context of superconductivity and nanotechnology.

1.8 Overview of chapters

In this study, chapter one discusses the case of exploring and categorising undergraduate pre-service physics teachers' alternative conceptions in superconductivity and nanotechnology. The background of the study, rationale, problem statement, study context, significance of the study and research questions were offered.

Additionally, chapter two deals with the overview of superconductivity and nanotechnology as well as the literature review of the past studies on conceptions in physics is discussed. Also, in the same chapter, quantum mechanics is discussed as well as the importance of superconductivity and nanotechnology in the curriculum. In addition, the theoretical framework and teaching superconductivity and nanotechnology globally are also discussed. In chapter three, the methodology is discussed while chapter four presents the results, which is followed by discussions in chapter five. The appendix includes the ethical clearance from the University of South Africa (UNISA), the similarity index of the dissertation from Turnitin, language editor’s certificate, an excerpt from the Focus Group Discussion, Non-verbal cues and the research instruments.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

Sound knowledge concerning superconductivity and nanotechnology are certainly not within a layperson's domain but is a concern to a physics educationist. Therefore, definitions of what is superconductivity and nanotechnology (see section 2.1.1 and 2.2.1), the importance of superconductivity and nanotechnology in everyday life (see sections 2.1.2 and 2.2.2) and in the curriculum (see section 2.1.3 and 2.2.3) are discussed. The theoretical framework for the study is presented (see section 2.5).

2.1 Superconductivity

2.1.1 What is superconductivity

Superconductivity refers to a quantum mechanical phenomenon in which current is transported at zero electrical resistance (Michelini, Santi & Stephanel, 2014). Consequently, when a material attains a superconducting state, heat and sound energies cease to exist. Additionally, most materials attain superconductivity at temperatures closer to the absolute zero. On the other hand, when a superconductor is subjected to high transport current or magnetic field, the resistive state is restored. On the contrary, some metals which are known to be good conductors at ambient temperature do not usually attain superconducting state but some alloys which are least expected, attain the state.

Despite superconductivity being a quantum-mechanical phenomenon, many investigators posit that the properties of superconductors namely; expulsion of magnetic flux and zero resistance can be explained from a classical physics perspective, that is, "they are perfect conductors" (Essen and Fiolhais, 2012). In particular, the researchers showed, from the work of de Gennes

(1999) the Meissner effect, which excludes magnetic flux inside a superconductor (B = 0), can be derived from the Maxwell's equations when the resistance is zero (R = 0) inside the superconductor (Essen & Fiolhais 2012).

At the same time, these researchers stressed on the possibility of the derivation of the London equations, anchored in the BCS theory, from classical electromagnetism (Michelini, Santi & Stephanel, 2014).

In addition, when Peña-Roche and Badía-Majós (2016) were trying to understand levitation of magnets on top of a superconductor, explained the Meissner effect in terms of electromagnetic energy, thermodynamic reversibility and irreversibility, Lenz and Faraday's laws of electromagnetic induction (Michelini, Santi & Stephanel, 2014). However, the attempt to explain how the resistance can be zero inside a superconductor requires understanding of quantum mechanics. The other concept of superconductivity is the high temperature superconductors, which refers to those conductors which were discovered in the mid-1980s which could conduct at higher critical temperatures than that of mercury (about 4 K) (Essen & Fiolhais 2012).

The basic phenomena of superconductivity include perfect diamagnetism, high temperature superconductors, second quantization, the Bardeen Cooper Schrieffer Theory, Meisner effect and Josephson's effect.

Perfect diamagnetism means that a superconductor does not allow external magnetic field to reach its interiors. This usually takes place at a temperature which depends on the material – critical temperature (Osborne, 1951). At this temperature, no form of energy exists in the form of heat or sound (Winkler 2003). Perfect diamagnetism refers to the expulsion of magnetic field inside a superconductor when a critical temperature of such a superconducting material is reached (de Gennes 1999; Essen & Fiolhais 2012).

High temperature superconductors on the other hand refer to materials that behave like superconductors at unusually elevated temperatures (Fogarty 2004).

Second quantization refers to a formulism that is employed in both the analysis and description of quantum many-body system (Van Ngu et al., 2015).

Bardeen Cooper Schrieffer (BCS) Theory on the other hand refers to one of the pioneering theories of superconductivity that effectively describes the concept of superconductivity as a microscopic effect that is necessitated by a condensation of Cooper pairs into a state that is boson-like. BCS is also used within the context of nuclear physics as a description of the pairing interaction witnessed between nucleons within an atomic nucleus (Kent 2006).

Meisner effect is the expulsion of magnetic flux within the interiors of a superconductor.

Josephson's effect refers to a super-current phenomenon that involves current flowing indefinitely between two points located long distances apart without any voltage getting applied across a given device (Osborne, 1951).

2.1.2. Importance of superconductivity in everyday life

Superconductivity, since its discovery, has found several applications in various fields. In addition, there is a distinction between high and low temperature superconductors. In this section, concepts of high energy physics are explained and its application in everyday life as a subset of superconductivity.

The importance of superconductivity in everyday life is a heavily researched area with a large number of literatures. Consequently, one of the most recent works on the importance and application of superconductivity to everyday life was presented by Keysan and Mueller (2012).

High Energy Physics

From the mid-1980s, the United States of America's superconductivity industry relied entirely on the Federal Laboratories for its superconducting wire supply which was used in particle accelerators in the field of High Energy Physics (H.E.P) research (Ghamsari, Abrahams, Remillard & Anlage, 2013). Such colliders need great amounts of superconducting NbTi wire which cost hundreds of millions of dollars (Pashkin & Leitenstorfer, 2014). The function of superconductors in particle accelerators is to focus and bend the beam of particles (Pashkin & Leitenstorfer, 2014). Additionally, the particle accelerators also find valuable applications in the detectors, which separate the colliding particles in the targeted area. These magnets usually operate at a high magnetic flux density of about 5 teslas (Malik & Malik 2014). This high magnetic flux density has an advantage of having a smaller size of the particle accelerator because the higher the operating field, the higher the energy of the particles produced (Amaldi & Kraft, 2005)). The superconducting magnets are advantageous because of the higher magnetic fields and low energy losses associated with them. Therefore, The LTS have an advantage over high temperature Superconductors in that they (LTS) help minimize the scattering of a beam of particles (Winkler 2003).

Transport

Superconductivity has revolutionized the transport industry. It has been applied in the levitation, guiding of high-speed ground vehicles, manufacture of motors and generators used in ships, locomotives and aircraft propulsion (Tidman 1996). The solution to transport problem is critical because most airports and highways around the world are congested resulting into delays that cost a lot in terms of time wastage (Raschbichler1994). In the US alone, the fuel used in transportation alone surpasses the domestic oil production and this means that supply for such energy resources will decrease as the demand for travel increases. However, it is estimated that about 50 high speed maglev train system could provide a solution to these problems in the US (Raschbichler 1994). There are two types of maglev trains; the attraction and repulsion types but only the repulsive types utilize the superconductivity phenomena.

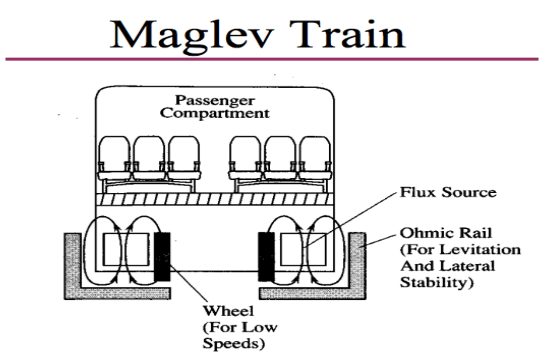

Fig.2.1 The superconducting Maglev train. Adapted from: Massachusetts Institute of Technology.

Electric power: Superconducting Generators

Superconducting generators have three advantages over conventional generators. Firstly, they have superior system stability due to the transients on the grid which are caused by the changes in frequency (Fogarty, 2004). Secondly, due to their ability to operate at a higher magnetic field, the generator sizes can be reduced to about 50% thereby reducing the costs in production (Snitchler, Gamble & Kalsi, 2005)). This ability can enable the manufacturers to save on capital costs significantly. Lastly, the generators' efficiency could be increased by about 0.5%

resulting into the fuel savings that payback the cost of production within the lifespan of such a generator (Fogarty 2004).

Medicine

Superconductivity has been used in medicine since the 1970s. Magnetic Resonance and Imaging (MRI) as well as magnetencephalography are some of the examples (Doyle, 2006). Magnetic Resonance and Imaging (MRI) is able to produce images of body tissues because each body tissues like bones, blood, vessels and organs have different proportions of hydrogen atoms (Baillet, Mosher & Leahy, 2001).

In addition, the feasibility studies on using low temperature superconductors in MRI and the production of these machines is now well established commercially (Muldoon et al. 2005). The MRI machines enable a strong magnetic field to produce pictures to distinguish between the tissues due to differences in the chemical environments. Therefore, their (MRI) ability to distinguish between tissues enables the MRI machines to provide a detailed diagnosis of the bodily disorders thus obviating the excessive x-rays exposure and exploratory surgery (Aarninck & Overweg, 2012).

Electronics and communication

Superconducting devices are used in communication circuits and have several advantages over the semiconducting circuits including lower power dissipation, lower signal distortion and higher switching speeds (Weber, 2011). Low temperature superconducting (LTS) devices used in communication have a long history in the United States having the research sponsored by the National Institute of Standards and Technology in conjunction with the Department of Defense (Kent, 2006). As a result, there are now many commercial LTS devices including millimeter wave mixers, the Superconducting Quantum Interference Device (SQUID) magnetometers Josephson voltage standards and quick data sampling circuits (Ghamsari, Abrahams, Remillard & Anlage, 2013; Chesca & Zang, 2001).

Accordingly, the digital devises manipulate data in discrete levels of 1's and 0's as opposed to the analogues systems whose information processing is in terms of continuous range of values (Fukuda et al. 2009). To create the discrete levels, the digital devices use the Josephson' junctions, unlike the conventional semiconductor digital devices, which perform the switching actions by use of transistors (Winkler 2003). Superconductors have been used in computing to make logic gates, interconnects and memory chips and faster analogue-to-digital converters (Subudhi, Gogate, Kshirsagar, Goswami & Kerawalla, 2016).

Even though initial investment into the LTS devices begun in the US in the early 1980s, Japanese companies took this program further and has even produced as many as 24,000 Josephson Junctions on a single chip. Such prototype of Japanese origin had a speed of 10 times more than the speed of gallium arsenide microprocessor and with a 500 times lower power dissipation compared to the semiconductor device processor (Fukuda et al. 2009).

2.1.3 Importance of including superconductivity in the curriculum

Superconductivity is a phenomenology that plays a vital role in the 20th century physics (Hake 1998; Ostermann & Moreira 2004). Since 2010, research was conducted among 393 high school students of different high schools on the feasibility of introducing superconductivity in the high school curricula (Michelini & Viola 2011). Their results showed the systematic interest the students had in the phenomena and that they were surprised, especially by the experiments such as the magnetic levitation. The researches were mostly on exploration and interpretation on hypotheses (Michelini & Viola 2011) and indicate that during the initial stages the students attribute the superconductive phenomenon to ordinary magnetic and electrical properties but this gradually changed when they recognized the nature of superconductors and diamagnets (Michelini & Viola 2011). In addition, the unit on superconductivity also invokes them to reanalyze critically whatever knowledge they acquired earlier on electromagnetism (Gonzalez-Jorge & Domarco 2004). The connection between quantum and classical physics ensures that the students understand the link between science and technology especially magnetic levitating (maglev) trains. Subsequently, superconductivity also ensures the students understand well the use of superconductivity in medical diagnostics (Ostermann 2000; Ostermann & Moreira 2004).

2.1.4 Teaching and learning of superconductivity globally

The superconductivity phenomenon is justified for inclusion into the high school curriculum since it is in unison with the science, technology and society (STS) emphasis and has several features that make it appealing to the students (Ostermann & Moreira, 2004). For example, there are some experiments that can be performed to illustrate the phenomena like magnetic levitation using a magnet, superconducting tablet as well as liquid nitrogen. This assures the students that they have witnessed the phenomenon instead of the purely abstract concepts. However, this topic cannot stand alone since it requires some previous knowledge of classical physics especially the electromagnetic and thermodynamic concepts (Michelini, Stephanel & Santi 2014). Thus, superconductivity introduction in high school may provide an interesting link between the topics that are already in high school physics and the ones that are yet to be incorporated into it to update it.

2.2 Nanotechnology

In the last two decades, many areas of science including physical chemistry, engineering, physics, microscopy and biochemistry have developed interest in the properties that materials exhibit at the sub-atomic scale and the possible applications to produce a wide range of products (Doyle 2006). Such technology has resulted into successful manipulation of quantum dots, buckyballs, nanotubes, dendrimers and nano-shells to produce nanotechnology products such as sunscreens, paints, self-cleaning glass, stain-resistant clothes paints, sport equipment and several other applications in electronics (Ajayan & Ebbesen 1997; Ganesh 2013).

2.2.1. What is nanotechnology

Nanotechnology refers to the manipulation of materials to the scale of 10^{-9} of a metre. This dimension could range from 1 to 100 nm (Doyle 2006; Roco 2003). At this scale, the physical, electrical, magnetic and optical properties of the materials differ a great deal from the macroscopic material properties and this phenomenon evokes novel applications (Yang et al. 2007). At the nano-scale, materials usually possess different properties such as electrical, optical, magnetic, mechanical and chemical properties (Doyle 2006). For instance, the electrical and physical properties of carbon significantly change when it is synthesized to form carbon nanotubes (Gupta et al. 2005; Guzey et al. 2006). Whereas the allotropes of carbon have a poor electrical conductivity and are not very strong except diamond, the carbon nanotubes are better conductors of electricity and are stronger than even a steel wires (Chico, Crespi & Benedict 1996). Therefore, this observation and many more, distinguish between the properties at nano-scale and those at the macro-scale.

Finally, the basic phenomena of nanotechnology investigated in this dissertation include: nanotechnology in the basic phenomena, nanosynthesis of materials, functional nanomaterials and applications of nanotechnology.

2.2.2. Importance of nanotechnology in everyday life

There are many naturally occurring nanomaterials since most living things operate at the nanoscale level (Doyle 2006). Therefore, nanotechnologists seek to utilize some of the naturally occurring and fabricated nanomaterials. They use several techniques to fabricate various nanomaterials including; top down method – the use of lasers, very fine grinders and vaporization and finally cooling to make nanostructures whose properties differ from their macroscale materials (Zhang & Feng 2006). For the complex nanostructures, the nanotechnologists prefer the bottom-up approach, which is the arranging of the molecules to give a more complex structure which possess both useful and new properties (Bhatia 2017). In other methods, they use solvent extraction method by dissolving some organic materials into solvents such as dichloromethane after which complex polymers are formed by evaporation, sonification, filtration and freeze-drying (Zhang & Feng 2006). Other synthesis method to obtain nanomaterials include crystallization for example synthesizing of glutamic acid in solutions of various types of amino acids (Boanini et al. 2006), self -assembly which involves the manipulation of a material's chemical conditions like pH, solute concentrations and temperature to facilitate self-assembly to induce the formation of nanostructures (Boanini et al. 2006). Nanomaterials are applied in the following areas:

Medicine

Nanomaterials have advantages over macromolecules because they have larger surface area to volume ratio as well as the enhanced properties; mechanical, chemical, physical and optical properties (Nikalje 2015; Bhatia 2017). This makes them a promising tool in various medical fields such as biomedical imaging, drug delivery to specific cells and diagnostics biosensors (Wickline et al.2006). Fig 2.2 shows the use of Carbon Nanotubes (CNTs) used in cancer treatment.

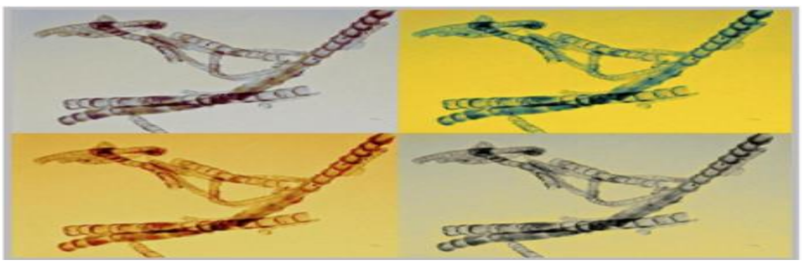

Fig. 2.2 The image shows the bamboo-like structure of nitrogen-doped carbon nanotubes for the treatment of cancer. (Photo Courtesy of Wake Forest and the National Cancer Institute).

Due to their peculiar sizes, chemical composition, shape, charge, surface structure and agglomeration and solubility, nanomaterials can greatly interact with cells and biomolecules. For instance, they have been used to produce the images of cancer tumor sites (Wickline et al. 2006). In addition, single-walled carbon nanotubes have successfully been used to transport and deliver biomolecules efficiently to the cells (Nikalje 2015).

Figure 2.3. A 7nm microchip displayed by SUNY College of Nanoscale Science and Engineering's student Lier, left, and IBM's Haranand (photo credit of IBM.)

Food packaging

Nanocomposite polymers enhance some improvements such as strength, antimicrobial properties and resistance to harsh weather conditions (Doyle 2006). For example, mixing clay with some Nano polymers like polylactic acid and ethylene-vinyl alcohol increased the clay products' barrier to oxygen. This means that the shelf-life of food products can increase in such containers (Mei, McClements, Wu & Decker, 1998). Other nanomaterials like polymer-silicate nanocomposites also show improved mechanical strength, oxygen-barrier properties and thermal stability (Moore 1999).

Agriculture

Biology-based technologies have also been linked with nanotechnology. Nanotechnology has been used to manipulate plant genetic materials to enhance a variety which is disease resistant and matures faster (Lagaron et al. 2005). This has the effect of reducing the losses to famers as well solve food shortage problems.

Food processing

Nanoparticles of silicon dioxide combined with reactive aldehyde groups were found to be capable of improving food flavor and addition of nutritional value by altering the food components when they acted on enzymes (Doyle 2006). They conveniently bound with tryglycerol lipase in olive oil to improve food stability, reusability and adaptability (Doyle 2006).

Sensors

Several research papers have described the possibility of detecting viruses, bacteria and fungi using nanotechnological methods (Rashidi & Khosravi 2011). These biosensors can then be used to detect toxins, pathogens and gases in the packaged foods to alert consumers, distributers and even producers on the safety of foods (Kim et al. 2006).

Nanotechnology is applicable to many other areas such as information technology, biotechnology and cognitive science. This is due to its ability to engineer materials to the smallest scale (Nikalje 2015). This technology is applicable to every facet of human life ranging from healthcare, agriculture, to security. Lastly, nanotechnology will modify regenerative medicine sector, research in pharmaceuticals and stem cell research (Nikalje 2015).

2.2.3. Importance of including nanotechnology in the curriculum

Having looked at the novel applications of nanoscience and nanotechnology (NST) and how its products play an important role in the medicine, agriculture, food packaging, food processing and electronics, the other question is, 'what is the importance of introducing these new fields into the science curriculum?' The size-dependent property of Nanoscience and Technology (NST) has opened doors to a number of applications. During the past 10 years, it has been associated with many important economic, societal and ethical issues (Laherto 2012). These developments in NST have resulted into many advocates including science and technology educators, governments, social scientists, engineers and public administrators recommend the inclusion of nanoscience and nanotechnology into the curriculum (Roberts 2004; Laherto 2012). Perhaps the most reasonable argument why the young generation has to be made aware of the importance of NST, is the impeding shortage of professionals such as engineers, researchers and teachers with the nanoscale specialization. In many situations the need to introduce NST in the curriculum has been accelerated by the desire to have scientific and technological literacy in the field (Stevens et al. 2009). These concepts of scientific literacy among citizens have always influenced the developments in curriculum worldwide (Roberts 2007). The primary idea is that soon every citizen will require some basic knowledge to navigate through the science based on the fact that it affects their lives every day.

In addition, there was also a Global Monitoring Report (GMR) by Education-for-all, which reiterated the importance of nanoscience and technology based on the prediction made in the 1990s that nanotechnology would have a promising future (Ajayan & Ebbesen 1997). The report made many industrialised countries invest millions of dollars for the development of nanotechnology to their best avail. For instance, in 2006, Japan's funding for nanotechnology amounted to about 1 billion dollars (Chesca, Muck & Zhang 2001). On the other hand, there were about 40,000 scientists and specialists who had qualified to work in the field of Nanoscience and Nanotechnology and up to the year 2015 (http://www.nano.gov). The budgetary allocation by the US government for NST has amounted to a trillion dollars (http://www.nano.gov). It is therefore apparent that such an emerging field requires public sensitization that can effectively be achieved by including NST in the primary and secondary curricular.

2.2.4. Teaching and learning of nanotechnology globally

Available literature indicates that the demands for nanoscience literacy have been followed by initiating nanoscience and introducing nano-education into the academics (Laherto 2012). In addition, several projects have been initiated which are aimed at incorporating nanoscience and technology in primary and secondary school curricular (Sweenay & Seal 2008). Most of the initiatives to systematically introduce NST into both primary and secondary curricular have been carried out in the United States and the projects have been funded by National Science Foundation as well as National Centre for Learning and Teaching in Nanoscience and Engineering (Laherto 2012). The purpose of such initiative is for these organizations to conduct workshops to clarify the core elements of NST which should be included in the curriculum and train educators on to handle the topic among learners.

Other reviews of literature on science and engineering education indicate that in the European countries, the teaching materials to be used for NST are being piloted by the NANOYOU project teams (Laherto 2012). This initiative by the European Commission has ensured that there are more modules and approaches for teaching nanoscience and technology (Jones et al., 2013). Additionally, after incorporating the agreed components of nanoscience and technology into the curriculum, the demand for the NST education has initiated several other informal projects globally such as web-based educational materials. These materials are directed to educate the public in addition to exhibition in science fairs and museums (Michelini et al. 2014).

In spite of the quality learning environments and the growing number of researches that are associated with NST, there is still lack of the systematic analysis on the meaning of nanotechnology, the nature and the relationship with the society. This has necessitated some literature reviews to lay the ground work for curriculum developments to address the needs arising from the rapidly advancing NST education (Laherto 2012).

2.3. Alternative Conceptions

Alternative conception is a term often used by science education researchers to describe a conception which contradicts or is inconsistent with widely accepted scientific views (Driver et al 1994, Duit 2003, Slotta, Chi & Joram 1995, Schneps & Crouse 2002). The alternative conceptions are also referred to as "alternative frameworks" (Driver & Easley, 1978), also "erroneous ideas" or "children's science" (Osborne1983), "misconceptions" (Brown & Clement 1989, Brown 2013) intuitive ideas (Chi & Slotta 1993, Preece 1997), "prescientific conceptions" (Good, 1991) and "naïve knowledge" (Champagne, Gunstone & Klopfer, 1983). For the consistency in this study, the term alternative conception is used since these conceptions are the ideas the individual mind constructs makes sense to those individuals and they get sense of new knowledge (Pardhan & Bano, 2001).

For more than three decades, alternative conceptions have been well documented for in many other physics topics such as Newton's laws of motion (Clark et al. 2011, Clement 1982, diSessa 1982) electricity (Baser 2006, Baser & Durmus 2010, Bilal & Erol 2009, Chabay & Sherwood 2006, Maloney et al., 2001), thermodynamics (Shayer & Wyllam, 1981), and optics (Bendall et al. 1993, Colin & Viennot 2001). Even though these researches have been on conceptions on different topics, some of the commonalities of these researches as depicted by their literatures are that the physics educators agree that there are pre-instructional conceptions among physics learners and there is need to worry about them (Hewson & Hewson, 1984; Bilal & Erol, 2009). This is mainly because conceptual change should inculcate meaningful learning to enable the learner to interpret physical situations in a different way from which he initially made mental constructs (Baser & Geban, 2007). This may encourage inventions and innovations which is much needed in superconductivity and nanotechnology as opposed to traditional teaching methods which tend to create human androids which are able to solve quantitative problems (Baser & Geban, 2007), while the conceptual difficulties remain unresolved. Studies should therefore identify the nature, extensiveness and consistencies/inconsistencies in the learners' alternative conceptions.

2.3.1 Alternative conceptions in superconductivity

Alternative conceptions in superconductivity among the students have not been well documented in either high schools or universities. For example, a literature search using Google scholar, JSTOR, springerlink, ERIC, WorldWideScience, Proquest, Web of Science and Ebsco only revealed the existence of misconceptions on superconductivity. The search reveals that over six decades, scientists have considered that niobium boride (NbB) as a classic example of one of the superconducting compounds (Abud et al. 2017). This assumption has been recorded in scientific journals as well as manuals for condensed matter physics but has been contested by researchers in the University of San Diego University in the United States and at the University of Sao Paulo in Brazil (Abud et al. 2017). The researchers, showed that the conductivity which was observed in NbB was not due to the compound but the filaments of the nearly pure niobium that were embedded in the grains of NbB. This is because pure niobium is in itself a superconductor without boron since it superconducts at the temperature of liquid helium (4.2 K) (Abud et al. 2017).

In other literature reviews, it is shown that most students mistake superconductors for ideal conductors. Consequently, Carr and Khachan (2010) explain that there is a difference between superconductors and ideal conductors in the sense that in superconductors cooling to critical temperatures expels the internal magnetic field while in ideal conductors, the internal magnetic field is retained.

The pre-service physics teachers and other students who major in physics usually enter the solid-state physics class after encountering conductivity (Khachan & Bosi 2015). Some students may carry a conception that the pure good conductors such as copper, silver and aluminum became the best superconductors after they are cooled to their respective critical temperatures, but presently, experiments have proved that even compounds and alloys (non-pure substances) reach superconductive state at much higher critical temperatures (Malik & Malik 2014) than good conductors.

As a result, the above are the reasons why this study seeks more alternative conceptions of superconductivity, a concept which is defined earlier as quantum mechanical phenomenon in which current is transported at virtually zero electrical resistance.

2.3.2 Alternative conceptions in nanotechnology

In another literature search using Google scholar, JSTOR, springerlink, ERIC, WorldWideScience and Ebsco only revealed fifteen misconceptions on nanotechnology. The reason for this could be that many countries are yet to include it in their school curricular so, the results of the search was not very helpful.

However, in one of the researches on nanotechnology concepts, a nanotechnology module was developed in the context of chemistry teaching in grade nine where the conceptual understanding of the basic concepts namely the size and scale and surface area to volume ratio of the nanoparticles were investigated (Blonder & Sakhnini, 2012). The researchers used a variety of instructional methods like learning with multimedia, project-based learning, game-based learning, project-based learning and storytelling. After the instruction using these variety of teaching methods, the researchers interviewed the students and also analyzed their projects how these methods impacted on the students' conceptual understanding of the basic NST concepts (Blonder & Sakhnini, 2012; Jones et al 2013).

2.4 Categorising of alternative conceptions

In the available literature of science education and cognitive science, the students' conceptions can be distinguished based on the structure and nature of the student's descriptions of a concept (Chi 2008; diSessa et al. 2004; Ioannides &Vosniadou, 2002; Chi & Slotta, 1993; McCloskey, 1983; diSessa, 1993). The categories are ontological alternative conceptions (Chi 2008; Chi &Slotta 1993), naïve physics (diSessa, 1982; McCloskey, 1983), Ohm's phenomenological primitives (p-primes) (diSessa 1993), and lateral alternative conceptions (Chi 2008; Chi & Slotta 1993). The characteristics of these alternative conception's themes are discussed in sections 2.4.1 to 2.4.4 below.

2.4.1 Ontological alternative conceptions

Categorisation is the process of assigning a concept to a category where it belongs and this is an important process in the learning of science. Most of the physics concepts can be categorised into attributes based on their descriptions (Chi 2008). The categorisation of scientific concept in an ontological category is in terms of matter and process (Chi 2008; Chi & Slotta 1993). For example, mass may at times be classified in the wrong ontological category as weight, while what is consistent with science is that weight is a force measured in newtons. This may arise from everyday use of the word "weigh" a certain grams of sodium hydroxide that the students meet in chemistry lessons or a hospital when a nurse says check his or her "weight". Thus, this is a construction of science concept from the environment.

2.4.2 Naïve Physics

This is intuitive physics which is defined as the theoretical views held by learners which are simplistic and less organised. Many people possess intuitive models that are not consistent with scientific models (Minstrell, 1982; diSessa,1993, & Brown& Clement 1989). These concepts are usually acquired experientially (McCloskey, 1983; diSessa, 1982). In Medieval physics, force implies velocity is a naïve physics since Newton's first and second laws explain that force implies acceleration and no force implies constant or no velocity (Dega, Kriek & Mogese, 2012).

2.4.3 Phenomenological primitives:

Phenomenological primes (p-primes) are defined the spontaneous physics that are made up of more fragmented structures (diSessa, 1993). The p-primes are of different forms depending on the concepts that are being investigated. The first form of the p-primes can be depicted by answer given when students are asked why the earth is hot during summer, and most answers were that the Earth has an elliptical orbit and that when it is hot, the Earth is probably closer to the sun (Hammer,1996) i.e. proximity means intensity. At this point, p-prime can related to the students' conception that relate intensity to proximity. That is, closer means stronger (Dega, Kriek & Mogese, 2012; Hammer, 1996).

2.4.4 Lateral Conceptions

This refers to the misclassification of concepts within one ontological category (Chi 2008). This means that the concept has been categorised into different branches. The example due to the oral literature, some stories depict the moon as a living thing or an animal (Venville et al; 2012) In other examples, the students may classify Electric Potential as a force. So, Electric potential and force may be classified in the same ontological category erroneously (Dega, Kriek & Mogese, 2012). These categories will be used when the students' conceptions will be categorized (see section 4.2 – 4.7).

2.4.5 Epistemological and ontological perspectives.

In the constructivist theory of learning, ontological and epistemological perspectives describe the meaning knowledge portrays to an individual rather than the world. In addition, this knowledge is constituted by individual conceptual structures (Dega et al. 2012, Vosniadou & Brewer 1987). In this regard, conceptual structures become knowledge when an individual connects them to experience. In this view, the students' alternative conceptions therefore refer to their understanding from the ontological and epistemological perspectives (Treagust & Duit 2008). While epistemological perspectives of conceptual change refer to how the students describe the concepts under investigation, ontological perspectives describe how the learners view the nature of the conceptions (Dega et al. 2012). This paper also compares between epistemological and ontological perspectives, in which the epistemological perspective is dominating over the epistemological perspective (see section 4.10).

2.5. Theoretical Framework

The constructivist theory of learning underpins this research. The theory reiterates that learning, being an active process, involves the students' construction of ideas depending on their past/current knowledge (Fernando & Marikar, 2017). The theory emphasizes that learning does not occur by memorization, recitation and repeating of facts but rather by socially mediated and internally constructed notions (Driver, Asoko, Leach, Mortimer & Scott, 1994; Dega et al. 2012).

According to the constructivist theory, the student constructs hypotheses, selects and transforms information and makes decision based on their cognitive structures (Fosnot 1996). These cognitive structures (schema and mental models) give organization and meaning to experiences and allows individuals to think beyond the provided information (Fosnot 1996).

As far as constructivist pedagogy is concerned, the teacher should encourage the students to discover the scientific principles by themselves. The student and the teacher should then engage in dialogue while the teacher translates what needs to be learnt into a state that is understandable to the students' current state of knowledge (Bilal & Erol 2009). If this is carried out, the students' alternative conceptions on superconductivity and nanotechnology would become useful in improving their conceptual understanding.

It therefore follows that by identifying pre-service teachers' alternative conceptions in superconductivity and nanotechnology and then categorizing them could form the basis of this dialogue. Consequently, the categorization has been done in terms of epistemological and ontological perspectives (see section 2.4.5). Epistemological perspective refers to how the students describe the concept under investigation, while ontological perspective describes how the students view the nature of concepts being investigated (Duit 2008). These perspectives connect knowledge to a student's individual learning experiences rather than what knowledge means to the world (Treagust & Duit 2008). That is, knowledge as perceived by individual learners (Dega et al. 2012). Knowledge is, when a person considers conceptual structures as viable in relation to experience (Duit 2008). However, these knowledge structures that they construct from environment and previous lessons often do not conform to the accepted scientific explanations (Vosniadou 2007).

An explorative case study design was followed which includes the analysis of both epistemological and ontological perspectives on student understanding of superconductivity and nanotechnology.

2.6. Summary of the Chapter

In this chapter, the definitions of superconductivity and nanotechnology have been discussed. Also discussed therein are the importance of superconductivity and nanotechnology in all spheres of life including medicine, electronics, sensors, agriculture and food packaging. In addition, the chapter also elaborates the importance of including these contemporary physics topics in the secondary school curriculum.

The chapter progresses by defining alternative conceptions and progresses well into classifying the alternative conceptions from previous researches into the presupposed themes. These include; naïve physics, phenomenological primitives (P-primes), lateral conceptions ontological alternative conceptions, loose ideas and mixed conceptions, in addition to the theoretical framework of the study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

An explorative case study design was employed, to explore and categorize the pre-service physics teachers' alternative conceptions in superconductivity and nanotechnology concepts at the Sultan Qaboos University.

The study seeks to answer the following research questions namely:

1. How do pre-service physics teachers depict basic concepts of superconductivity and nanotechnology?
2. What are the differences (if any) of pre-service teachers' depictions, when compared to what is scientifically accepted conceptions of superconductivity and nanotechnology?
3. How extensive are categories of the pre-service physics teachers' alternative conceptions?
4. How consistent/inconsistent are the pre-service teachers' alternative conceptions in the categories that exist?

In order to answer the first and the second research questions, students were expected to write a CSSN test (see appendix D) (see section 3.4.1) to find a way of classifying them into homogeneous focus groups. Homogeneous focus groups were used to reduce the potential domination of the focus group by dominant voices who want only their opinions articulated. Other reasons for choosing homogeneous focus groups rather than mixed-ability groups are: it is easier to evaluate the output from homogeneous focus groups, the group dynamics tend to be inhibited in mixed-ability focus groups but in homogeneous focus group, there is no inhibition (Morgan, 2010).

After the focus groups were formed, focus group questions (see appendix B) were used to investigate how these pre-service physics teachers depict basic concepts of superconductivity and nanotechnology as stated in the first research question. To answer the second research question, the differences between the pre-service teachers' depictions on superconductivity and nanotechnology vis-a-vis the scientifically acceptable facts were investigated. These differences were categorised by investigating the extensiveness as well as the consistencies or inconsistencies among the pre-service physics teachers' alternative conceptions to answer the third and fourth research questions (see sections 1.5, 3.6.2 & sections 4.1 – 4.11).

3.2 Research Design

An exploratory case study research design was followed to elicit responses from the pre-service physics teachers. Yin (1984) described three case study designs namely, exploratory, explanatory and descriptive. The following are the distinguishing characteristics of the three-case study designs as well as why the exploratory case study was preferred:

An exploratory case study design is usually used to explore a phenomenon in the data which the researcher is interested in. It usually involves general questions which opens way for further questions to examine the phenomenon. For example, "do pre-service physics teachers have alternative conceptions" and "if so, to what extent?" also, an exploratory case study design is characterized by a pilot study before the research questions are prepared for the main study Yin (1984).

On the other hand, descriptive case study describes natural phenomena that are available in the data for example what are the different strategies that the reader identifies and how can he use them. The descriptive case study design involves the researcher giving account of the data as they occur. Other researchers like McDonough and McDonough (1997) also opine that the descriptive case study may also be in narrative form.

Thirdly, the explanatory case study design involves the examination of data both at surface level as well as deeply to explain the phenomena in the data. Furthermore, it involves the formation of a theory by the researcher and goes ahead to test the theory (Zaidah, 2003). In addition, the explanatory cases are usually used in causal studies where the researchers use patter-matching to investigate multivariate and complex cases (Yin & Moore, 1987). These complex and multivariate cases can then be explained by three theories thus; problem-solving theory, knowledge-driven theory and social interaction theory. The above theories are mostly employed when researching about commercial products.

The explorative case study design was suitable for this study because it involves the general questions which opens doors for further questions to investigate a phenomenon, such as the ones used in the focus group discussion (see appendix B). Also, the research was preceded by a pilot study which is a characteristic of explorative case study design.

3.3 Sample

This study involved 23 third year pre-service physics teachers aged between 19 – 24 years who enrolled for a solid-state physics unit at the Sultan Qaboos University, Oman in 2016. All the pre-service physics teachers enrolled formed part of the study. All of the students completed the Conceptual Survey of Superconductivity (Scholarexpress, 2015) and Nanotechnology (CSSN) test (Sanfoundry, 2015) as it was related to their course content.

For the focus group discussion, based on the results of the CSSN test, the students were grouped. They were purposefully mixed according their ability to reduce the chances of the potential domination of the students who are above average (Dega et al. 2012). The students who performed better in the CSSN test were evenly distributed among the focus groups. There were 4 groups formed comprising of 4 - 5 pre-service physics teachers. However, two pre-service physics teachers did not want to continue in the discussions as they took part voluntarily and they could withdraw when they decided to do so, leaving a sample of 21. Ethical issues were dealt with (see Section 3.7 and appendix A).

3.4 Instruments

There were two data collection instruments used in this study namely the Conceptual Survey of Superconductivity and Nanotechnology (CSSN) as well as Focus Group Discussion (FGD).

3.4.1. Conceptual Survey of Superconductivity and Nanotechnology

Conceptual survey tests have been applied in many areas of physics to test the students' conceptual knowledge in areas such as electricity and magnetism (Maloney et al. 2001, Dega et al 2012), mechanics (Hestenes, Wells & Swackhamer, 1992) as well as quantum mechanics (Wuttiprom, Sharma, Johnston, Chitaree & Soankwan, 2009). Generally, the conceptual surveys involving the students' conceptions in direct current circuits and mental models of the earth (Vosniadou 1992) show some consistencies in the alternative conceptions since the concepts are easily observable in their immediate environment (Planinic, Boone, Krsnik &Beilfuss, 2006).

The format of Conceptual Survey of Electricity and Magnetism (CSEM) (Maloney et al. 2001) was used in this dissertation but the content was excluded as the survey covers many conceptual areas of electricity and magnetism and not superconductivity and nanotechnology.

Hence, the Conceptual Survey of Superconductivity and Nanotechnology (CSSN) were adapted from and internet and a textbook (https://www.sanfoundry.com/engineering-chemistry-questions-answers-nanotechnology/ and “Introduction to Superconductivity” by A C Rose-Innes and E H Rhoderick) and modified them in a language that can be deciphered by the pre-service physics teachers. A 25 multiple-choice question diagnostic test was developed to assess the epistemological conceptions in the areas of superconductivity and nanotechnology.

To elicit student understanding, and to establish the consistencies or inconsistencies, 25 questions were developed. Questions 1 - 13 (see table 3.1 and appendix D) covered topics on superconductivity whereas questions 14 - 25 were on nanotechnology (see tables 3.2).

Questions on superconductivity consisted of three on basic phenomena of superconductivity, two questions on perfect diamagnetism, one question on second quantization, one question on Meisner effect, three on BCS theory, one on Josephson’s effect and two on types of superconductors (see tables 3.1 and 3.2 and section 4.2 – 4.7). The tables 4.2 – 4.7 show the misconceptions that the students possess. On the areas of nanotechnology concepts, three questions were on basic phenomena of nanotechnology, three on nanosynthesis, two questions on properties of nanomaterials, two on functional materials and one on applications. These specific areas were chosen from literature (see section 2.1.1 paragraph 5 and 2.3.1 paragraph 2) because these are areas where the misconceptions are prevalent.

Table 3.1 The distribution of CSSN test in the phenomena of superconductivity

Basic phenomena of superconductivity	Perfect diamagnetism	Second quantization	Meisner Effect	BCS theory explanation	Types of superconductors	Josephson's Effect
1.When a material attains a superconductive state, the conductivity becomes **A.**Zero **B.**Finite **C.**Infinite **D.**None of the above	2. The superconducting state is perfectly _____ in nature. **A.** Diamagnetic **B.** Paramagnetic **C.** Ferromagnetic **D.** Ferromagnetic	3. In superconductors, the Fermi energy level is **A.** Below the ground state **B.** Midway between the ground state and first excited state **C.** Above first excited state **D.** At first excited state	4. There are three important lengths which enter the theory of superconductivity except **A.** London penetration length **B.** Intrinsic coherence length **C.** Normal electron mean free length **D.** Mean path length	5. What do we call the maximum current which if surpassed destroys superconductivity? **A.** Induced current **B.** Critical current **C.** Eddy current **D.** Hall current	6. Which of the following are the properties of superconductors? **A.** They are diamagnetic in nature **B.** They have zero resistivity **C.** They have infinite conductivity **D.** All of the above	7. What do we call the maximum current which if surpassed destroys superconductivity? **A.** Induced current **B.** Critical current **C.** Eddy current **D.** Hall current
8. In a superconductor, what happens to the resistance of the materials? It becomes… **A.**Zero **B.**Infinite **C.**Finite **D.**All of the above	9. The magnetic lines of force cannot penetrate the body of a superconductor, a phenomenon is known as **A.** Isotopic effect **B.** BCS theory **C.** Meissner effect **D.** London theory			10. The energy required to break a cooper pair is ___ of the energy gap of superconductor. **A.**One half **B.**Equal to **C.**Twice **D.**Thrice	11.Which of the following conductor has highest critical temperature? **A.** Aluminium **B.** Zinc **C.** Molybdenum **D.** Tin	
12. The temperature at which conductivity of a material becomes infinite is called **A.**Critical temperature **B.**Absolute temperature **C.**Mean temperature **D.**Crystallization temperature				13. The copper pair has I.Equal and opposite momenta II.Equal and opposite spin III.Unequal and same spin Which of the above are true? **A.** Only i **B.** Only ii **C.** i& ii **D.** i& iii		

Table 3.2 The distribution of CSSN test in the phenomena of nanotechnology

Basic phenomena of Nanotechnology	**Nanosynthesis**	**Properties of Nanomaterials**	**Functional materials**	**Applications of nanotechnology**
1. What is the ultimate result of Quantum confinement? **A.** Energy gap in semiconductor is proportional to the inverse of the square root of size **B.** Energy gap in semiconductor is proportional to the inverse of the size **C.** Energy gap in semiconductor is proportional to the square of size **D.** Energy gap in semiconductor is proportional to the inverse of the square of size	2. Which of the following is an example of top-down approach for the preparation of nanomaterials? **A.** Gas phase agglomeration **B.** Molecular self-assembly **C.** Mechanical grinding **D.** Molecular beam epitaxy	3. The properties like melting point, solubility, colour, etc changes on varying the **A.** Size **B.** Composition **C.** Surface properties **D.** None of the mentioned	4. What advantages do nano-composite packages have? **A**. Lightness and biodegradability **B**. They enhance thermal stability, mechanical strength and conductivity. **C**. they have gas barrier properties **D**. All of the mentioned	5. Which of the following is the application of nanotechnology to food science and technology**?** **A**. Agriculture **B**. Food safety and biosecurity **C**. Product development **D**. All of the mentioned

6. Which ratio determines the efficiency of the nanomaterials? **A**. Weight to volume **B.** Surface area to volume **C.**Volume toWeight **D.** Pressure to volume	7. Which of the following is an example of bottom-up approach for the preparation of nanomaterials? **A.** Etching **B.** Dip pen nano-lithography **C.** Lithography **D.** Erosion	8. Select one property of nanomaterials which differs with property at the macroscale. **A**. Size distribution **B.** Specific surface feature **C.** Quantum size effects **D**. All the mentioned	9. Nanotubes usually form in bundles. Which is the best description of such a bundle? **A.** The tubes are connected together by covalent C-C bonds **B.** The tubes are randomly organized, with the axes of the tubes lying in random directions **C.** The tubes are aligned, axes parallel, with van der Waals forces operating between adjacent tubes **D.** The bundles are of discrete sizes, and dipole-dipole forces hold the tubes together
10. Which of the following dimensions is referred to as the nano-scale? **A.** 10^{-10} m **B.** 10^{-12} m **C.** 10^{-9} m **D.** 10^{-15} m	11.Select the incorrect statement from the following options. **A**. Self-assembly is a top-down manufacturing technique **B**. In self-assembly, weak interactions play very important role **C**. Self-assembling molecules adopt an organized structure which is thermodynamically more stable than the single, unassembled components **D**. Compared to the isolated components, the self-assembled structure has a higher order	12. What advantages do nano-composite packages have? **A**Lightness and biodegradability **B**. They enhance thermal stability, mechanical strength and conductivity. **C**. they have gas barrier properties **D**. All of the mentioned	

3.4.2 Validity and reliability of the Conceptual Survey of Superconductivity and Nanotechnology.

3.4.2.1 Validity

In order to probe diverse aspects of science education, conceptual surveys have been progressively popular in many topics for assessing the efficacy of a pedagogical material and also investigate, assess or explore the students' understanding of the basic concepts in certain topics (Chan, Fowles & Weiner, 2010). The main aim of this study was to explore and categorize the pre-service physics teachers' alternative conceptions in the areas of superconductivity and nanotechnology.

The first stage in the development of the CSSN was to take relevant multiple-choice questions from the internet as well as end of topic questions from a solid-state physics book. The survey was then sampled according to the fundamental areas in superconductivity and that the lecturers had identified caused learners' difficulties. Therefore, 22 multiple choice questions were obtained from the internet and three questions from a text book (See section 3.4.1). This is because the multiple-choice questions are economical and easy to administer and grade, have objective scoring and are amenable to statistical analysis that is able to compare instructional methods or student populations.

To establish the CSSN's face and content validity, the test was given to experts in the department of physics who were responsible for the course content of solid-state physics. Superconductivity and nanotechnology are topics dealt with in solid-state physics. These experts were asked to compare the research question, the multiple-choice questions and the course content and verify that students will understand the questions. These experts agreed that face and content validity have been addressed.

Finally, after the experts agreed that the CSSN test was consistent with what it needs to test, this survey was piloted with 45 students in the physics department. The purpose of the pilot study was to examine the feasibility of a research instrument that was intended to be used in a full-scale study.

3.4.2.2 Reliability

The survey was then administered to other 25 pre-service physics teachers at the Nizwa University of Science and Technology (NUST), which is 160 kilometers away and the results reflected the same trend. Using the data from the sample population of 21 at SQU, a statistical test was performed using the Kuder-Richardson (KR-21) reliability test in order to evaluate the test's reliability. The formula for KR-21 used was [n/(n-1) * [1-(M*(n-M)/(n*Var))] Where n is the number of items in the test, M is the mean score while Var is the variance for the test.

The result of the KR-21 reliability test was 0.81. This statistical tool approximates the consistency between items. A high value shows a strong relationship between the items (reliable) while a lower value indicates a weaker relationship (unreliable). The mean score is part of the formula and the KR-21 coefficient ranges from 0 – 1. The result of this reliability test shows that the instrument is reliable.

Even though the results of the CSSN test were reliable, the purpose of this dissertation was to categorize the conceptions of the pre-service physics teachers' alternative conceptions which is best done using the explorative case study design (see section 3.2). The design allows more questions to emerge which is not possible to be answered using the multiple-choice questions hence, the best way to capture the alternative conceptions was the FGD.

3.4.3 Focus Group Questions and Discussion (FGD)

The focus group discussion emerged as a data collection and a bridging approach between the scientific knowledge and local knowledge (Cornwall & Jewkes, 1995). It is usually seen and accepted as a promising and a cost-effective alternative in a research that requires participation and also has some differing paradigms on how the world works (Orr 1989; Morgan 1996). Psychologists and sociologists have used this data collection method since the 1940s (Merton & Kendall 1946; Merton, Lowenthal & Fiske, 1956). Nevertheless, its application and popularity has spread to many other disciplines such as communication and media studies (Lunt and Livingstone 1996), feminist research (Wilkinson 1998), marketing research (Morgan, Krueger & King 1998; Szibillo & Berger 1979) and education (Flores & Alonso 1995, Nyumba et al. 2018).

The focus group discussions (FGD) were to elicit pre-instructional responses from the pre-service physics teachers so, they were conducted before the beginning of the learning of superconductivity and nanotechnology lectures.

These questions were developed in such a way that they would address the set research questions. The questions of FGD consisted of 10 questions carefully selected according to the research questions in the areas of superconductivity and nanotechnology that were developed taking note of the revised Bloom’s taxonomy (See appendix B).

3.4.4 Validity and Reliability of the Focus Group Discussions

Validity refers to the extent in which a research instrument measures what it is intended to measure. However, focus group data often has problems with reliability but these can be minimised if the facilitator is highly trained and the questions that are used are relatively specific. The sections 3.4.4.1 and 3.4.4.2 below discuss how the researcher ensured the validity and reliability of the focus group discussions to explore and categorize the 21 pre-service physics teachers' understanding of superconductivity and nanotechnology concepts.

3.4.4.1 Validity of the Focus Group Discussions

To ensure validity, the researcher again consulted with two experts of the physics department at the Sultan Qaboos University in Oman, one in the field of superconductivity and the other, in nanotechnology. We discussed the research questions and discussed the course content. These experts suggested the focus group questions be modified to reflect the revised Bloom's taxonomy and this was implemented. Finally, there was consensus on the modified focus group questions among the researcher, the two experts, and an assistant researcher who would be present during the focus group discussions. The role of the assistant researcher was to ensure validity and reliability of the analysis of the focus group discussions.

3.4.4.2 Reliability of the Focus Group Discussions

The researcher followed focus group discussion guide developed by Krueger (1994) and did not intervene by imposing his ideas during the focus group discussions. The assistant researcher was present during the FGD to ensure that no guidance was offered.

3.5 Data collection

The data on the first instrument was collected by distributing the CSSN to all the pre-service teachers. The CSSN test was conducted in class at the beginning of the semester before introductory parts of superconductivity and nanotechnology content covered. The duration of the FGD was 60 minutes although 80 minutes were allocated for the discussion.

3.6 Data analysis

3.6.1 Conceptual Survey of Superconductivity and Nanotechnology

The CSSN test was marked and the percentage scores of the pre-service physics teachers on each of the multiple-choice options were obtained. This was done to form approximately homogenous focus groups (see section 4.1).

The analysis the answers of their results indicated a low response state. The method of reporting the response pattern combines the concentration factor with the scores. For example, the questions with low score (concentration factor) but high concentration (score) is denoted as LH, the question with LL means that the questions have low score and low response (Bao & Reddish 2001). The significance of low response state is that most of the students have no dominating model in the topic and responses indicate that their answers were evenly distributed among the four choices available. The four choices had one correct response and three distractors (Bao & Reddish 2001; Dega, Kriek & Mogesse 2012). This showed that the pre-service teachers' conceptions were inconsistent and diversified.

3.6.2 Focus Group Discussion

Data from the FGD was collected by recording the pre-service physics teachers' responses (see appendix E) on the questions (see Appendix B), which elicited their alternative conceptions. In addition, notes were taken to capture their non-verbal communications (Dega et al. 2012). The examples of such non-verbal cues recorded were; some members of a group nodding their heads when agreeing with the points during discussions, a simple nod of the head when validating a point contributed by a group member and hand movements to show that the contributor is just not sure of what he/ she is saying (see appendix G). Additionally, the focus group data were then grouped independently (by the researcher and the research assistant) (see tables 4.3 – 4.8 and appendix E) into the predetermined themes and then compared. In most cases, the classification into naïve physics, ontological alternative conceptions, lateral alternative conceptions, Ohm's p-primes, mixed conceptions and loose ideas that the researcher classified were replicated by the assistant researcher. The few cases of inconsistencies, which involved whether to classify an alternative conception into mixed or loose ideas, were discussed and consensus reached into what category they were supposed to be classified. These inconsistencies are discussed in section 4.11 and table 4.11.

The qualitative techniques that can be used to analyse data include content analysis (Onwuegbuzie 2008; Morgan 1988), grounded theory analysis (Onwuegbuzie 2009; Charmaz 2006; Glaser 1978, 1992; Glaser & Strauss 1967) and discovery analysis (Potter & Whetherell 1987).

This research is on the exploration and categorization of pre-service physics teachers' conceptions. Therefore, the favourable qualitative technique is the content analysis also known as the 'framework analysis' method (Krueger 1994; Ritchie & Spencer 1994; Charmaz 2006;

Dega et al. 2012; Nyumba et al. 2018). The reason for favouring this method of analysing the focus group data is that it allows room for more themes to develop from the presupposed themes and even new ones that emerge (Krueger 1994; Ritchie and Spencer 1994; Charmaz 2006; Dega et al. 2012; Nyumba et al. 2018). In this study, the presupposed themes (Rabie 2004) that were developed from past literature include Ohm's phenomenological primes (p-primes), naïve physics, lateral alternative conceptions, ontological alternative conceptions, mixed ideas and loose ideas. Similar themes were identified by Dega, Kriek and Mogese (2012), and were used as guidelines.

Focus group data analysis was done using a five-stage framework analysis (Richie & Spencer 1994). These five stages were familiarization, identifying themes, coding, charting and interpretation.

Familiarization: This stage involved the verbatim audio-recording of interviews which were complemented with observation notes. The audio which was recorded in mp3 format, was replayed and lesson notes re-read to understand sense of the entire interviews. This means that a systematic review of transcripts and observational notes was carried out at this level.

Identification of framework: This stage involves the identification of recognition of the presupposed themes. This stage also involved filtering of unnecessary statements which were outside the research questions. It should be noted that the pre-service teachers' expert-like responses were also irrelevant in relation to the research questions. Open-mindedness was also maintained to avoid forcing data within the presupposed themes. There were also two themes in which if a conception could not be categorised as naïve, lateral alternative conception, ontological or Ohm's p-prime they were classified under loose ideas and mixed conceptions.

Loose ideas arose from conceptions which did not fall within any presupposed themes while mixed conceptions were those ideas which fell within more than one of the presupposed themes.

Coding: This stage involves the placing of transcribed data into the corresponding categories or themes. This stage involved coding the transcripts according to the categories that they belong to, together with the focus group it emanated from. For example, the segment which was from naïve physics and that was discussed by the first focus group was given the code; NAIVFG1 (see appendix E). Likewise, a segment of the transcript from Ohm's phenomenological primes that was discussed by the second focus group was coded as OHMFG2.

Charting: This stage involves the analysis of the specific of information that were coded and arranging them in tables of categorical themes (see sections 4.3 – 4.8)). The segments were organized in tables in categories in relation to discussion questions during the focus group discussion (see appendix B). In short, the students' alternative conceptions were organized into categories which consisted all the presupposed themes. The themes depended on the students' own knowledge structures and the explanation that was given in relation to the conceptual question and according to the research question requirements.

Interpretation: This last stage involved the evaluation of the key characteristics that are laid out in the tables (see section 4.9 and 4.10). The analysis was able to come up with a set of data in tabular form. Interpretation was therefore done on each category in terms of frequency, consistency/inconsistency, extensiveness (Rabie 2004), extensiveness, and also the distribution of the pre-service teachers' conceptions across and within the categories. The key characteristics were explored as follows:

Frequency and Extensiveness: Frequency in this context is used to refer to how often an idea or conception was made among the four discussion groups, while extensiveness is the total frequency of one alternative conception in every category (Dega, Kriek & Mogese, 2012). The analysis of the students' alternative conceptions revealed that the frequency is the same as the focus groups that discussed such a particular alternative conception. The analysis further revealed that the maximum frequency was four, corresponding to the total number of the focus groups, while the minimum was one. On the other hand, extensiveness was analysed in order to ascertain the frequency of the pre-service teachers' conceptions were distributed in the categories. These analyses of frequency and extensiveness were tabulated in the results section (see tables 4.9).

Consistency/inconsistency: This refers to the variations of the pre-service physics teachers' conceptions across and within the presupposed categories. Such inconsistencies/consistencies of pre-service teachers' conceptions were provided in the table in the results chapter (see table 4.10)

Distribution: This refers to the number of pre-service physics teachers' alternative conceptions in each category of conceptions. Consequently, the percentage shows the fraction of the number of each category's alternative conception expressed as a percentage of all alternative conceptions in all other categories.

These data were counterchecked by the assistant researcher, who is also a lecturer in physics at a different university in Oman. The grouping into pre-determined themes was done independently by both the researcher and his assistant and where there were few cases of inconsistency after which a discussion was held and consensus reached after reasoning.

3.7 Ethical Consideration

The research participants were treated as independent individuals of whose decisions on whether or not to participate were respected. The participants' permission was requested along with the Sultan Qaboos University Physics department's support before data collection commenced. The students were assured that the research test scores would be confidential and that it would have no impact on their classroom assessment. In the focus group discussion, two pre-service teachers decided to withdraw however, it was assumed that this had a limited effect on the findings. In addition, a request for ethical clearance from Ethical Review Committee of the Institute for Science and Technology Education at the University of South Africa was made and approval was granted (see appendix A).

3.8 Summary of the Chapter

In this chapter, the research design, the methodology used in the research and the participants in this study were explained. The instruments used and its validity and reliability as well as how the data was collected and analysed was discussed. This chapter also outlined the ethical procedures followed in this research.

CHAPTER 4: RESULTS

In order to allocate students into the different focus groups, their scores in the CSSN test were analysed (see section 4.1). The results were analyzed and this provided answers to the first research question on how the pre-service physics teachers depict basic concepts of superconductivity and nanotechnology from the FGD (see sections 4.2 – 4.8). The presupposed alternative conception categories included: lateral alternative conceptions, naïve physics, ontological alternative conceptions, and Ohm's phenomenological primes, mixed conceptions and loose ideas (see sections 4.2 – 4.8). In this study, the order of presentation follows the frequency and extensiveness of the pre-service teachers' alternative conceptions (Dega, Kriek & Mogese, 2012). The presentation of these were as follows:

4.1 CSSN

In the test, questions 1 - 14 deal with superconductivity, while questions 15 - 25 deal with nanotechnology. The table 4.1 shows the number of answers from the students in each multiple-choice option and the bold indicates those who answered the correct question.

Table 4.1 The pre-service physics teachers' response to the CSSN test.

Question	**A**	**B**	**C**	**D**	**N = 21**	**Percentage Pass (%)**
1	7	6	**3**	3	21	14.29
2	**9**	5	5	2	21	42.86
3	**2**	8	6	5	21	9.52
4	4	**5**	8	4	21	23.81
5	**3**	7	6	5	21	14.29
6	3	3	8	**7**	21	9.52

7	5	**4**	6	6	21	19.05
8	7	**6**	5	3	21	28.57
9	3	5	**9**	4	21	42.85
10	4	6	5	**6**	21	28.57
11	4	5	**7**	5	21	33.33
12	7	6	3	**5**	21	23.81
13	**6**	3	8	4	21	28.57
14	7	5	**4**	5	21	19.05
15	5	**7**	3	6	21	33.33
16	**5**	4	8	4	21	23.81
17	6	7	3	**5**	21	23.81
18	3	3	8	**7**	21	33.33
19	**6**	5	6	4	21	28.57
20	8	5	4	**4**	21	19.05
21	4	7	6	**3**	21	14.29
22	5	**4**	5	7	21	19.05
23	6	8	**2**	5	21	9.52
24	5	3	**10**	3	21	47.62
25	7	6	6	**2**	21	19.52
Mean percentage pass						29.05

4.2 Discussion of the CSSN test results

The results of the CSSN test indicate that in question one for example, among the 21 pre-service physics teachers who sat the test, only 3 of them got the right choice correctly, contributing to 14.29 % pass. The question asked what happens to conductivity when a material attains superconducting state. Most pre-service physics teachers chose response “A” instead of the correct response “C”. This could have been due to the confusion which arises when the resistance becomes zero and the conductive state becomes infinite.

Whereas the CSSN test was used to group the PSTs into focus groups, the CSSN test could possibly influenced their response during the focus group discussions since some questions were similar, for example; question 7 of the FGD corresponds to the question 18 of the FGD. It is therefore noted that this could have influenced their participation in the focus group as the question was already familiar to most of them. However, the influence of this nature was regarded as minimal as this was the only question and the other questions were not repeated.

The pre-service physics teachers’ average score in the CSSN test was 29.05%. The analysis of the answers of their results indicated a low response state, that is, a response in which their answers were evenly distributed among the four choices available where there were three distractors and only one correct response (Bao & Reddish 2001; Dega, Kriek & Mogesse 2012).

4.3 Theme 1: Naïve Physics

In the pre-service teachers’ descriptions, naïve physics is one of the themes that was developed. In the superconductivity and nanotechnology conceptions, 19 alternative conceptions were categorized into naïve physics (see table 4.3). Out of these alternative conceptions, three were in basic phenomena of superconductivity; three were on perfect diamagnetism and three on second quantization and BCS theory. On the part of nanotechnology, the alternative conceptions were as follows; two on basic phenomena of nanotechnology, four on properties of nanomaterials compared to the macroscale and two on nanosynthesis methods.

The following examples are presented to illustrate naïve physics: Some of the pre-service physics teachers (see table 4.3) argued that the more conductive a material is, the more superconductive it becomes when cooled. This conception is not consistent with the canonical scientific facts because it has been observed that there are many alloys and ceramic materials, which are poor conductors but at lower temperatures they attain superconductivity while some good conductors at ambient temperatures do not attain superconductivity.

Another naïve physics observation is a material with a lower ionization energy becomes superconductive at higher temperature while one with a higher ionization energy becomes superconductive at a lower temperature. The concept of ionization energy is discussed in chemistry when learning the trends down and across the periodic table in high school. It was thought by the researcher that this could have caused the pre-instructional instruction in superconductivity.

In another example, it was mentioned that perfect diamagnetism ‘means’ a magnet has two poles. This conception shows that the learners had not been exposed to such a term and could have tried to use his own guess to try and coin the meaning of the word.

Table 4.3 shows the pre-service teachers' conceptions, which are categorized under naïve physics in relation to frequency and extensiveness.

Table 4.3: Naïve Physics

Concepts	**Naïve Physics**	**Frequency**
Basic phenomena of superconductivity	The more conductive a material is the more superconductive it is.	2
	Superconductivity is attained at higher temperatures when the ionization energy of an element is lower.	1
	All metallic elements conduct electricity and can attain superconductivity when cooled to their respective critical temperatures.	2
Perfect diamagnetism	Diamagnetism means a magnet has two poles.	1
	Perfect diamagnetism means the magnetic field is maximum inside a conductor.	1
	Perfect diamagnetism means relative permeability is unity inside the superconductor.	1
Second quantization	Superconducting current is quantized in one electron current.	1
BCS theory explanation	During superconductivity, the electrons leave no energy gap.	1
	The lower the resistivity of a material, the higher the chances of it being a superconductor.	2
Basic phenomena of nanotechnology	Nanomaterials have the same properties as the macroscale.	1
	Nanotechnology refers to the technology of anything small.	2
Properties of nanomaterial compared to macro material	There is no colour change when a material attains nano size.	1
	The conductivity of nanomaterials is similar to the conductivity of bulk materials.	2
	Optical and mechanical properties depend on the type of materials, not the size.	1
	An electromagnetic property of nanoparticles is independent of the particular size.	2
Nanosynthesis methods	Bottom-up nanosynthesis approach involves building nanomaterials from down, going upwards.	1
	Top down nanosynthesis approach involves building nanostructures from up, going downwards.	1
Extensiveness of naïve physics conceptions:		23

4.4 Theme 2: Lateral Alternative Conceptions

In the analysis of the superconductivity and nanotechnology concepts, there were 7 lateral conceptions as shown in the table 4.4 below. For example, the pre-service physics teachers conceived superconductivity as a force. The properties they describe are those that belong to force. Even though they share some properties meaning they belong to same ontological categories, they belong to different lateral categories.

For example, a student (S1G2) from focus group 2 when asked what he understands by the term superconductivity answered as follows:

Researcher: Ahmed, what do you understand by the term superconductivity?

Ahmed: It is when the force of friction that becomes zero when electrons flow in a material.

This was a classification of superconductivity phenomenon under some properties as force even though they belong differently.

Another example was when the pre-service teachers portrayed superconductivity as kinetic energy of the electrons when the electrons move through a region of zero electrical resistance (see table 4.4). The other lateral alternative conception under this classification was observed when the pre-service physics teachers described perfect diamagnetism as a force of attraction between the opposite spins that have different poles.

In this particular area of alternative conceptions, the alternative conceptions documented as follows; three in the basic phenomena of superconductivity, one in the perfect diamagnetism, two in the concept of second quantization and the BCS theory and one in basic phenomena of nanotechnology.

Table 4.4: Lateral alternative conceptions

Concepts	**Lateral Alternative Conceptions**	**Frequency**
	Superconductivity as a force: Superconductivity means zero frictional force to the electron flow.	2

Basic phenomena of superconductivity	*Superconductivity as potential Energy*: is an energy that transports electrons when the resistive forces are zero.	1
	Superconductivity as kinetic Energy: Superconductivity is the kinetic energy that the electrons possess when they move through a region of zero resistance.	2
Perfect diamagnetism	*Perfect Diamagnetism as a force*: Magnetic flux being zero is caused by lack of resistive forces.	3
Second quantization	*Second Quantization as a covalent bond*: Electron pairing occurs as a result of a covalent bond.	1
	Second quantization caused by a force: The second quantization is due to the attractive force between the electronic opposite spins with different poles.	1
Basic phenomena of nanotechnology	*Nanotechnology is superconductivity*: nanotechnology is cause of superconductivity.	1
Extensiveness of lateral alternative conceptions:		11

4.5 Theme 3: Ontological Alternative Conceptions

The alternative conceptions discussed here were centered on whether the pre-service physics teachers have classified the conceptions under investigation in the right ontological category. Under this theme, six alternative conceptions (table 4.5) were recorded where two were in basic phenomena of superconductivity, one in perfect diamagnetism, one in type I superconductors, one in second quantization and lastly, one in the basic phenomena of nanotechnology.

For instance, the pre-service physics teachers considered superconductivity and superfluidity to be in the same category of matter. While superconductivity is phenomenon involving electrons, superfluidity involves liquid matter involving motion with zero viscosity. In addition, some students described that type I superconductors are conductors that behave like semiconductors yet in another, nanotechnology was described as the technology of manipulation of materials to the micro-scale.

Table 4.5: Ontological Alternative Conceptions

Concepts	Ontological Alternative Conceptions	Frequency
Basic phenomena of superconductivity	Superconductivity involves positive and negative charges	2
	Superconductivity involves the flow of charges just like water in a pipe without friction (resistance).	1
Perfect diamagnetism	The electrons form permanent magnets inside a superconducting device.	2
Type I superconductors	Those conductors that behave like semiconductors.	1
Second quantization	When the fermions condense, they become liquid which flow in the superconducting device in liquid form.	1
Basic phenomena of nanotechnology	This is the manipulation of materials to the micrometer scale.	1
Extensiveness of ontological alternative conceptions:		**8**

4.6 Theme 4: Ohm's P-Primes

This category of conceptions was also analyzed during the focus group discussions. For instance, student (S2G3) indicated that when current increases inside a superconductor, the superconductivity also increases just as voltage is directly proportional to current in Ohm's law. In addition, some pre-service teachers opined that perfect diamagnetism increases with increase in current (table 4.6). In such cases, as shown (see table 4.6), the Ohm's phenomenological primes is depicted that superconductivity is proportional to current flowing inside a material.

Table 4.6: Ohm's Phenomenological Primes.

Concepts	Ohm's Phenomenological Primes	Frequency
Basic phenomena of superconductivity	Superconductivity increases directly as the current flowing inside the material increases.	3
Perfect diamagnetism	Perfect diamagnetism increases with conductivity	1

Type I superconductors	A material becomes type I superconductor when it allows low current flows through it, otherwise, type II superconductor when it can allow high current through it.	2
Basic phenomena of nanotechnology	As the material becomes smaller, its superconductive properties reduce.	1
Properties of nanomaterial compared to macro material	Nanomaterials are less superconductive than micromaterials.	1
Extensiveness of Ohm's Phenomenological primes:		8

4.7 Theme 5: Mixed Conceptions

This category of alternative conceptions is one of the themes that were presupposed from past researches after realizing that a conception had more than one of the characteristic features of the pre-determined themes as discussed in section 3.6.2 paragraph 6.

In the FGD student (S3G2) was asked what he understood by superconductivity, he said that the property of a material which increases when the temperature increases because of the delocalize electrons present in the materials (see table 4.7). This clearly shows mixed ideas (Ohm's p-primes and naïve physics) as the student mixed the knowledge of metallic bonding learnt previously in chemistry with physics ideas.

In addition to the above, another student (S4G2), when asked about perfect diamagnetism, he said that the electrons have opposite poles which make them repel each other and this causes superconductivity (see table 4.7). His ideas depict mixed alternative conceptions (naïve physics and lateral alternative conceptions).

Table 4.7: Mixed Conceptions

Concepts	Mixed type	Mixed Conceptions	Frequency
Basic phenomena of superconductivity	Naïve physics and Ohm's p-primes	Superconductivity increases when the temperature of the material increases and it happens because the free delocalized electrons in the lattice attract the positive polarity of the electrons so, they move faster.	2
Perfect diamagnetism	Naïve physics and lateral conceptions	In perfect diamagnetism, the opposite poles of the electrons repel each other and this makes them travel	1

		at higher speeds in the opposite directions bringing about superconductivity.	
Second quantization	Naïve physics and lateral conceptions	Many fermions can occupy one quantum state and they are can condense into a superfluid.	1
Extensiveness of mixed conceptions			4

4.8 Theme 6: Loose Ideas

This category of alternative conceptions involves those ideas that could not be classified into the four predetermined themes (see section 3.6.2). This theme exists because of the verbosity of the ideas that they could not be classified into any predetermined themes or mixed conceptions. For example, the pre-service physics teachers (see table 4.8) described superconductivity as a phenomenon in which there is no energy in the superconducting materials. In this case, the students did not conceptualize the fact that electrons moving inside the superconductor have kinetic energy. The table 4.8shows the loose ideas in which one alternative conception was in superconductivity in basic phenomena, one again in perfect diamagnetism, one on second quantization, and the last one on the basic phenomena of nanotechnology.

In other examples, the pre-service physics teachers (see table 4.8) discussed that in a superconductive state, there exists no magnetic field, meaning even outside the material that exhibits superconductivity. Whereas the magnetic field exists, it is outside the superconductor because of the expulsion from within the material. The other loose idea is when they presented that in second quantization, two fermions can occupy the same quantum state.

In the last row of Table 4.8, the concept basic phenomena of nanotechnology is presented. One student (S5G2) indicated that on the conceptions of nanotechnology concepts, one of the loose ideas was that nanoparticles are those materials that exist but cannot be seen by microscopes.

While simple light microscopes cannot locate nanoparticles, electron microscopes and atomic force microscope can be used to study them.

Table 4.8: Loose ideas

Concepts	Loose Ideas	Frequency
Basic phenomena of superconductivity	In superconductivity, there is no energy in the materials: the students did not specify that there is no energy loss. The simply talked of no energy in a superconducting device.	2
Perfect diamagnetism	In a superconducting state, the magnetic field ceases to exist: the preservice physics teachers did not indicate that the magnetic field is only expelled within the material.	1
Second quantization	Second quantization means two fermions occupy the same quantum state	1
Basic phenomena of nanotechnology	Nanotechnology ensures materials are made to a scale that the particles become invisible to microscopes.	1
Extensiveness of loose ideas		5

4.9 Depictions of pre-service teachers' conceptions compared to what is scientifically accepted.

This section responds to the second research question. The table 4.9 shows how the pre-service physics teachers depicted the following; the basic phenomena of superconductivity, perfect diamagnetism, second quantization, BCS theory, basic phenomena of nanotechnology and nanosynthesis methods. This was discussed in light of their depictions against the accepted canonically accepted scientific facts.

Table 4.9: Depictions of alternative conceptions against the accepted scientific concepts.

Concepts	Pre-service teachers' alternative conceptions	Scientifically accepted explanation
Basic phenomena of superconductivity	The more conductive a material is the more superconductive it is.	Most materials which attain superconductivity are poor conductors at ambient temperatures
	Superconductivity increases as ionization energy decreases.	Only conductivity increases when the ionization energy decreases among metals.
	All metallic elements conduct electricity and can attain superconductivity when cooled to their respective critical temperatures.	Some metals which are good conductors do not attain superconducting state while some alloys which are poor conductors attain superconductivity.

	In superconductivity, there is no energy in the materials: the students did not specify that there is no energy loss. The simply talked of no energy in a superconducting device.	This is a loose idea. There is kinetic energy of the moving electrons but there is no energy loss in superconductors.
Perfect diamagnetism	Perfect diamagnetism means a magnet has two poles.	Perfect diamagnetism means that all the magnetic field has been expelled from within the superconducting material.
	In a superconducting state, the magnetic field ceases to exist.	In perfect diamagnetism, the magnetic field is outside the conductor.
	Perfect diamagnetism means the magnetic field is maximum inside a conductor.	There is no magnetic field within a superconductor.
	Perfect diamagnetism means relative permeability is unity inside the superconductor.	There is no relative permeability when a conductor attains superconductivity.
Second quantization	Many fermions can occupy one quantum state and they are can condense into a superfluid.	According to the Pauli exclusion principle (first quantization), only one fermion can occupy a quantum state.
	Superconducting current is quantized in one electron current.	There are two electrons which form bosons which can cause current flow in a superconductor.
	Second quantization means two fermions occupy the same quantum state	It means only bosons can condense to occupy one quantum state.
Basic phenomena of nanotechnology	This is the manipulation of materials to the micrometer scale.	This is the technology of manipulating materials to the scale of a nanometre (10^{-9}m).
	Nanomaterials have the same properties as the macroscale.	Physical, chemical and optical properties of micromaterials differ a great deal from those of macro materials.
	Nanotechnology refers to the technology of anything small.	This is an ambiguity (loose idea) because small is relative. Its scale must be to that of a nanometre.
	Nanotechnology is superconductivity: nanotechnology is cause of superconductivity	This is not true, they belong to different ontological categories. While nanotechnology through synthesis is believed to be capable of making a material super conduct, they do not mean the same thing.
Properties of nanomaterial compared to macro material	Electromagnetic properties of nanoparticles are independent of the particular size.	The magnetic properties of materials depend on particular size.
	Optical and mechanical properties depend on the type of materials, not the size.	When materials are synthesised to the nano-scale, their optical and mechanical properties change.
Nanosynthesis methods	Top down nanosynthesis approach involves building nanostructures from up, going downwards.	This is a method of synthesis of nanomaterials where the crystal planes already present on the substrate and are etched out from the nanostructures.
	Bottom-up nanosynthesis approach involves building nanomaterials from down, going upwards.	A method of synthesis where nanostructures are synthesized onto the substrate by arranging atoms onto each other giving rise to crystal planes.

The table presents that the pre-service physics teachers' alternative conceptions vacillated in different contexts, peculiar, and diversified. (Li et al 2006) (see table 4.9). These researchers indicated that this could be as a result of inappropriate and inadequate conceptual understanding. Furthermore, learners who are good at passing examinations and problem-solving skills may be having problems with understanding concepts that are accepted as correct descriptions of sound facts in physics (Aalast 2000). In short, they have misconceptions, a term used to describe inappropriate and common constructions in understanding physics (Falk, Linder & Lippmann 2007). For example, in table 4.10, the pre-service teachers' misconceptions are presented. Their misconceptions may originate from past learning experiences either in the classroom (even from other subjects like chemistry) or in the course of interaction with the environment, the misconceptions are stable, widely spread among the pre-service physics teachers and resists changes (Smith, diSessa and Roschelle 1994). To replace misconceptions, the teacher should confront the misconceptions and let the learner enter into a cognitive conflict, be dissatisfied with the conception then the instructor should then engage an instructional method to replace it. However, the pre-service physics teachers were not taught explicitly these sections which involve very deep clarification of concepts and they found it difficult because it is natural to try to figure out the meaning or sense of these new ideas from the previous lessons (this was a pre-instructional study), but nonetheless a useful endeavor to determine their misconceptions to address teaching these topics in future.

4.10 Extensiveness of Alternative Conceptions in the Categories

The third research question was on the extensiveness of the alternative conceptions among the categories. A summary of the pre-service physics teachers' alternative conceptions in their extensiveness as well as the frequency is presented in table 4.10. The results from the table show that naïve physics and lateral alternative conceptions were more extensive than the other two predetermined themes (Ohm's p-primes and ontological alternative conceptions). The other themes (mixed conceptions and loose ideas) were less extensive. The total number of conceptions in the naïve physics and Ohm's p-primes, were 19 plus 8 which equals to 27 out of 47 (57.4 %) while the total number of ontological and lateral alternative conceptions were 13 (32%).

The analysis shows that the epistemological perspective of conceptual change was dominant over the ontological perspective of conceptual change (see section 4.10). When individual categories within either epistemological or ontological perspectives were considered, there was no major differences between the categories (see table 4.10).

Generally, the previous physics education research studies on alternative conceptions were either based on ontological or epistemological perspectives. Therefore, the P-primes and naïve physics were classified as being epistemological in nature while lateral and ontological perspectives of conceptual change were classified as ontological in nature.

Table 4.10: Distribution of the alternative conceptions, frequency and extensiveness in the categories.

Category		**Frequency**				
	Distribution of alternative conceptions	4	3	2	1	**Extensiveness**
Naïve Physics	19 (40.4 %)	-	1	6	11	23(39.0%)
Lateral	7 (14.9 %)	-	1	2	4	11(18.6%)
Ontological	6 (12.8 %)	-	-	2	4	8(13.6%)
Ohm's p-primes	8 (17.0 %)	-	1	1	3	8(13.6%)
Mixed	3 (6.4%)	-	-	1	2	4(6.8%)
Loose ideas	4 (8.5%)	-	-	1	3	5(8.5%)
Total	47	-	3 6.9%	13 30%	27 62%	59

4.11 The inconsistencies in the alternative conceptions

This section first discusses the general consistencies/inconsistencies encountered when classifying alternative conceptions and goes further to highlight the inconsistencies observed in the pre-service physics teachers' conceptions in the superconductivity and nanotechnology concepts. This was done based on the empirical evidences from each perspective.

Researchers have identified some consistent perspectives of alternative conceptions. For example, there are five mental models of the Earth (Vosniadou 1992, Dega et. al 2012), which are naïve in nature: hollow earth, rectangular earth, dual earth, disc earth, and flattened sphere. In addition, the other consistent alternative conception was from the Newtonian mechanics. When the students study motion of macroscopic objects, for instance, for an object to move, there must be force i.e. motion implies force (Clement 1982). In addition to the example above, another consistent perspective is the way the students describe models in direct current circuits; clashing model, the sink model (Fredette & Lochhead 1980; Osborne 1981), and the current consumption (attenuation) model (Osborne 1983, Shipstone 1984). Generally, what determines whether an alternative conception becomes consistent/inconsistent is whether they are related to the learners' daily experiences. For example, the conceptions regarding the Newtonian mechanics and DC circuits are very much related to the students' daily experiences hence they may have consistent alternative conceptions about them (Planinic et al. 2006). That is, the conception is consistent if it is found within one presupposed theme and not a variety of them.

In contrast, inconsistencies are observed in abstract topics like superconductivity and nanotechnology concepts, which are not easily observable and learner lacks previous knowledge or they are just starting to learn new concepts. It therefore follows that their responses depend on the context being discussed (Bao & Redish 2006). In other words, the students at that point possess knowledge in pieces (diSessa 1993) that are weakly connected. In other studies, the science students' alternative conceptions are observed to be idiosyncratic and that they oscillate from one context to another. In short, they are dependent on the context (Tao & Gunstone 1999) hence can vacillate from one presupposed theme to another. In this regard, they become inconsistent.

In response to the fourth research question, the tables 4.3 to 4.8 were combined (see table 4.11). The analysis on consistencies or inconsistencies of the alternative conceptions of the superconductivity and nanotechnology concepts among the pre-service physics teachers within and across all the categories were presented as shown below.

Table 4.11: Inconsistencies in the alternative conceptions.

Category	Concepts			
	Basic phenomena of superconductivity	**Perfect diamagnetism and 2nd quantisation**	**BCS theory**	**Nanotechnology**
Naïve physics	The more conductive a material is the more superconductive it is. Superconductivity increases as ionization energy decreases. All metallic elements conduct electricity and can attain superconductivity when cooled to their respective critical temperatures.	Diamagnetism means a magnet has two poles. Perfect diamagnetism means the magnetic field is maximum inside a conductor Perfect diamagnetism means relative permeability is unity inside the superconductor.	Superconducting current is quantized in one e-current.	Nanomaterials have the same properties as the macroscale. Nanotechnology refers to the technology of anything small. The conductivity of nanomaterials is similar to the conductivity of bulk materials. Optical and mechanical properties depend on the type of materials, not the size
Lateral alternative conception	*Superconductivity as a force*: Superconductivity means zero resistance force to the electron flow *Superconductivity as Potential Energy*: is an energy that transports electrons when the resistive forces are zero. *Superconductivity as kinetic Energy:* Superconductivity is the kinetic energy that the	*Perfect Diamagnetism as a force*: Magnetic flux being zero is caused by lack of resistive forces. *Second Quantization as a covalent bond*: Electron pairing occurs as a result of a covalent bond. *Second quantization caused by a force*: The		*Nanotechnology is superconductivity*: nanotechnology is cause of superconductivity

	electrons possess when they move through a region of zero resistance.	second quantization is due to the attractive force between the electronic opposite spins with different poles.		
Ontological alternative conception	Superconductivity involves positive and negative charges Superconductivity involves the flow of charges just like water in a pipe without friction(resistance)	Those conductors that behave like semiconductors The electrons form permanent magnets inside a superconducting device. When the fermions condense, they become liquid which flow in the superconducting device in liquid form.		This is the manipulation of materials to the micrometer scale
Ohm's p-primes	Superconductivity increases directly as the current flowing inside the material increases.	Perfect diamagnetism increases with conductivity		Nanomaterials are less superconductive than micromaterials As the material becomes smaller, its superconductive properties reduce.
Mixed conceptions	Superconductivity increases when the temperature of the material increases and it happens because the free delocalized electrons in the lattice attract the positive polarity of the electrons so, they move faster	In perfect diamagnetism, the opposite poles of the electrons repel each other and this makes them travel at higher speeds in the opposite directions bringing about superconductivity.	Many fermions can occupy one quantum state and they are can condense into a superfluid.	
Loose ideas	In superconductivity, there is no energy in the materials: the students did not specify that there is no energy loss. The simply talked of no energy in a superconducting device.	In a superconducting state, the magnetic field ceases to exist: the preservice physics teachers did not indicate that the magnetic field is only expelled within the material. Second quantization means two fermions occupy the same quantum state		Nanotechnology ensures materials are made to a scale that they become invisible such that only powerful microscopes can see the devices which are made as a result of the technology

The data in table 4.11 above shows the inconsistencies observed from the results of FGD. The alternative conceptions were inconsistent across all the four presupposed categories (loose ideas and mixed conceptions), the students had multiple alternative conceptions of one concept (mixed conceptions) in all the categories.

For example, the pre-service physics teachers' conceptions in the area of superconductivity was found in all the four categories. These were; superconductivity increases as conductivity increases(naïve), superconductivity mean zero resistance force to the flow of electrons (lateral alternative conceptions), superconductivity involves positive and negative charges (ontological alternative conception) and superconductivity increasing as the current being transported increases (Ohm's p-primes). This was because the pre-service physics teachers were not aware of the cause or causes of the phenomenon and made the inconsistencies to be depicted in all the categories. This could have been as a result of lack of everyday experience with the topics of superconductivity and nanotechnology.

4.12 Summary of Chapter

The chapter shows that when pre-service physics teachers' alternative conceptions are extensive and inconsistent among and across the categories as depicted in tables 4.2 and 4.11.

CHAPTER 5: DISCUSSION ON FINDINGS AND RECOMMENDATIONS

5.1 Overview

This study was conducted to explore and categorize undergraduate pre-service physics teachers' alternative conceptions in superconductivity and nanotechnology in one university in Oman. Besides, the study explored how the pre-service physics teachers depict some basic concepts of superconductivity and nanotechnology, as well as identified the differences of their depictions when compared to the widely accepted scientific concepts. This study also investigated the extensiveness of the emerged categories as well as how consistent or inconsistent these pre-service teachers' alternative conceptions are in the categories that exist.

5.2 Discussions

A total of 44 alternative conceptions and 4 loose ideas were discussed among the pre-service teacher participants (N= 21) in the four discussion groups (see section 4.10), 6.9% of the alternative conceptions was discussed thrice, 30% of the conceptions discussed twice and 62% of the alternative conceptions discussed once while none was discussed four times (table 4.10). This indicates that the pre-service teachers' conceptions showed inconsistency and highly vacillated within and among the focus groups. This agrees with the earlier ideas that the learners' conceptions in science concepts from what they construct from the environment is highly vacillated (Tao & Gunstone 1999; Li et al. 2006; Dega et al. 2012) but on the contrary, they are not stable. This instability usually happens when the topic under investigation is not encountered by the learners in every day undertakings (Bao & Redish 2006).

In addition, the most frequently depicted lateral alternative conceptions were superconductivity as a potential energy and superconductivity as a force (see table 4.4). In the other categories, the distributions of pre-service teachers' alternative conceptions showed a similar trend in the sense that distributions were observed to have approximately comparable values (table 4.10). This means that the theme with the highest number of conceptions also has the highest number of extensiveness across the focus groups. This indicated the diversification of the pre-service teachers' alternative conceptions in the conceptual categories.

From the data in table 4.11, it is clear that the alternative conceptions are inconsistent because, the lessons on superconductivity and nanotechnology had not been introduced. This also means that the students lacked experience about the topic while their responses are supposed to be dependent on the context (Bao & Redish 2006). Therefore, they possessed the knowledge in pieces which are weakly connected. The knowledge in pieces, according to Posner et al. (1984), requires assimilation or conceptual capture (Hewson 1981) and accommodation (Posner et al. 1984) or conceptual change (Hewson 1981) of concepts to bring about change in their understanding. While assimilation entails the use of existing conceptions to deal with the new scientifically sound conceptions, accommodation refers to the replacement of the students' persistent alternative conceptions which do not match with accepted scientific explanations (Dega et al. 2012). According to Carey (1985), assimilation and accommodation of knowledge in pieces involve 'weak restructuring' and 'radical restructuring'. The former one involves the modification of an alternative conception while the latter involves the total replacement of a conception with a new accepted explanation.

For the conceptual change to be effective in a scenario where the epistemological perspective is dominant, it calls for a model that takes care of the pedagogical content knowledge (PCK) which introduces a Model of Educational Reconstruction based on knowledge in pieces (Clark et at. 2011). This is because the pedagogical content knowledge involves the teachers' relational understanding, competencies on the subject delivery and the conceptual approach during the teaching process. This can only be effective when the physics teachers have knowledge on alternative conceptions. Moreover, the PCK is more student-based approach in dealing with subjects which require a higher cognitive ability such as physics, especially in superconductivity and nanotechnology.

The consistent alternative conceptions of the learners are usually observed when the topic being investigated are directly experienced by students in their daily undertakings (Planinic2006) and easily observable. Such alternative conceptions require a conceptual change process that first identifies to the learners that they have misconceptions, ensuring that they are dissatisfied and then replacing the alternative conceptions with sound scientific concepts (radical restructuring) (Carey 1985). However, the concepts of superconductivity and nanotechnology are microscopic and are not easily observable therefore belong to inconsistent perspective of alternative conceptions. Besides, such ideas that are simply incoherent. This inconsistency of superconductivity and nanotechnology concepts is supported by the tables 4.8 and 4.9 as well as the analysis in the paragraphs above.

This dissertation did not take sides on the controversy between the coherence versus fragmentation. In addition, it also analysed the dominance of the epistemological or ontological conceptions to categorize the pre-service teachers' conceptions in superconductivity and nanotechnology. Further, the study indicates that epistemological perspective on the concepts, naïve physics and Ohm's p-primes were dominant over ontological and lateral conceptions. The lateral conceptions, though not dominating, were also vital for the study. This research therefore uses an inclusive approach to avoid disputes arising from researches that either study epistemological alternative conceptions or ontological conceptions.

5.3 Conclusions

This study on the pre-service physics teachers on their alternative conceptions on superconductivity and nanotechnology is one of its kind in Oman. The study approaches the alternative conceptions from a holistic perspective namely from epistemological and ontological perspectives. In this work, six categories of alternative conceptions were diagnosed all of which were presupposed from previous studies (see paragraph section 3.6.2 and tables 4.9 – 4.11). The following are the general conclusions that were reached concerning the study on alternative conceptions in superconductivity and nanotechnology.

- The pre-service teachers' alternative conceptions differ with established epistemological concepts that are supported by solid scientific knowledge.
- The pre-service teacher's alternative conceptions are different across the themes when compared to scientifically accepted conceptions.
- The alternative conceptions within the naïve physics theme is the most extensive.
- Both ontological and epistemological perspectives were considerable and comparable.
- The pre-service physics teachers' alternative conceptions were diversified and inconsistent.

5.4 Recommendations

The main goal of Physics Educational Researches (PER) is to improve the quality of physics education and to move away from the traditional methods of teaching. The focus of PER on teaching is to take students' pre-conceptions into account because the traditional methods of teaching did not care about the pre-instructional conceptions that the learners had. PER helps to design the teaching methodology and content which integrates the learners' pre-instructional conceptions with a view of reducing them. This kind of integration is opposed to traditional teaching and learning methods were concerned with mastery of the content and replicating them for examination purposes. This study therefore recommends the following:

For the improvement of learning, superconductivity and nanotechnology should be taught while considering the two major existing conceptual change perspectives (epistemological and ontological) while designing an all-inclusive curriculum to take care of coherence and fragmentation.

- Teachers currently in the teaching profession should be made aware of the existing alternative conceptions through professional development interventions. During these opportunities, teachers need to be exposed to various misconceptions the students might have and provide possible ways to overcome them.
- The curriculum designs for high schools' process should follow a Model of Educational Reconstructions, which integrates both the learners' and the science instructors' perspectives to design a suitable learning environment. This will ensure the pre-instructional or alternative conceptions are taken care of to ensure the teaching of these contemporary physics topics is more developed according to the students' needs.

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APPENDICES

APPENDIX A: ETHICAL CLEARENCE

UNISA university of south africa

ISTE-SUB RESEARCH ETHICS REVIEW COMMITTEE

Date: 09/12/2014

Ref #: 2014_CGS/ISTE_013
Name of applicant (student/researcher): **Mr. JOHN OYIER OJAL**
Student #:**55757952**
Staff #:

Dear **Mr. JOHN OYIER OJAL**,

Decision: Ethics Approval

Name: Mr. JOHN OYIER OJAL, P.O. BOX 1101, POSTAL CODE 0132, ALKOUDH, MUSCAT -OMAN, ojaljohns@gmail.com +968 95776465, +968 94400801.

Proposal: AN INVESTIGATION INTO PRE-SERVICE TEACHERS' CONCEPTION OF SYNTHESIS OF NANOMATERIALS AND ENHANCE SUPERCONDUCTIVITY.

Qualification: Postgraduate degree (MSc) research

Thank you for the application for research ethics clearance by the *ISTE SUB* Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the study

The application documents were reviewed in compliance with the Unisa Policy on Research Ethics by the Committee/Chairperson of ISTE SUB RERC on 09 September, 2014. The decision will be tabled at the next RERC meeting for ratification.

The proposed research may now commence with the proviso that:

1) *The researcher will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics, which can be found at the following website: http://www.unisa.ac.za/cmsys/staff/contents/departments/res_policies/docs/Policy_Research%20Ethics_rev%20app%20Council_22.06.2012.pdf. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the ISTE Sub Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those*

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APPENDIX B: QUESTIONS FOR FOCUS GROUP DISCUSSIONS

1. Explain what do you understand by the term superconductivity?
2. Explain what is your understanding of second quantization?
3. When does material attain perfect diamagnetism?
4. Describe what the BCS theory entails?
5. What do you understand by the terms type I and type II superconductors?
6. What is nanotechnology?
7. Which properties of the nanomaterials differ from the same materials at the macroscale?
8. What are the dimensions and size of nanomaterials?
9. Describe bottom-up, top down and self-assembly as methods of nanosynthesis?
10. What methods are used in nanosynthesis?

APPENDIX C: SIMILARITY INDEX

Turnitin Originality Report

AN INVESTIGATION INTO PRE-SERVICE TEACHERS' CONCEPTION OF SYNTHESIS OF NANOMATERIALS IN ENHANCING SUPERCONDUCTIVITY by Oj Ojal

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5 1% match (student papers from 30-Aug-2017)
Submitted to King's College on 2017-08-30

6 < 1% match (student papers from 10-Oct-2016)

APPENDIX D: CONCEPTUAL SURVEY TEST

Conceptual Survey of Superconductivity and Nanotechnology (CSSN)

Developed from the Internet Sources and some end of topic questions from a text book

Purpose	To Explore and Categorize Pre-service Physics Teachers' Conceptions in Superconductivity and Nanotechnology.
Format	Pretest, Multiple-choice
Duration	50 min
Focus	Electricity / Superconductivity and Nanotechnology Content knowledge (Superconductivity: critical temperature, diamagnetism, Meisner effect, Energy, resistance, Critical current and copper pair. Nanotechnology: Nature and dimensions of nano, synthesis methods, characteristics of nano compared to macro-scale.)
Level	3rd year college.

1. When a material attains a superconductive state, the conductivity becomes
A. Zero
B. Finite
C. Infinite
D. None of the above

2. In a superconductor, what happens to the resistance of the materials? It becomes…
A. Zero
B. Infinite
C. Finite
D. All of the above

3. The temperature at which conductivity of a material becomes infinite is called
A. Critical temperature
B. Absolute temperature
C. Mean temperature
D. Crystallization temperature

4. In superconductors, the Fermi energy level is
A. Below the ground state
B. Midway between the ground state and first excited state
C. Above first excited state
D. At first excited state

5. The superconducting state is perfectly _____ in nature.
A. Diamagnetic
B. Paramagnetic
C. Ferromagnetic
D. Ferromagnetic

6. Which of the following are the properties of superconductors?
A. They are diamagnetic in nature
B. They have zero resistivity
C. They have infinite conductivity
D. All of the above

7. What do we call the maximum current which if surpassed destroys superconductivity?
A. Induced current
B. Critical current
C. Eddy current
D. Hall current

8. The energy required to break a cooper pair is ___ of the energy gap of superconductor.
A. One half
B. Equal to
C. Twice
D. Thrice

9. The copper pair has
I. Equal and opposite momenta
II. Equal and opposite spin
III. Unequal and same spin

Which of the above are true?
A. Only I
B. Only II
C. I&II
D. I&III

10. There are three important lengths which enter the theory of superconductivity except
A. London penetration length
B. Intrinsic coherence length
C. Normal electron mean free length
D. Mean path length

11. The magnetic lines of force cannot penetrate the body of a superconductor, a phenomenon is known as
A. Isotopic effect
B. BCS theory
C. Meissner effect
D. London theory

12. Which of the following conductor has highest critical temperature?
A. Aluminium
B. Zinc
C. Molybdenium
D. Tin

13. The tunneling of the cooper pair between two superconductors sepapated by an insulator is called

A. Josephson's effect
B. a.c Josephson's effect
C. The London effect
D. d.c Josephson's effect

14. Which of the following is an example of top-down approach for the preparation of nanomaterials?
A. Gas phase agglomeration
B. Molecular self-assembly
C. Mechanical grinding
D. Molecular beam epitaxy

15. Which of the following is an example of bottom-up approach for the preparation of nanomaterials?
A. Etching
B. Dip pen nano-lithography
C. Lithography
D. Erosion

16. The properties like melting point, solubility, colour, etc changes on varying the
A. Size
B. Composition
C. Surface properties
D. None of the mentioned

17. What is the ultimate result of Quantum confinement?

A. Energy gap in semiconductor is proportional to the inverse of the square root of size
B. Energy gap in semiconductor is proportional to the inverse of the size
C. Energy gap in semiconductor is proportional to the square of size
D. Energy gap in semiconductor is proportional to the inverse of the square of size

18. Select one property of nanomaterials which differs with property at the macroscale.
A. Size distribution
B. Specific surface feature
C. Quantum size effects
D. All the mentioned

19. Select the incorrect statement from the following options.
A. Self-assembly is a top-down manufacturing technique
B. In self-assembly, weak interactions play very important role
C. Self-assembling molecules adopt an organized structure which is thermodynamically more stable than the single, unassembled components
D. Compared to the isolated components, the self-assembled structure has a higher order

20. Which of the following is the application of nanotechnology to food science and technology?
A. Agriculture
B. Food safety and biosecurity
C. Product development
D. All of the mentioned

21. What advantages do nano-composite packages have?
A. Lightness and biodegradability
B. They enhance thermal stability, mechanical strength and conductivity.
C. they havegas barrier properties
D. All of the mentioned

22. Which ratio determines the efficiency of the nanomaterials?

A. Weight to volume **B**. Surface area to volume **C.** Volumeto Weight D. Pressure to volume

23. Nanotubes usually form in bundles. Which is the best description of such a bundle?

A. The tubes are connected together by covalent C-C bonds

B. The tubes are randomly organized, with the axes of the tubes lying in random directions

C. The tubes are aligned, axes parallel, with van der Waals forces operating between adjacent tubes

D. The bundles are of discrete sizes, and dipole-dipole forces hold the tubes together

24. Which of the following dimensions is referred to as the nano-scale?

A. 10^{-10} m

B. 10^{-12} m

C. 10^{-9} m

D. 10^{-15} m

25. What advantages do nano-composite packages have?
A Lightness and biodegradability
B. They enhance thermal stability, mechanical strength and conductivity.
C. they have gas barrier properties
D. All of the mentioned

APPENDIX E: AN EXCERPT FROM FOCUS GROUP DISCUSSION (NAÏVE PHYSICS)

RESEARCH QUESTIONS AND ANSWERS:

1. **Researcher: Explain what do you understand by the term superconductivity?**

NAIVEFG1

S1G1: A material which is more conductive a material is the more superconductive when temperatures are lowered.

NAIVEFG3

S1G3: Superconductivity is attained at higher temperatures when the ionization energy of an element is lower.

NAIVEFG4

S4G4: All metallic elements conduct electricity and can attain superconductivity when cooled to their respective critical temperatures.

2. **Researcher: What do you understand by the term superconductivity?**

NAIVEFG2

S1G2: Superconductivity occurs when the force of friction that becomes zero when electrons flow in a material.

3. **Researcher: Explain what is your understanding of second quantization?**

NAIVEFG3

S4G3: Superconducting current is quantized in one electron current.

4. **Researcher: When does material attain perfect diamagnetism?**

NAIVEFG3

S3G1: Diamagnetism means a magnet has two poles.

NAIVEFG2

S1G2: Perfect diamagnetism means the magnetic field is maximum inside a conductor.

NAIVEFG4

S4G4: Perfect diamagnetism means relative permeability is unity inside the superconductor.

5. **Researcher: Describe what the BCS theory entails?**

NAIVEFG1

S1G1: During superconductivity, the electrons leave no energy gap

NAIVEFG3

S3G3: The lower the resistivity of a material, the lower the chances of it being a superconductor.

APPENDIX F: LANGUAGE EDITOR'S CERTIFICATE

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WordWorks

TO WHOM IT MAY CONCERN

DECLARATION OF EDITING

DISSERTATION FOR MSc DEGREE IN PHYSICS EDUCATION:

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I, Louise M Grobler, as a private language practitioner and registered member of the South African Translators' Institute, hereby solemnly declare that I have edited Mr. John Oyier Ojal's dissertation for the MSc degree in Physics Education, **Exploration and Categorisation of Pre-Service Physics Teachers' Alternative Conceptions in Superconductivity and Nanotechnology.**

BA, B.Ed., MEd (*cum laude*)
15 February 2019

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Let your Words Work!

APPENDIX G: NON-VERBAL CUES IN FOCUS GROUP 1

PST WITH NON-VERBAL CUE	**CONTRIBUTION BY**	**STUDENT'S NON-VERBAL CUES**	**POSSIBLE MEANING**
S2G1	*S1G1:* *A material which is more conductive a material is the more superconductive when temperatures are lowered.*	Nodding the head	Affirms validates the point the group member has contributed.
S3G1	*S3G1:* *Diamagnetism means a magnet has two poles.*	Gestures/ hand movements: the pre-service physics teacher's (PST) hand is pulled backwards and closed when talking	He is not sure with his contribution. Just speaking for the sake of it.
S3G3	*SIG1:* *During superconductivity, the electrons leave no energy gap*	Inclination/interest: The PST maintained proper eye contact and posture.	Interested in the discussion and pays attention.
S2G1	*S1G2:* *Second quantization means two fermions occupy the same quantum state*	Inclination/interest: looks side by side, here and there instead of paying attention.	Lacks interest in the discussion.
S1G1	*S1G1:* *Magnetic flux being zero is caused by lack of resistive forces.*	The voice tone/ pitch	The tone varies to express that he is not sure of his point.
S2G2	*SIG2:* *Superconductivity means zero frictional force to the electron flow.*	Facial expression: frowns at the point contributed	Not supporting the point by the other PST