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COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER AND THE IMPACT ON RESEARCH INSTRUMENTATION

BY

BRIDGET KLUTSE

A thesis submitted in partial fulfilment of the requirements for the

Master of Science

Major in Chemistry

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2021

THESIS ACCEPTANCE PAGE

Bridget Klutse

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Matthew Miller
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This thesis is dedicated to my loved ones; my children-Etornam Amevinya, Enam Amevinya and Elikplim Amevinya

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ABBREVIATIONS

PNM	Particulate Nature of Matter
PSU	Particulate and Sound Understanding
PSM	Particulate with Some Misconception
NPU	Non-Particulate and No Understanding

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ABSTRACT

COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER AND THE IMPACT ON RESEARCH INSTRUMENTATION

BRIDGET KLUTSE

2021

The main objective of this research was to explore the understanding and conceptions of Particulate Nature of Matter (PNM) with Chem 115 L students as the participants. Conceptions were defined specifically as beliefs and alternative beliefs about topics. The research also assessed the impact of analytical instrumentation in the chemistry laboratory on learning chemistry concepts. Eight questions (8) with multiple choice answers were administered to 10 students at the beginning and after the Fall 2018 semester via selective/purposeful sampling. Data were collected using surveys (pre- and post-surveys) and interviews (pre- and post-interviews), then analyzed quantitatively and qualitatively. The eight questions on the surveys also requested that students provide reasons for their choice of answers. Using the answers selected and the reasons given in pre- and post-surveys, the researcher categorized students as having Particulate and Sound Understanding (PSU), Particulate and Some Misconception (PSM), and Non-Particulate with no understanding (NPU) conceptions at these corresponding times. From the surveys (pre- and post-), we found out that the overall % of all students in the NPU category reduced from 60 in the pre-survey to 25 in the post-survey. Similarly, the

PSM category also reduced from 310% in the pre-survey to 250% in the post survey. However, the PSU increased from430% to 525%. The increase in PSU with corresponding significant reduction in PSU and PSM indicates a positive impact on student learning, since the results suggest an improvement in the understanding of PNM. This could indicate that research instrumentation had an impact, but alone this data does not provide full evidence of this statement. The interview data was used to provide additional support. Interview records were transcribed, then analyzed and assessed for reliability using intercoder-reliability verification for consistency. The transcribed interview data was subjected to intercoder reliability and the reliability index was 0.79. When the students were asked if the instrumentation had an impact on their learning, their responses strongly suggested a positive impression and impact of instrumentation learning and understanding PNM.

CHAPTER 1.0 INTRODUCTION

Purpose and Significance of the Study

The major objective of this study was to explore Chem 115 students' understanding and conception of particulate nature of matter (PNM), and to find if the use of research instrumentation in the instructional chemistry laboratory had any impact on their understanding of PNM. This would help in seeking to verify the relationship between applied theory to practical chemistry concepts (in the lab) for students in this course, and it would help to determine the effectiveness of the pedagogy and structure of the Chem 115 lab course in the chemistry department at South Dakota State University (SDSU).

Background to the Study

The latter part of the 20th century witnessed a huge research effort into learners' understanding of scientific concepts. Much of this research concerned perceptions of learners' inabilities to understand scientific concepts or develop conceptual understanding about mental models and PNM that were in accord with scientific or teaching models and strategies [1-4]. Kinetic models and PNM have been the most utilized tools to evaluate the understanding of chemistry by many researchers [4-13].

Theory-making and practice of chemistry and science is dominated by using mental models. Since scientists seek to understand macroscopic properties, they inevitably need to consider what is happening at the microscopic level [14, 15]. Because we cannot see what happens at the microscopic level, we need to develop mental images or mental models of what matter is and what its changes might be like at this level. One of the most important models in physical science that has helped explain the behaviour of particles at

the microscopic level is the kinetic theory. This theory, for instance, helps us to understand and explain changes (such as melting and evaporation) at the microscopic level [16-18]. It also helps to rationalise scientific laws such as the gas laws [19]. The kinetic theory of matter is a key component in several science education curricula from as early as upper primary school years to various stages of high school to college [15, 17, 19-21]. In fact, this theory is relied upon by researchers to explain many phenomena in chemistry.

Mental models represent ideas in an individual's mind used to describe and explain phenomena [22, 23]. According to Van Der Veer and Melguizo [24], mental models are constructed from perception, imagination, or from the comprehension of discourse. Mental models are used to produce simpler forms of concepts, and to provide stimulation and support for the visualization, which can be useful when explaining scientific phenomena [25-27]. In science, "mental models are used to describe a system and its component parts as well as its states, to explain its behaviour when changing from one state to another and to predict future states of the system [15, 20, 25, 28-30]. When studying science, mental models can help students to gain understanding of the concepts as a result of the teaching process and exposure to such models [30-32], and helps them to effectively create their own mental models through this exposure during the learning process [11, 25, 31, 33-35].

Chemical models and diagrams provide visual prompts of the sub-microscopic level. An explanatory tool such as a diagram or an image can provide the learner with a way of visualizing the concept, helping them to develop a mental model for the concept [36-39]. Analogies, diagrams and pictures are additional examples of teaching models used to

represent science concepts in textbooks [37, 38, 40, 41]. Modelling has been described as making the connection between the target and the analogue [42-44].

While good modelling ability has been associated with improved understanding of science concepts based on the different analogical models, different students may have diverse mental model interactions as presented by the teacher or in textbooks, leading to various misconceptions. There is strong evidence that suggests some students are not able to interpret the scientific analogical models for the purpose for which it is intended, and also they may not be able to find a combination or multiple models that enhance quicker understanding as expected, leading to misconceptions [11, 45]. Thus, there are significant problems associated with using analogical models for teaching and in learning, as teachers are incapable of predicting how students may interact with the models, be it in textbooks, videos or computer animations and simulations, leading to alternative conceptions [11, 45, 46].

Another concept that has been used in teaching and learning chemistry is the PNM. PNM in its simplistic form, refers to all matter being made of tiny discrete particles, which are very small, can occupy space and are capable of continuous motion and attracting each other. PNM concepts form the basis for explanations in almost all topics studied in chemistry, and is the principal concept in particulate theory used to explain most phenomenon in chemistry at all levels such as chemical reactions, chemical equilibrium, chemical bonding, chemical energetics, solution chemistry, atomic structure, molecules and their behaviour, etc. [7, 8, 47-50]. Most authors have rated PNM as being significant in providing success in understanding chemistry for students in the long term, and as essential in learning chemistry [50-54].

Several studies relating to students' understanding of the PNM at various levels have been documented since the 1970s. Most of the research has been carried out in the 1980s and 1990s, with a smaller number of studies since the beginning of the twenty-first century [45].

Ozmen and Kenan [55] reported that primary school pupils have difficulty understanding spaces between particles and how size and speed of particles change during change of state. According to these authors, some students think that the number and size of particles change when matter changes state. Also, they found that some students believe that the speed of particles increases or does not change during condensation. Furthermore, they found that students had difficulty understanding how the spaces between solid, liquids, and gases change when they are compressed. Most students believed there are no spaces between solid particles. Pereira and Pestana [56] also found many high school students had misunderstandings about the relative distance between particles in the three states of matter. The reason could be that while explaining the structure of solids, it is explained that generally none or very little space exists between the structures of solid. Boz [57] found that students think that particles in a solid have no movement. This was explained based on particles that are very close to each other, tightly packed in a solid substance, and the motion is limited or non-existent. These results show that students have insufficient microscopic level ideas about kinetic-particulate nature of matter and therefore many hold incorrect mental models that they use to explain the observable macroscopic properties of matter.

In the teaching and learning of chemistry, the use of instruments and practical laboratory experience is paramount and is one of the most effective active learning and

classroom participation strategy that helps to promote student-centered learning. In fact, almost all chemistry students at all levels are exposed to some lab activity as part of the training, and its imbedded in all chemistry teaching syllabi or curricula. The use of instruments by chemists, both in industry and research, or in other professional domains is ubiquitous, and all undergraduate academic programs in chemistry integrate laboratory activities and hands-on experiences with instrumentation into the syllabi. Instrumentation use has been the corner stone of undergraduate degree programs for many years to facilitate teaching and learning, while preparing students for their various professional careers [58, 59]. Student learning goals with respect to general skills, practical and scientific, as they pertains to chemistry have been reported [60], and some activities have been done to connect how instrumentation skills in the laboratory help in teaching and learning chemistry [58, 59, 61-65].

Quite recently, Warner *et al*.(2016) [58] reported on the correlation of teaching and learning chemistry using laboratory instrumentation such as the balance, GC, GC/MS, IR, NMR, polarimeter, and UV−vis, where students were surveyed about their knowledge and experience with these types of instrumentation. Their research work spanned through eight semesters over five years with a survey of pre- and post-organic chemistry students. The goal was to verify students' abilities to use critical thinking and problem-solving skills by making intentional choices about the type and nature of instruments required for solving particular and defined chemical problems. The ability to do so exhibited sound knowledge of facility and chemical instrumentation [58]. After the exploration, they found that the level of exposure with the instrumentation in the lab can affect some changes in the student, and that upgrading the instrumentation does not necessarily

impact the students' knowledge of the instrumentation. However, providing instrument-intensive labs and continuous access to instrumentation did help in the technical competency of the student. Furthermore, the results suggested that the abilities of students to use critical thinking in solving problems can be improved by increased exposure, and continuous and increased opportunities working with the laboratory instrumentation. They also found that general chemistry students' abilities in solving problems improved significantly when they were introduced to FT-IR and GC.

Reeves and Pamplin (2001) [62] incorporated hands-on GC-MS into their general chemistry lecture and laboratory courses and found that the introduction of GC-MS helped students not only gain mastery of the instrumentation but also improved their understanding of isotopic abundance distribution. Students recognized the relationship to the atomic mass and that isotopic distribution can be inferred from their atomic masses based on the number of peaks in the mass spectrum. This was confirmed by calculations and NIST library resources for the halobenzenes and carbonyl compounds and several transition metals studied.

MacNeil and Volaric (2003) [61] explored the incomplete combustion phenomenon of candles using instrumentation. Students used a gas chromatography-thermal conductivity detector (GC-TCD) to explain the concepts of incomplete combustion, thermodynamics and kinetics during their first-year. Results from this work showed that incomplete combustion is mainly due to kinetic processes, rather than thermodynamics. Essentially, the students were asked to write the chemical equations for the combustion, measure the amounts of oxygen and nitrogen gas using GC-TCD in a sealed spaced after the candle flame had been burnt to extinction. The students were able to estimate the

levels of O_2 as well as ratios of O_2 and N_2 after post-combustion from the enclosed space. After the experiment with the candle flame and the GC-TCD, the students were asked to re-take a pre-lab. Subsequently, their overall performance after engaging in the experimental exercise rose from 33% to 79%, with scores about the knowledge of oxygen and nitrogen composition in the air, rising from 11% to 97%. This is an indication that the experiment with the GC-TCD instrumentation contributed to their overall performance.

In 2007, Csizmar *et al*. [64] reported how beneficial the implementation of GC-MS and microscale distillation was for the understanding of intermolecular forces. Briefly, students were given some tutorials on distillation, gas chromatography, trends of some selected chemicals such as molecular weight and polarity, and the nature of Lewis structures. Students were made to go through the practical aspects of the microscale distillation and the gas chromatography practical. After the experiments and exchange of data for each student, a survey conducted showed that 133 out of 149 of the 'GC-distillation' experiments helped them to understand the relationship between molecular structure, intermolecular forces and boiling point. Overall, the response from a majority of the students indicated that the laboratory experiment with the 'GC-distillation' was highly informative, beneficial, exciting and enjoyable, suggesting a significant contribution of the 'GC-distillation' for improved learning.

Statement of the Problem

The ability to explain macroscopic properties in terms of microscopic behaviour of particles of matter has been found to be problematic for students. Studies on students' understanding of the PNM indicate that areas which challenge students include the explanation of change of state, conservation of mass following change of state, and

difficulty in conceptualizing a vacuum. For example, Tailor and Coll [66] reported that most of the Fijian, Indian and Australian pre-service primary teachers could not explain how condensation of water vapour occurs. Most of the participants believed that spaces between gas molecules are occupied by some other gases, again verifying the difficulty of understanding space in matter. Even though there were some studies on students' mental models of the PNM, evidence of students' conceptual difficulties concerning other areas such as students' explanations of the non-ideal behaviour of gases appear to be few in the literature. Furthermore, available studies on Research Instrumentation in the Chemistry Laboratory and its impact on understanding of PNM in the literature is limited. There is, therefore, the need to bridge the knowledge gap created in this regard.

Purpose of the Study

The purpose of this study was to explore selected CHEM 115 students understanding of the particulate nature of matter. Further, the study sought to find out if the use of *research* instrumentation in the chemistry laboratory has any impact on their understanding of the particulate nature of matter. Finally, the study sought to identify student's correct and alternative conceptions concerning the particulate nature of matter.

Research Questions

The following research questions were asked to help address the purpose of the study.

- What is the Perception of students on particulate nature of matter?
- What are students' alternative conceptions relating to the particulate nature of matter before and after the use of instrumentation?
- What is the impact of instrumentation on mental model concerning particulate nature of matter?

Assumption

To achieve the purposes of this study, it was assumed that all the students selected for the study were familiar with the postulates of the particle theory of matter. The reason for this assumption was that students were in their first year of study in a chemistry or biochemistry program and brought prior chemistry experience with them, therefore it was assumed that students were familiar with the particle theory of matter. However, it was not assumed that this prior knowledge was perfect without any misconceptions.

Significance of the Study

This study will be beneficial to chemistry instructors who wish to teach students the PNM from the constructivist perspective. In a constructivist learning model, the learner's preconceptions play an important role in learning of the material. According to Swafield [67], 'new learning is highly dependent on prior learning and so teachers must explore pupils' current understanding in order to support further development. Literature on Research Instrumentation in the Chemistry Laboratory and its impact on understanding of Particulate Nature of matter is limited, making the planning of activities on this topic within the constructivist model difficult. The findings of this study could therefore be significant in this respect. The findings of this study could also influence chemistry department curriculum involving the use of research instrumentation in the chemistry laboratory.

Limitation of the study

The results obtained in this study will be difficult to generalise, however with some verification, the results may be applied to colleges/students that have similar characteristics.

Organisation of the Rest of the Study

The study is divided into five main chapters. Chapter One is the introduction part. Chapter Two is the literature review which reviews studies which are pertinent to the students understanding of the particulate nature of matter, which is the topic under study. Chapter Three explains the methodology of the study, the research design used in the research work, the population, sample and sample procedure and instruments used for the data collection. The chapter seeks to describe the procedure used in data collection. Data analysis procedures were also discussed. Chapter Four is on data presentation, analysis and discussion of finding. Chapter Five outlines the summary, conclusion and recommendations.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses how PNM has been used in evaluating misconceptions. The application of PNM in analytical instrumentation as an instructional tool for the laboratory classroom set point is also discussed.

PNM as a Tool for Evaluating Misconceptions/Alternative conceptions

'If ... all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis, ... that all things are made of atoms, little particles that move around in perpetual motion, attracting ... [or] repelling ... one another' (Richard Feynman, 1994, p. 4) [8].

PNM can be used to describe the various phases of matter. Based on the transitional phases that exist, matter can be readily classified into solid, liquid, gas, or plasma. In a solid, the particles (ions, atoms or molecules) are closely packed together. The forces between particles are strong so that the particles cannot move freely but can only vibrate around a fixed point [68]. When the temperature of a solid is raised, the velocity of the particles increases. The collisions between the particles occur with greater force, causing the particles to move farther apart. The ordered arrangement of the solid breaks down and a change in physical state occurs. As a result, a solid has a stable, definite shape and volume. Solids can only change their shape by force, as when broken or cut.

Studies on chemistry conceptual knowledge indicate that both teachers and students do not have sound knowledge of some fundamental concepts such as atoms and molecules, conservation of matter, and the PNM resulting in a lack of knowledge about

the discipline [68, 69]. PNM stands out as one of the most difficult concepts for teachers and students to understand [55, 69]. Yet, the PNM provides a basis for understanding the invisible microscopic events underlying natural phenomena. As such, there is a consensus among chemistry teachers that the PNM is fundamental toward understanding other chemical concepts [7, 69, 70]. For example, teachers or students with poor knowledge about the PNM are likely to have difficulties in understanding other aspects of chemistry such as phase change, chemical kinetics, intermolecular forces, etc.

PNM has been one of the most acceptable concepts in science education and serves as a powerful tool in studies related to misconceptions [47, 71]. A review of many science educational materials show that PNM is one of the central instructional goals of most science curricula found in many schools. Most often, relations between PNM and the scope, nature and direction of science education are the focus of the teaching and learning approaches [47, 71]. The analysis around these concepts are done in such a way that makes more intelligent students' inclination to reveal all kinds of macroscopic and microscopic aspects of PNM in relations to science [47, 71]. Several studies involving PNM via qualitative research methodology has shown a significant improvement in understanding of science post-PNM, as compared to pre-PNM [47, 69, 71]. This is not surprising because obtaining sound understanding and grasping of concepts of many topics in many science disciplines such as physical, life and earth sciences depend largely on the ideas about the molecular constitution and composition of matter. PNM is so important that, making no reference to a particle model makes it nearly impossible to simplify and explain the macroscopic properties of matter [10]. Thus, the PNM is the 'gateway' of unlocking the complexities and misconceptions about science, especially in

the teaching and learning of chemistry and in research, where it has been the means by which students and researchers makes connections to the ‘real world’ to improve their understanding.

PNM therefore is a concept that must be carefully integrated into learning and success in the construction of PNM knowledge is important while evaluating the effectiveness of pedagogy. An increased emphasis on PNM in introductory chemistry courses, as suggested by James and Nelson [72], along with careful representation of particles by chemists when used in instruction might help to make chemistry more understandable by providing the framework underlying the discipline. Additionally, this approach may bring about an increased ability to solve chemistry problems. Several modules of PNM have been used to evaluate misconceptions of PNM in science at different levels of education.

According to Boz [69], the primary physical characteristics of the various states of matter are the volume and the shape of the material. These characteristics are what really define the states. Osborne and Cosgrove [73] in a study on the changes of states of water found that 25% of their sample of 17-year-old chemistry students thought that the bubbles in boiling water were made of air [73-76]. Shepherd and Renner [77] who examined student's perceptions of the states of matter on the microscopic level, found none of the high school students in their sample had a sound understanding of the particulate nature of gases, liquids, and solids, and that only 43% had a partial understanding. This lack of understanding of the PNM was confirmed by Novick and Nusshaum [48, 78] who found that although misconceptions diminish with schooling, they persist in university students. They found that among students in the university and

in high school, 50% did not attribute the uniformity of particle distribution in gases to inherent particle motion, and over 60% did not appropriately address space in gaseous media [48, 78-80].

Several studies have examined and reported a variety of results regarding students' and teachers' knowledge of the PNM. For example, Boz [69] reported that middle and high school students had difficulties in applying the PNM theory to explain phase changes, even after instruction. Similarly, Ozmen and Kenan [55] found low levels of understanding about the microscopic properties of matter among students in grades 4 to 6. However, in comparing middle school students' ideas about the PNM to those of elementary school students, Nakhleh et al. [68] showed that most middle school students knew that matter was composed of atoms and molecules and some of them were able to apply this knowledge to explain phase transitions of matter. A major obstacle to students' understanding of the PNM is the intuitive belief that matter is continuous in nature rather than particulate. Additionally, students struggle to understand the nature of existence of the particles. Do they exist in contact with one another with no empty spaces between the particles [5] or as continuous matter, consisting of particles in a substance [81] or with all particles of that matter possessing the macroscopic properties of the substance [8, 82-85]?

Students are also unable to conceptualise the weakening of the intermolecular forces as the molecules move further apart from one another when substances melt or boil. Studies involving changes of state from liquid or solid to gas have indicated that students generally have trouble in conceptualising gas to be a substance, with many believing that gas is weightless or is lighter than solids and liquids [86, 87]. Besides, only

a relatively small number of students were able to explain these changes of state making use of the particulate nature of matter theory. It appears that younger students conceptualise a gas in macroscopic terms, as a kind of continuous matter. Only as they progress further can they conceptualise a sub-microscopic theoretical interpretation.

Another study shows students' inabilities to use the PNM to display their understanding of the concepts of solids and liquids and explain the process of evaporation, but the majority could use the theory to define gases [86-88]. This occurrence was expected as students intuitively believed solids to be hard and rigid while liquids could be poured like water. As a result, the presence of particles in solids and liquids was counter-intuitive to students' knowledge about these two states of matter. Diagrams showing the spacing of particles in the three states of matter are often depicted in a distorted manner in textbooks, contrary to the scientifically accepted ratios of 1:1:10 for the spacing between particles in solids, liquids and gases. The discrepancy continues to be perpetuated when teachers use the same diagrams in classroom instruction. In an Australian study, students assumed that particles in a solid were in contact with each other, liquid particles were about one particle apart and gas particles about three to four particles apart [8, 10, 89].

Research results reported by Nakhleh et al. [68] (summarized above) and Ayas, Ozmen and Calik [90], suggest that students' understanding of the PNM increase with educational level because students in higher grades demonstrated more knowledge about PNM than those in lower grades. In recent times, Harrison and Treagust [8, 89] also recommended more research be conducted at senior and post-secondary level that would inform practice. The topic of PNM is first introduced in elementary grades and details on

structure of matter are taught in middle and high schools. At high school level, the PNM is dealt with in different chemistry and physics lessons. The concepts on structure of matter taught in school form a basis for learning other chemical and physics concepts at the tertiary level of education. Therefore, it is critical for students to gain a thorough, correct understanding of this theory in order to be successful in chemistry [8, 89, 91].

Students memorize facts about particle theory with little understanding of the sub-microscopic phenomena [8, 10, 50, 89, 92]). How does this memorization impact them? Spencer [92] found that chemistry students can memorize enough information to correctly answer test questions without developing a sound conceptual understanding of chemistry. This memorization of facts as opposed to a sound understanding of the concept leads to difficulty in chemistry studies [92].

Researchers such as Treagust et al. [93] have studied students' conceptions of gases, and found that students do not initially appear to be aware that air and other gases possess material character. It is common for students to think that air and gas have contrasting affective connotations, such as air is good because it's used for breathing and life, whereas gas is bad because it may be poisonous, dangerous, or flammable. Research also indicates that younger students tend to regard any rigid material as a solid, any powder as a liquid, and any non-rigid material, for example, a sponge or cloth, as intermediate between a solid and a liquid [10]. Pupils explained that powders are liquids because they can be poured and that non-rigid materials are intermediate because they are soft, they crumble, or they can be torn. Thus, students often identify the state of a material according to its appearance and behaviour, with the result that they associated solidity with hardness, strength, and non-malleability.

Three Levels of Representation and Misconceptions

Chemistry is one of the most important branches of science. Because topics in chemistry are generally related to or based on the structure of matter, chemistry always proves to be a difficult subject for many students. Chemistry, by its very nature, is highly conceptual [50] and while much can be acquired by rote learning (this often being reflected by efficient recall in examination questions), real understanding demands the bringing together of conceptual understandings in a meaningful way. Thus, while students show some evidence of learning and understanding in examination papers, researchers find evidence of misconceptions associated with rote learning. Investigations into the reasons why students would struggle to master chemistry concepts have revealed several areas that cause trouble for students rooted in the rigorous mental requirements of the subject matter [50]. An issue involving the abstract nature of the study of chemistry is the requirement that students must be able to use and comprehend three levels of representation: *macroscopic, sub-microscopic, and symbolic representations* [94]. *Macroscopic refers* to what can be observed using the human senses of sight, smell, touch, and hearing. *Sub-microscopic refers* to what scientists believe is taking place at the particulate level (atoms, ions, and molecules) in a chemical reaction.

What about the symbolic? According to Chandrasegaran and Treagust [94], human eyes cannot observe the actual breaking and forming of chemical bonds or the spreading of water molecules as they enter the gaseous state. Humans can only observe the macroscopic evidence that chemical and physical changes are occurring at the sub-microscopic level. It is these changes occurring at the particulate level that students have difficulty in comprehending and relating to their macroscopic observations [95-97]. Students tend to extend macroscopic properties of a substance to sub-microscopic

particles [92]. *Symbolic representation* refers to the chemical symbols found on the periodic table and other symbols used in writing chemical formulae and equations. Since students do not fully understand chemical occurrences at the sub-microscopic level, the symbols and formulas in chemical equations lack meaning. These abstract concepts are important because further chemistry/science concepts or theories cannot be easily understood if these underpinning concepts are not sufficiently grasped by the student [5, 98, 99] .

Unfortunately, the focus in chemistry courses is on the memorization of outcomes in chemistry referred to as "declarative knowledge"[100] rather than on developing a true understanding of the science processes and concepts which require a correct mental framework of chemistry phenomena. This emphasis on rote learning tends to diminish the connections students make across the three representations in chemistry. In addition to struggling to comprehend the three levels of representation in chemistry, studies have reported that high school students hold Alternative Conceptions (AC) in chemistry, related to chemical changes in matter specific to the PNM [10, 50, 92, 94, 96].

Johnstone [101] identified five main areas of difficulty in chemistry studies, namely, curriculum content, overload of students' working memory space, language and communication, concept formation, and motivation of students. The advent of revised school syllabi in the 1960s and 1970s in many countries saw a move toward the presentation of school chemistry in a logical order, the logic usually being that of the experienced academic chemist. Similarly, early chapters in almost all textbooks for first level higher education courses start with topics like atomic theory, line spectra, Schrödinger equations, orbital, hybridisation, bonding, formulae, equations, balancing

chemical equations, calculations, and stoichiometry [101]. Johnstone [101] argued that this logical order may not be psychologically accessible to the learner.

Language has been shown to be another contributor to information overload [102]. Language problems include unfamiliar or misleading vocabulary, familiar vocabulary which changes its meaning as it moves into chemistry, the use of high-sounding language, and the use of double or triple negatives. Words, which were understandable in normal English usage, changed their meaning when transferred into, or out of, a science situation. For example, the word 'volatile' was assumed by students to mean 'unstable', 'explosive' or 'flammable'. Its scientific meaning of 'easily vaporised' was unknown. The reason for the confusion was that 'volatile', applied to a person, does imply instability or excitability and this meaning was naturally carried over into the science context with consequent confusion. Gabel [39] noted that difficulties students have with chemistry may not necessarily be related to the subject matter itself but to the way of teaching.

Chemistry learning requires much intellectual thinking and discernment because the content has many abstract concepts. Unless these fundamental concepts such as dissolution, PNM, and chemical bonding are understood, topics including reaction rate, acids and bases, electrochemistry, chemical equilibrium, and solution chemistry become arduous [5]. Conceptions or pieces of intellectual thought either reinforce each other or act as a barrier for further learning to develop since new ideas are linked together and the learner does not always correctly make such links. This may, however, also lead to misconceptions.

Griffiths [103] asserted that misconceptions may not be just the student's fault. For

example, chemical knowledge structures in combustion, physical and chemical changes, dissolving, and solutions by their very nature leads to alternative conceptions. Bodner [50] indicated that the learner does not come to chemistry with empty minds and often when the teacher first introduces an idea, the learner may already possess previous experience. These ideas are derived from personal experiences and sources such as the media, which may lead to confusion. The process of learning chemistry may involve the modification or alteration of previously held ideas and this is a natural process. It is unique to each individual and there is no way by which the teacher has the time or capacity to approach each learner on an individual basis. However, if concepts are developed with care and built on the language and construct already present within an individual and allowing concepts to be approached from several directions, the learner will be enabled to develop ideas more meaningfully.

The Laboratory Teaching Classroom: The Constructivism Approach

In order to make the teaching, learning and understanding of chemistry accessible, many academic institutions make the teaching laboratory a compulsory part of the course. The practical experiences in laboratory works are aimed at linking the theoretical aspects of chemistry to practice, so that the concepts of chemistry can be well comprehended and assimilated by students. At South Dakota State University (SDSU), the teaching lab enrols not less than 500 students in the fall semester, and Chem 115 specifically enrols chemistry and biochemistry majors. In CHEM 115 students have the opportunity to use analytical instruments in understanding chemistry.

Chemistry laboratory provides the necessarily tools for learning chemistry, which is largely constructivism in nature. The laboratory classroom provides a very good environment for students to actively complete laboratory experiments and learn chemistry

using a variety of laboratory instructional styles, namely expository, problem-based, inquiry and discovery [104]. Expository and problem-based are mainly deductive, while inquiry and discovery are inductive [104]. Typically, students performing experiments under different instructional styles are more likely to have different learning experiences and outcomes [104, 105]. The instructional laboratory courses at SDSU incorporate both deductive and inductive learning approaches but are largely more deductive-centered. The deductive learning approach involves having students apply a more general technique, concept, or principle to understand the material or topic under consideration [104]. The major approaches of laboratory instruction used by many chemistry departments in academic institutions, including SDSU are the expository and problem-based inquiry approach. In expository, students are expected to follow steps/directions in the lab manual to get their results. The students compare their results to an expected one and must explain why their results vary with possible reasons and conclusions based on the results obtained [104]. For the inquiry-based laboratory instruction, there can be different levels of inquiry based from 'guided' to 'open'. In the guided-inquiry, students are made to select their own procedure based on a set questions while the open inquiry allows student to think through the process themselves without any form of help [104]. Even though problem-based inquiry laboratory experiments can be time consuming, it promotes the development of higher cognitive skills by helping students develop and trouble shoot the 'defined problem' and thereby increases overall understanding of the topic under consideration [104, 106].

Irrespective of the instructional style used, students preferred to work in groups, or collaboratively, as in the 'think-pair and share strategy [104, 107, 108]. Thus, making

students work in pairs helped in knowledge sharing and construction, and fostered confidence and motivation. It is important to note that the laboratory aspect of teaching and learning chemistry is very crucial in understanding chemistry and shaping the student's ability to comprehend and develop their skills that would be applicable in research, academia or industry. Such skills cannot be learned in the traditional classroom settings either via demonstration or through lecture. It has well been established that, students learn more by doing the activity themselves, and therefore the laboratory classroom is a key supplement to the learning process for chemistry programs [104, 105, 107-109], including Chem 115 at SDSU.

Use of Lab Instrumentation in Evaluating Chem 115

The Chem 115 lab at SDSU is a well-organized lab with several analytical instruments to help the student understand analytical chemistry for their respective disciplines. The main purpose of this project is to verify the usefulness of the analytical instrumentation in the teaching lab. That is, how does the instrumentation help students toward understanding chemistry? This was accomplished by evaluating the pre- and post-PNM through a qualitative research methodology.

The majority of Chem 115 lab instrumentation and curricula is based on Spectroscopy and Separation science techniques. Analytical spectroscopic techniques such as Atomic Absorption Spectrometry (AAS), Ultra-Violet Visible (UV-VIS) Spectrometry, Fourier Transform Infra-Red spectroscopy (FTIR) and Fluorescence are the main foci of the syllabus. The separation techniques Gas Chromatography (GC), High Performance Liquid Chromatography (HPLC) and Electrophoresis are also explored.

AAS is a powerful technique for elemental analysis (typically volatile metals such as iron, arsenic, lead, cadmium etc) [110-114] , whereby the free gaseous atoms are made

to absorb electromagnetic radiation (ER) at a specific wavelength characteristic of the element to produce a signal that is quantifiable. The signal produced when free gaseous atoms absorb ER in the optical path of the analytical device is proportional to the concentration of the gaseous atoms present [115-118]. The quantification principle is based on Beer's law [115, 116]. For the Chem 115 class, a typical example was the determination of the concentration of iron (Fe) in cereals by AAS. The elements in the sample were converted to gas using a high thermal energy source through the atomizer. This technique involves PNM because the process involved a phase change, i.e., the samples are changed from solid/liquid to gas at high temperatures prior to analysis. When a solid sample was involved, an electrothermal atomization technique (e.g., graphite furnace) was typically used for the direct analysis [115]. Figure 2.1 shows a schematic for a typical AA spectrometer [115].

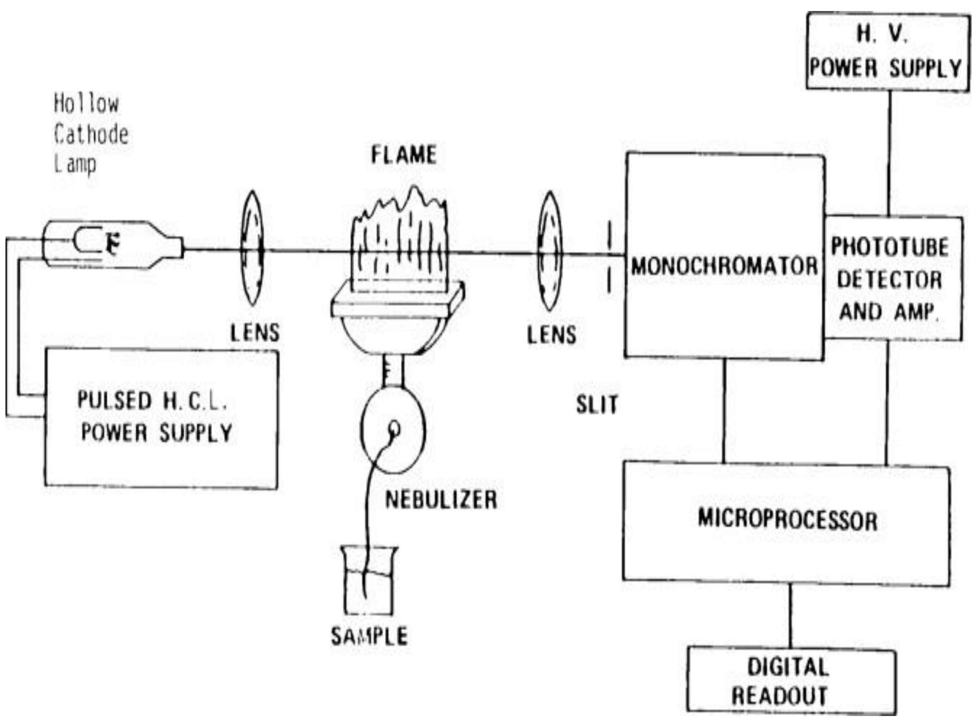

Figure 2. 1. Schematic Components of a typical AAS instrument [115].

The sample is vaporized and the element of interest is also atomized through the flame atomization system (normally an air-acetylene flame at 2300 °C) or high energy furnace. The concentration of the element is quantified based on the attenuation or absorption by the analyte gaseous atoms of a characteristic and specific wavelength that is emitted from a hollow cathode lamp light source. The lens focuses the light through the monochromator which separates the element spectra and that of the light source, while the detector is typically a photomultiplier tube aided by an amplification device for easy read out and interpretation [115].

UV-Vis spectroscopy is one of the most used analytical techniques in most chemistry labs both in academia and industry for both quantitative (e.g., trace amounts of metals content in alloys [119, 120] or even some amount of drugs [121-123], and sugars [124-126]) and qualitative purposes (e.g., identification of functional groups in molecules, especially organic molecules [127, 128]). Electromagnetic radiation of certain frequencies is unique for every molecule, and these specific UV frequencies are absorbed by the electrons of the molecule, subsequently causing excitation of these electrons from the ground state to an excited state. These electronic transition energies are quantized, and the amount of light absorbed by the solution containing the analyte depends on the concentration of the analyte, the path of length of the light and the molar absorptivity of the analyte, as stipulated by Beer's Law [128-131]. In fluorescence spectroscopy, the frequencies of light emitted after absorption of light by molecules in the sample are measured [130-132]. In the Chem 115 class, UV-Vis was used for copper determination in a penny and the standardization of a solution used in titration while the fluorescence spectroscopy was applied in free energy studies and calorimetry. FTIR was applied in several situations for the identification of organic compounds in samples or for characterization of inorganic compounds as well [133-135]. In Chem 115 this technique helped identify organic functional groups.

GC is a widely used analytical separation technique [136-138]. It uses gaseous molecules as a mobile phase transport to move the sample (which have been also heated into the gas phase) through a packed column or a capillary column containing a polymeric stationary phase with a small internal diameter [139, 140]. The sample containing the analyte of interest is introduced in the liquid form or on micro fibre (Solid Phase Micro Extraction [141, 142]) or sorptive bars [143, 144], where they are heated into the gaseous phase by a thermal source in the Inlet, or the thermal desorption unit prior to separation in the GC oven. Most GC carrier gases or mobile phases are gaseous helium, hydrogen or nitrogen, which flow under pressure to carry the analyte through the column in the GC oven, then to the detectors (Figure 2.2). The data generated from the detector are then analysed with the computer with a specialized software. GC are used mostly for volatile compounds and in CHEM 115 was used to identify specific alcohols in a mixture.

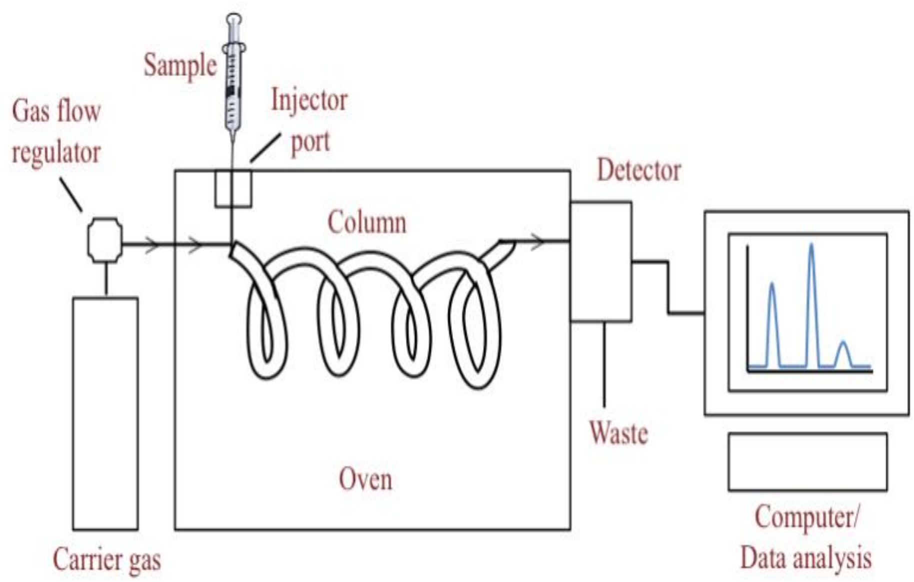

Figure 2. 2. Components of Gas Chromatographic instrumentation. Adapted from https://bitesizebio.com/28687/carrying-gas-chromatography/ on January 2, 2020.

In contrast, HPLC methods are used to separate compounds in the liquid form. The mobile phase is a liquid solvent in which the analytes are transported from the sampling lines through to the column and to the detector. The stationary phases are mostly solid support, and the separation is based on the distribution of the analyte between the mobile and the stationary phase during the migration. For separation to be effective, an appropriate column and solvent are selected to provide wide separation and resolution of peaks [145, 146]. HPLC was applied to quantify caffeine in various substances for the Chem 115 class.

Electrophoresis is a separation method for charged molecules where the separation is based on the migration of the charged particles (ions) under the influence of an electric field through an appropriate medium. The velocities of the ions govern the separation which are in turn affected by the particle (ion) size, shape, charge, temperature, pH, ionic strength, and other electrophoretic electrical parameters such as current, voltage and power [147]. In CHEM 115 electrophoresis was used to separate basic biomolecules.

Most of the techniques described briefly above employ several fundamentals of PNM, including phase change, intra- and intermolecular interactions and therefore are explicitly explained through an understand of PNM. Consequently, for students to understand these techniques they must have PNM while using these instruments. Therefore, we propose that the CHEM 115 laboratory could be used to measure changes in PNM as students use these techniques.

Warner et al. [58] explored the impact of instrumentation on learning by conducting an instrumentation survey. Students in a laboratory section who were exposed to GC-MS, IR and UV-Vis analytical instruments during an organic course were asked to respond. The results suggested that hands-on use of these instruments mattered in enhancing technical knowledge, and with a more guided inquiry approach problem solving capabilities were improved [58].

Wedvik et al. [63] also studied student learning of intermolecular forces involved in separation and identification of mixtures using n-alkanes as forensic ‘arson samples’. GC-MS, computer modelling, and viscometry were used and students interpreted these data. The conclusions from the use of this variety of experimental data helped the students understand more about intermolecular forces and how these forces were involved in these chemistry processes resulting in their ability to solve ‘crimes’ [63].

In 2011, Csizmar et al. [64] employed GC and microscale distillation as analytical tools for evaluating teaching and learning of chemistry. Student understanding of the relationship between intermolecular forces and structural basis of these forces were measured. Briefly, the students were introduced to Lewis structures of selected organic compounds, their molecular weights, increasing polarity and collected data on distillation rate and retention time after post microscale distillation and GC analysis, respectively. Surveys and student presentations after a laboratory exercise indicated that students were able to understand the relationship of intermolecular forces with chemistry concepts. 133 of 149 either strongly agreed or agreed that the approach helped in understanding the relationship between molecular structure, intermolecular forces and boiling point. Furthermore, 116 out of 149 strongly agreed or agreed that the experiment helped them to

increase their chemical knowledge and skills [64]. The results also suggested the majority of the students found the laboratory exercise to be highly informative, beneficial and enjoyable.

Several other researchers have reported the significance of laboratory work as a tool for enhancing teaching and learning of science (chemistry). Cunningham et al. [148] reported in 2018 that boiling point determination and dual GC were successful in providing a valuable insight into the molecular intermolecular forces when students investigated the structural differences between ethanol and 1-butanol using these analytical methods [148]. Blonder et al. reported that an open-ended inquiry-based experiment using GC with different high school students of different abilities deepened their understanding in diverse ways, as per their different levels [149]. Bruce et al. [150] reported that students constructed an infrared spectrometer after the use of PhET simulations and visiting the American Chemical Society Climate Science Toolkit. Results from this inquiry-based investigation showed the laboratory activity had a positive influence on the students regarding their understanding of concepts on the identification of greenhouse gases [150].

Cavinato [151] explained that there could be some challenges (e.g., time and effort from instructors and students) associated with the implementation of active learning in an analytical laboratory settings. Students feedback from open-ended projects indicated overall benefits were positive, as students had the propensity to gain hands-on knowledge, sharpen their analytical and critical thinking skills. Additionally, the significant improvement in lab skills also boosted student self-confidence and independence [151].

The focus of this work is to verify how the lab-based work using analytical instrumentation improves the teaching and learning of chemistry in the Chem 115 class. Specifically, we used PNM as a concept to measure the impact of the use of instrumentation in the course.

CHAPTER 3: METHOD

Research Design

Research site

The location of the study was the SDSU Chemistry and Biochemistry Department. SDSU is a four-year public university of average size with high performance in research activity. The department runs three major programs for its undergraduate students: biochemistry (accredited by the American Society for Biochemistry and Molecular Biology), American Chemical Society endorsed chemistry, and chemical education. Additionally, the department offers opportunities in honors and pre-professional programming for its majors and additional courses for non-science majors. The target population for this study was freshmen enrolled in the Chem 115 and 115L courses. Students in 115/115L are enrolled as one of the three departmental majors, or one of the three departmental majors working for honors distinction, or another science major taking the honors 115/115dL sequence. Chem 115 and 115L chemistry students were selected for the study because of the variety of instrumentation used in the CHEM 115L courses.

Sample

The accessible population was the Chem 115 and 115L chemistry students who likely had previous experiences with/or had learned about the topic of PNM. This was because students in CHEM 115/115L had prior chemistry courses which likely provided minimal exposure for students to the PNM. Therefore, we began this study under the

assumption that students had at least a minimum understanding of PNM or were familiar with it.

Selective/purposeful sampling was employed as students in the CHEM 115 and CHEM 115L classes were provided the opportunity to participate. Upon receiving approval for human subject's research (Appendix A), the instructor's permission was obtained to visit the class at which time the researcher distributed and discussed consent forms for CHEM 115 & 115L students. The discussion comprised a framework of the project, a copy of consent forms, and an invitation letter to partake in the project. All documents are found in human subjects' research proposal in Appendix A. These were handed to students over 18 years of age and those agreeing to take part in the study were then asked to respond to the questionnaire/survey. The survey was collected and evaluated to allow the researcher to determine which individuals to interview.

Monitoring PNM

In this study, the purpose was to explore Chem 115 students' understandings and conceptions of the PNM and to find out if the use of research instrumentation in the chemistry laboratory had any impact on their understanding of the particulate nature of matter. A survey was used to monitor students' understanding of the PNM. The results of the questionnaires were analysed scientifically and objectively by the researcher. When the data were quantified, the results were used to compare and contrast other research and to measure change in PNM.

In this study, the data collected using the questionnaire involved both numeric and text information. The numeric and text information represent the quantitative and

qualitative data respectively. The qualitative data was collected first followed by quantitative data regarding students' understanding of the PNM.

In addition to the survey, three sets of interviews were completed, one at the beginning of the semester, the other at mid-semester and the last one at the end of the semester. Additional detailed information was collected from each participant to provide individualized data about changes in student views of the PNM and the impact from instrumentation.

The surveys were given to participants the first day. They were asked to complete these surveys and bring them to the next CHEM 115 class period. The researcher collected surveys as they entered the room and students were asked if they would volunteer to take part in the interviews. Those who agreed were given interview consent forms and dates were scheduled. Students were interviewed, answers to questions recorded and analysed.

Part one of data collection involved an exploration of CHEM 115 students' understandings and conceptions of the PNM. The completion of a pre-survey at the beginning of the semester and post-survey at the end of the semester were done in approximately 30 minutes.

In the second phase of the study, 3 interview sessions were held in the researcher's office. It took approximately 30-60 minutes for each interview, which was digitally recorded. The interview was done in English. The type of questions asked regarding the PNM during interviews can be found in Appendix C.

Data Collection Procedure

Data were collected in two phases. The first phase of data collection involved an exploration of students' understanding of the PNM through the survey/questionnaire

approach. On meeting the class, the first day and time, prospective students were briefed and those who volunteered were selected to participate in the intended study. I informed those students participating in the pre-and post-survey process that a pizza party would be provided before the end of the Fall 2018 semester. For each student participating in all three interviews, ice cream would also be provided following the third interview. When students were asked to complete the consent form, they were given the questionnaire to complete, and a date and time were arranged for their return. Given approval by participants, the researcher met participants on the approved date and time to collect the answered surveys. In the second phase of the study, the researcher similarly obtained permission from the students and scheduled the first interview which focused on the initial knowledge of PNM. In this study the researcher used structured interview protocols which included a specific list of questions for the interviewee. The goal of the first interview was to establish a baseline on students' knowledge of the PNM.

During second interviews which occurred during mid-semester, students were asked to ascertain whether CHEM 115 and 115L had impacted their understanding of the PNM. The third interview was conducted at the end of the semester to further investigate the impact of the lab and instrumentation used on the individual's PNM knowledge.

Overall data was made up of interviews (qualitative data) and surveys (qualitative data). Qualitative data was part of four major groups: interviews, documents, observations and audio-visual materials, and surveys.

Survey Questions

The survey questions were created based on the issues about the concepts of PNM to which we had interest. Several prior surveys about PNM [51, 73, 152-161] provided

questions for my surveys, depending on specific content of interest to my work and to work with my adviser and other colleagues.

Individual Interview Protocols

The interview protocols were created based on the survey questions to get an in-depth understanding from students' answers given on the survey. l searched and researched from papers and work of others to generate interview protocols to fit my project, and with the help of my adviser and colleagues we were able to tailor it to my topic. The interview was intended to provide rich details of students' understandings of the PNM on research question one (1) how do students explain the properties of and changes of state using particulate mature of matter. The individual interview was conducted using a structured interview approach. This approach involves the interviewer having written list of questions[160] (shown in Appendix C) to ask the interviewee during the interview.

Data Analysis

The analysis of the data for this study was in three different steps: a) coding of surveys   b) transcribing of interview transcripts and c) coding transcribed interviews. Data analysis was a continuous process beginning when student information on multiple-choice questions (surveys) were sorted looking for themes in students' responses. The multiple-choice responses had one identified correct answer but also included answers which are considered misconceptions. The answers chosen by students allowed the investigator to identify those students who do not understand the PNM. The themes and codes assigned to the data were continuously merged resulting in the identification of three codes: 1) Particulate nature and Sound Understanding (PSU), 2) Particulate nature

and Some Misconception (PSM), and 3) No particulate nature and no understanding (NPS). Percentages for each code were calculated.

Pre/post survey students' responses were grouped and codes were compared to identify trends that emerged from student understanding of the PNM. The surveys included open-ended questions and students' response were also categorized using the same themes and sorted into codes. Frequency distribution of the alternative conceptions held by the participants were determined.

The students' audio recorded interviews were transcribed at the end of each survey period. Themes were identified and the same codes were used for analysis.

Validity and Reliability

Validity was ensured using triangulation of data. Multiple and different sources of data were collected through pre/post survey and three sets of interviews to provide extra support to the finding from the study. For instance, students were asked probing questions to buttress the multiple-choice questions they answered in the survey and the use of multiple sources helped to verify student statements.

Reliability was ensured using interrater reliability studies. During data analysis, coding rules were developed then shared with a chemical education colleague. My colleague and I discussed the rules then she used the rules to code a small portion of the data. The interrater reliability coefficient was 0.79 which was acceptable reliability value for qualitative study.

Role of the Researcher

As a student of qualitative research, the researcher role was focused on the instrumentation in this project. The interest in qualitative research stems from my

background as a Chemistry Educationist with 21 years of teaching experience. My focus for the project was qualitative research and I have used surveys and interviews in my prior master's project and various graduate level courses to answer some research questions. My experiences helped in preparing the interview protocol to ask specific questions with other follow-up questions during the interview, allowing for a rich data set.

As a professional, experienced teacher and teaching assistant, the researcher understands the concept of PNM which helped in coding of PNM answers given by students. Also, as a researcher my role was to make sense of the data collected, grouping them into similar and different themes. During the interview, the researcher oversaw digital recording of each interview session and writing field notes alongside. It was an important task to keep the information safe. The digital recording was used by the researcher to record interactions. All student interviewees were given pseudonyms. For all discussions about the data, pseudonyms were used to protect student confidentiality.

Researcher Bias

The researcher's prior knowledge and biases were reduced due to the use of multiple data collection methods. Validity and reliability measures also helped to reduce bias. First and foremost, as a teaching assistant of the chemistry laboratory, I knew of student's attitudes towards chemistry labs. Some students' comments and attitudes showed they did not understand or learn anything in the lab activities and they typically expressed that they did not see any connections between the theory taught in class and the experiments performed in labs. This knowledge of student perceptions was not allowed to influence the development of instruments, the data collection, or conclusions drawn from the study.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the analysis and discussion of results of the data collected through surveys and interviews. Data obtained from students pre/post survey, multiple-choice questions, and open-ended responses from interview questions will be discussed to present the outcome of the research instrumentation in chemistry laboratory and the impact on their understanding of PNM.

To verify for trends in correct understanding and some common alternative conceptions that students may have about aspects of matter and molecules using the PNM, a pre/post survey was administered to the students at the beginning and at the end of the semester, and three set of interviews were administered (beginning of semester, mid-semester and end of semester). The written responses students gave were qualitatively analysed. The items on the questions administered were meant to find out how the students think about the particulate nature of matter and how physical changes in matter differed using scientific thinking. These differences included molecular conceptions concerning the nature, the arrangement, and the movement of molecules as well as macroscopic and microscopic conceptions concerning the nature of matter and how it is affected by physical change.

The research was conducted at the chemistry & biochemistry department at SDSU with Chem 115 students during the Fall semester in 2018, with ten (10) students as overall respondents for pre-surveys, and eight (8) students for post-surveys. Seven (7) were interviewed during the early part of the semester, 5 at the mid-semester and 5 after the semester concluded**.** Survey responses were coded, interview responses/transcripts were transcribed, and coded for each question's category, respectively, as applied in

quantitative research methodology. Inter-coder reliability was carried out, and the reliability coefficient was 0.79, which is generally regarded as reliable [162-168].

The students' responses to each question were categorised into particulate nature and sound understanding (PSU), particulate nature and some misconception (PSM) and non-particulate nature and no understanding (NPU). The responses that included totally correct explanations is the PSU category. Responses that included illogical or incorrect student answers which could not be accepted as reliable or not related to scientific knowledge are classified as PSM. The responses that contained irrelevant information or an unclear response; responses such as "I do not know, lt is a guess" or no response are grouped under NPU.

Research question 1: What is the Perception of Students on Particulate Nature of Matter (PNM)

Students perception on the PNM were reviewed by asking eight (8) questions which were generally centred on properties of matter/ change of states and other topics in PNM (Appendix B). After analyzing the response from the students, it was observed that the students had different levels of understanding to the PNM at varying degrees. The most frequently selected answers by students were largely the correct answer from the multiple choice provided for each respective question (Q1 through Q8). In exception of Q3 between 50% to 80% of all the students chose the most frequently selected answer, which was also the correct answer for each question (Q1, Q2, Q4, Q5, Q6, Q7, Q8), respectively. For Q3, the most frequently selected answer was 50% of all the students, which was the wrong option from the multiple-choice answers given for Q3. From Q1 to Q8, Students who selected the correct answers and provided a sound explanation (sound

and particulate) for their choice of answers were between 30% to 70% of all the students. Figure 1 and Table 1 outlines the details.

Properties of Matter/Change of States of Matter

The students' mental models on PNM and properties of matter were verified using eight survey questions, given consecutively, that the students provided responses to and gave written reasons why they chose a particular response. The questions were asked on properties of gas, changes of states; difference between the solid, liquid and gaseous state of matter using the PMN as well as the arrangement of the molecules of each state of matter. The responses students gave under each of these were tallied as: number of students who gave correct reason (particulate and sound understanding) PSU, number of students who gave incorrect reason (particulate with some misconception) PSM and number of students who made no attempt (non-particulate with no understanding), NPU. Also, all the student's written responses were quoted verbatim and analysed qualitatively.

Figure 4.1 shows students' pre-survey responses for the questions in Appendix B. The most frequently selected answer for all questions is shown in Figure 1. Example, for Question 1 (Q1), students were asked to indicate with reasons "which of the following must be the same before and after a chemical reaction". They were given the following options to select from:

(a) The sum of the masses of all substances involved.
(b) The number of molecules of all substances involved.
(c) The number of atoms of each type involved.
(d) Both (a) and (c) must be the same.
(e) Each of the answers (a), (b), and (c) must be the same.

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

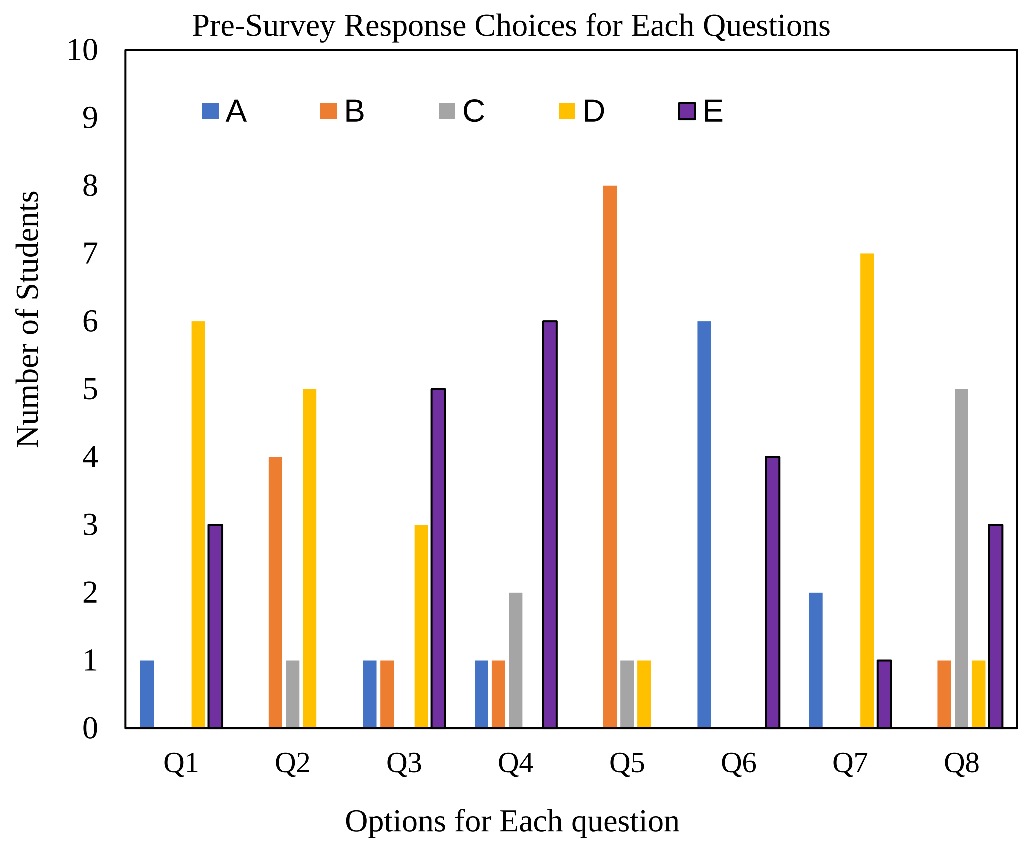

Figure 4. 1. Pre-survey responses (labelled A, B, C, D, and E) to research questions in Appendix B.

The students had different answers for each question type asked, and not all 10 students gave one answer to a question. Example for question 1 (Q1), one student (10%) opted for option A, 6 (60%) selected option D, and 3 (30%) students picked option E, respectively. In question 6 (Q6), 6 students chose option A, while 4 selected option E, representing 60 and 40 % of all the students, respectively. The most frequently selected answer given for each question, Q1 through Q8 are presented in Table 4.1. The % correct answers for each question are also provided alongside.

Table 4. 1. Comparison of most frequently selected answer and correct answer

Question	[b]Most frequently selected answer (%)	[c]Correct answer with sound explanations (%)
Q1 [a](D)	60% option D	50%
Q2 (D)	50% option D	50%
Q3 (D)	50% option E	30%
Q4 (E)	60% option E	60%
Q5 (B)	80% option B	70%
Q6 (A)	60% option A	60%
Q7 (D)	70% option D	70%
Q8 (C)	50% option C	40%

[a] letters in parenthesis are the correct answers from the multiple choice given.
[b]" Most frequently selected answer" are not necessarily the correct answer., e.g., question 3 (Q3). [c] Correct answer includes both right multiple-choice answer and sound explanation to the answer

Correct answers/responses in Table 4.1 refer to PSU (particulate and sound understanding). Technically, PSU is defined in this context as choosing the correct answer from the multiple choice given and offering sound explanation/reasons for choice of answer. Conversely, PSM is defined as selecting correct answer from the multiple choice and providing wrong explanation or selecting wrong answer from the multiple choice and providing correct explanation**.** NPU are those who selected wrong answer

choice and gave incorrect explanations. In question 1 (Q1) in Table 4.1, the most frequently selected answer (mode) was 60% (of all the students). The correct answer for Q1 was option D (in parenthesis under the question section) but the explanations given for answers varied, and this can be seen in the "Correct answer with sound explanation section" in Table 4.1. Thus, for Q1, the most frequently selected answer was 60% but only 50% of all the student chose the correct answer with a sound explanation, meaning that 10% of all the student could not give the desired explanation even though they selected the correct answer (option D) from the multiple-choice answers set provided. By definition, these 10% who selected the correct answer from the multiple choice but could not offer a sound explanation for their answers automatically falls under the PSM category. In summarizing the scenario in Q1, it can be concluded that 50% of all the students can be regarded as PSU with at least 10% of all the students in the PSM category; the other 40% of all the students may be only PSM or only NPU or a combination of both PSM and NPU (i.e., a fraction of NPU and PSM**).** Figure 4.2 shows the overall categorization of the students. For the Q1 discussed earlier, the PSM and the NPU were 30% and 20% of all the students, respectively, (PSU was 50% of all the students). Similarly, in Q5, 80% of all the student selected option B (most frequently selected answer, and correct answer-shown in parenthesis) but 70% of all the student got everything correct (both correct answer choice and had a sound explanation), implying that 10% of all the student gave incorrect explanation even though they selected the correct answer (option B). Hence for Q5, we have 70% of all the students as PSU, and at least 10% of all the students as PSM, while the remaining 20% of all the students may be only NPU or only PSM or a fraction of PSM and NPU. As shown in Figure 4.2, the

summary for the categorization for Q5 were as follows: PSU-70% (of all the students), PSM-20% (of all the students), and NPU-10% (of all the students), respectively. Same trend was observed in Q8, where 50% of all the students selected the correct choice (option C) but 10% out of the 50% were not able to provide sound explanations for their choice of answers, indicating a 40% of all the students can be categorized as PSU and at least 10% of all the students as PSM, and the remaining 50% of all the students could be either NPU or PSM or both. There was no NPU category in Q8 (i.e., NPU= 0%). As indicated in Figure 4.2, the percentage of PSU and PSM were 40 % and 60%, of all the students, respectively. For Q2, option (D) was the most frequently selected at 50% of all the students, while 50% of all the students selected the correct answer (option D) and gave sound explanations. This means that we have 50% of all the students categorized as PSU, and the remaining 50% of all the students may be either PSM only or NPU only or both NPU and PSM. A closer look of the categorization in Figure 4.2 for Q2 revealed that there was no NPU (NPU= 0%) while PSU and PSM were 50% and 50%, (of all the students), respectively. A similar trend was observed for Q4 and Q6 where 60% of all the students were most frequently selected answer (mode) which also happened to be the correct answer from the multiple-choice questions (option E and A respectively for Q4 and Q6), and all 60% of all the students offered sound explanations for their answers respectively, leading to automatic PSU of 60% each of all the students for Q4 and Q6, respectively. The other 40% of all the students, each in Q4 and Q6, may be NPU only or PSM only or a fraction of PSM and NPU**,** respectively for Q4 and Q6. In Q4, the PSM was 40% of all the students, while the PSM in Q6 was also 40% of all the students. In both Q4 and Q6, there was no NPU (Figure 4.2). Q3 is quite a unique situation from all

the other questions, in that the most frequently selected answer (option E) was 50% of the all the students. However, the most frequently selected answer by all the students was not the correct answer from the multiple-choice answers given (the correct choice was option D). Consequently, the 50% of all the students that selected option E i.e., the most frequently selected of all the students) automatically falls under either PSM or NPU or a fraction of PSM and NPU. As outlined in Figure 4.2 (for Q3), 30% of all students fall under the PSU category, while 50% and 20% of all the students were PSM and NPU, respectively. None of the 50% from the most frequently selected option in Q3 qualified to be in the PSU category, since they selected the wrong answer.

It is clear from Table 4.1 that some students, if not all, had different levels of understanding to the PNM at varying degrees as seen from the responses for Q1 to Q8. Figure 2 shows the details of student performance with respect to PSU, PSM and NPU, respectively for the pre-survey questions.

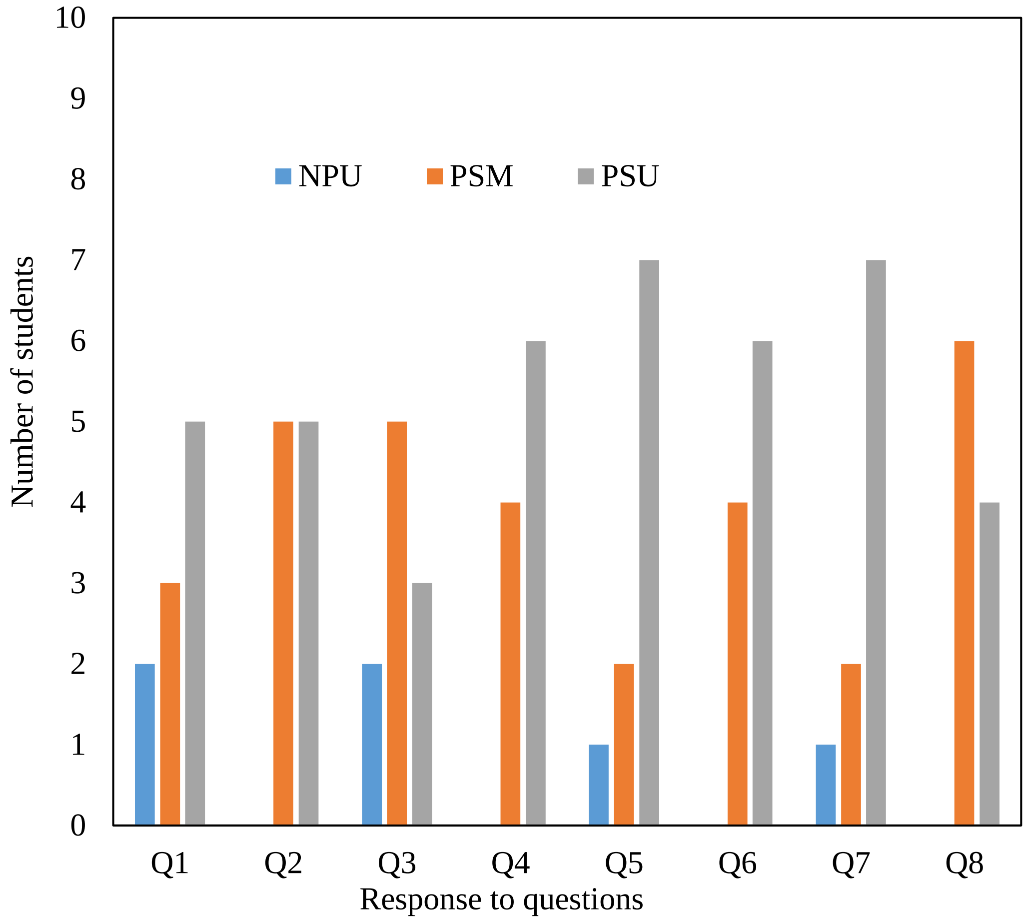

Figure 4. 2. Alternate conception to PNM Grading Scale to Students Responses (No. of Students, N, = 10) for Pre-survey questions (Q1 to Q8). PSU=Sound understanding of PNM, PSM is particulate with some misconception, and NPU is non-particulate with no understanding.

PSU are those with correct answers and some good explanation for the questions asked on PNM. PSM categories are those whose answers can be regarded as partially correct or partially incorrect. NPU are those whose answers are completely incorrect. In Question 1(Q1) for example, 50% of all the students had correct answer with sound understanding of PNM, while 30% and 20% of all the students can be categorized into the PSM and NPU, respectively.

From Q2, 50% of all the students can be categorized as PSM, and the other 50% of all the students as belonging to the PSU. Similarly, as can be seen for Q8 in Figure 2, 40% of all the students answered correctly with acceptable explanations (PSU) while 60% of all the students had a partially correct answer (PSM) with 0% of all the students completely wrong answers. Overall, at least 50% of the students answered the questions correctly with sound explanations (PSU) for most of the questions, except Q3 and Q8 that had 30 and 40%, of all the students as PSU, respectively.

The responses given by each student from Q1 to Q8 are extensively outlined in Table 4.2 below. The following are some correct reasons/explanations the students provided for their choice of answers for question 1 (Q1) above.

> "According to the law of conservation of mass, the mass of the system must remain constant. Also, the number of atoms must stay the same because they cannot be created or destroyed." (Student A)
>
> "...number of molecules change usually in a chemical reaction" (Student B)
>
> "...new molecules may form during the chemical reaction" (Student C)

From these explanations, it is evidently clear that such students have some good understanding and/or background knowledge of PNM: that option D is correct (50% of all the students had this correct-Table 4.1) and that "the sum of the masses of all substances involve and the number of atoms of each substance must be the same before and after a chemical reaction".

Conversely, some students gave completely wrong answers with some incorrect explanations (NPU), as can be seen in Figure 4.2, especially for Q1 (20% of all the students), Q3 (20% of all the students), Q5 (10% of all the students) and Q7 (10% of all the students). Some of the reasons given for their incorrect answers for Q1 are quoted below:

> "Mass can change after chemical reaction" (Student D)
>
> "Atoms and moles are correlated and are proportional" (student E)

Students who wrote these reasons might have either forgotten or did not grasp the concept of conservation of mass from high school or earlier parts of their college classes. Chemistry students tend to construct inappropriate mental models of abstract phenomena that makes it difficult for them to understand the concepts [95, 96]. Therefore, its important to use multiple teaching methods, including experiments with analytical instruments.

Table 4. 2. Students explanations/reasons for their answers.

Student Response	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8
Student 1	The sum of masses must stay the same	Water can change into oxygen and hydrogen gases	Assumed that there needed to be 3 oxygens	Gas molecules move faster and are further apart	More water less molecules	In evaporation water changes into oxygen and hydrogen	There is always matter be- ween oxygen molecule	pressure will have affect molecule amount and size
Student 2	Atoms and molecules are correlated and proportional	Bubbles rising is oxygen floating to top	Felt the need of oxygen to be an even number	Gas molecules moves faster and have more space	Water dilutes things	Water does not exist anymore	No space between molecules no air or water vapor	Gas under pressure gets more or less
Student 3	Mass can change after chemical chemical reaction	The bubbles release O2 and H2 into the air	E represents 2SO3	Gas has more spaces between them	m1v1=m2v2	Water turns into a gas	Matter seemed appropriate	nrT/PV Number of particles will not
Student 4	Masses would not change	Heat changes the state of water	Each S is paired with an O3	Gas molecules spreads out	molecules will be less packed	water evaporates into the air	nothing between them	pressure decreases molecule shink in size
Student 5	The number of molecules is not the same before and after the reaction	Water is changing state from liq. to gas	Enough O2 for 4SO3 and 2S atoms will be left	molecules spaced further apart	Dilute solution with sugar present	water evaporates into the air	only molecule in the gas is O2	pressure do not change the size of molecule
Student 6	Number of atoms must remain constant,	heat turns water from liq. of	ratio of S to O is 1:3 thus	Water molecules are still	ppm /ppb decrease as soln.	Water transitioned from liq.	Only Oxygen in the sample	As pressure increase density

	also they cannot be created or destroyed	state to gas state	3 oxy-gen to 1 sulfur	intact	diluted	to gaseous state		increases
Student 7	number of molecules change usually in chemical reaction	Water turns into vapor when boiling	S atoms have their energy level filled	Gas are freely moving	Molecules of sugar spread out more	Molecules become much smaller when they evaporate	nothing between the mole- cules	As pressure reduced CO_2 have to spread out and disperse
Student 8	Number of atoms and molecules remain the same	O and H want to rise when heated (bubbles)	6 O for every 2 S atoms	Water molecules leaves into air when water evaporates	same amt of sugar molecules remain after H_2O is added	Evaporation is oxygen and hy- drogen in the air	Nothing exist between them	Pressure would force the mole- cules to grow larger
Student 9	New molecules may form during a chemical reaction	molecular struture is not broken	$2SO_3$ So 2 S atoms and $3O_2$ atoms	Particles get farther apart but dont break into individual atom	Water double & sugar stays same so half surgar particles	Water molecules evaporated	Only thing between O molecule is bond to hold them together	The particles wont be moving as fast if pressure is reduced
Student 10	molecules will spilt	Assume the bubble contain hygrogen and oxygen gas	D has same number of O and S as the picture	Water evaporates in to form single H and O_2 molecules	sugar molecules wld spread out with addtn of more H_2O	Water molecule will separate into H and O_2 gas molecules	Matter is between the O_2 gases	Molecule would spread out apart from each other

"St Re" refers to students explanation, "St.1, St.2, St.3"..…….denotes student 1, 2, and so on

Analysis for the post surveys revealed a very interesting trend, as outlined in Figure 4.3. Generally, the responses from the pre-survey and the post-survey were quite different, with some shifting from one of the categories (i.e., PSU, PSM and NPU) to the other across all the eight questions (Q1 to Q8). Using Q1 responses as an example, 5 students (i.e., 50% of all the students) each fell under the category of PSM and PSU respectively, with no NPU (i.e., 0% of all the students as NPU). This observation can also be seen for Q8 responses. For Q2 responses, a student (12.5% of all the students) shows no knowledge at all (NPU) for the question while 2 (25% of all the students) gave some answers but with some elements of misconceptions (i.e., partially correct answers, PSM) while 5 (62.5% of all the students) students gave correct answers with sound explanations (PSU). As shown in Figure 4.3, most of the students gave correct answers (PSU, between 50% and 87.5% of all the students, respectively) across board after the post-survey, while a few gave wrong answers (between 0 and 12.5 % of all the students, respectively) with the 12.5% (of all the student) in as shown in Q2 and Q5 at 12.5% of all the students, respectively. For Q2, a student gave a totally wrong answer (NPU) while 2 and 5 students gave partial (PSM) and correct answers (PSU), respectively. Conversely for Q5, a student gave wrong answer while 2 and 5 students gave partial and correct answers, representing 12.5 % of all student as NPU, 25% of all students as PSM and 65% of all students as PSU, respectively.

Comparing the pre-and post-survey responses show an overall general trend of increased understanding and knowledge in PNM for most of the questions asked. The improvement in the post-survey response may be due to the additional teaching exposure,

both theory and practical (including the experience with the analytical instrumentation). Table 4.3 shows the stark differences in the responses for the NPU, PSM and the PSU categories.

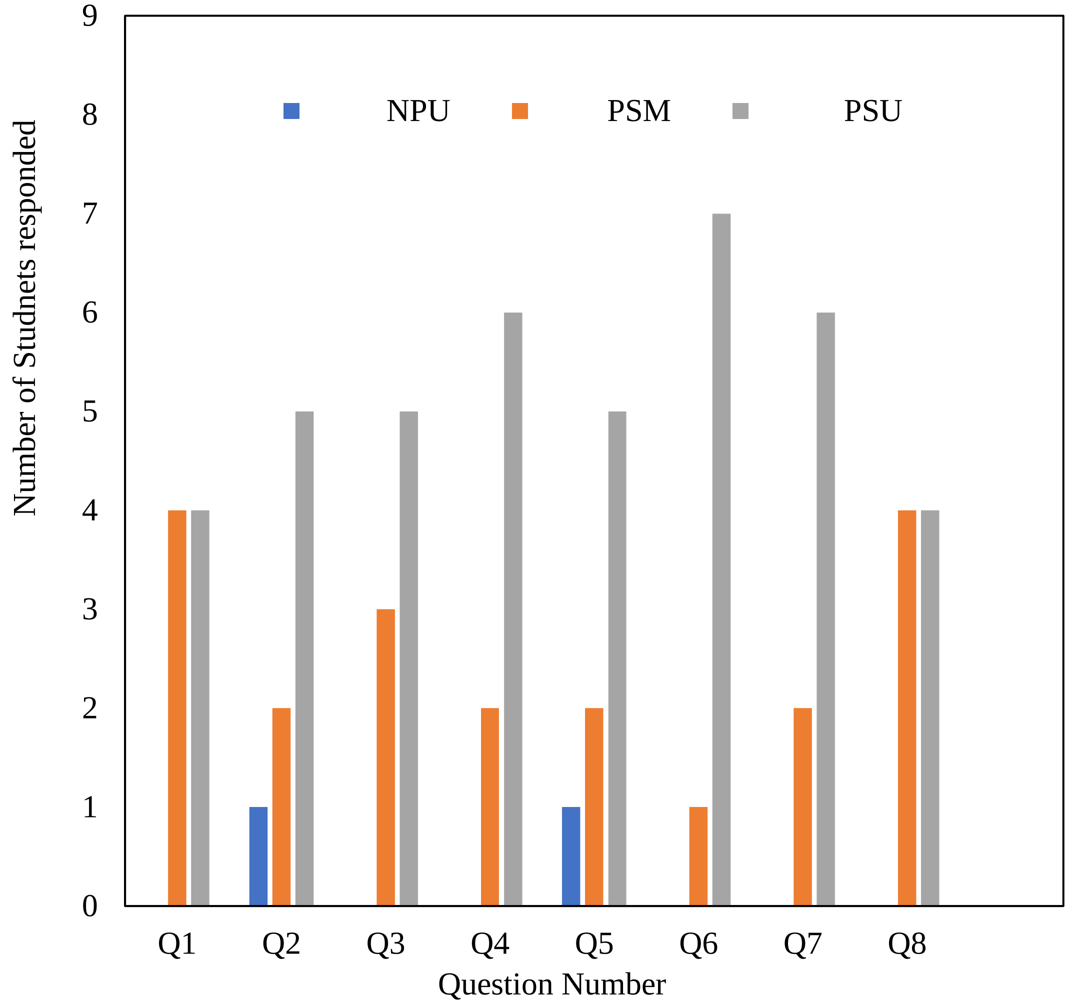

Figure 4. 3. Post-survey responses and conception scale for the respondents (No. of students, N = 8).

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Table 4. 3. Comparison of Pre- and Post-Surveys

Question No.	Category of Answers					
	NPU		PSM		PSU	
	% Pre S[a].	% Post S[b]	% Pre S.	% Post S	% Pre S.	% Post S
Q1	20.0	0.0	30.0	50.0	50.0	50.0
Q2	0.0	12.5	50.0	25.0	50.0	62.5
Q3	20.0	0.0	50.0	37.5	30.0	62.5
Q4	0.0	0.0	40.0	25.0	60.0	75.0
Q5	10.0	12.5	20.0	25.0	70.0	62.5
Q6	0.0	0.0	40.0	12.5	60.0	87.5
Q7	10.0	0.0	20.0	25.0	70.0	75.0
Q8	0.0	0.0	60.0	50.0	40.0	50.0

[a] Pre-survey, [b] Post survey, NPU = incorrect answer, PSM = partially correct answer, PSU = correct answer

For the same set of questions, a decrease (net) in the % of NPU (from pre- to post-survey) with corresponding increase (net) in % PSM and or PSU is an indication of positive impact (increased knowledge and understanding of PNM). Furthermore, a decrease (net) in % PSM followed by an increased PSU can be regarded as a positive

impact (provided the NPU remained the same or reduced). A positive impact may also come about when there is a significant increase (net) in %PSU with a corresponding decreased (net) in %NPU and PSM, respectively. However, a negative impact is characterized by a significant decrease (net) in % PSU and or PSM with attendant increased (net) in NPU. Taking the NPU category for example, there was slight decrease in that for Q1, Q3 and Q7 but an increase in Q2 and Q5 for the pre-and post-survey analysis. Similarly, there was a general decrease for the PSM category for Q2, Q3, Q4, Q6, and Q8 with a corresponding increase in the PSU for all the selected question categories, respectively. More details on the overall alternative conception and impact of the research are elaborated in the preceding sections.

Researcher Question 2: What are Students' Alternative Conceptions Relating to the PNM Before and After use of Instrumentation?

In order to determine and assess some common alternative conceptions (i.e., misconceptions) that the participants (students) had about some aspect of PNM before and after use of analytical instrumentation, the data gathered from pre-surveys and post-surveys were compared in Table 4.3. Table 4.4 outlines the alternative conceptions for the PSM group which is an index of the misconception obtained from the pre- and post-surveys.

Table 4. 4. Percent Alternative Conception outlook for Pre- (N=10) and Post- (N=8) survey

Que. No.	Category PSM		Category PSU		Observed Trend and Remarks for Each Question
	% Pre S.	% Post S	% Pre S.	% Post S	
Q1	30	50	50	50	Increase in PSM by 20%, no increase in % PSU
Q2	50	25	50	62.5	25% PSM decrease with 12.5 % increase in PSU
Q3	50	37.5	30	62.5	22.5% PSM decrease with 32.5 % PSU increase
Q4	40	25	60	75	15% PSM decrease, with 15% PSU increase
Q5	20	25	70	62.5	5% PSM increase with 12.5% PSU decrease
Q6	40	12.5	60	87.5	27.5% decrease in PSM, 27.5% increase in PSU
Q7	20	25	70	75	5% increase in PSM, 5% increase in PSU
Q8	60	50	40	50	10% PSM decrease, 10% increase in PSU

"Pre S" represents Pre-Survey, "Post S" is Post-Survey.

For both pre-surveys and post-surveys, there were some significant amount of alternate conception for all the answers provided for the eight set of questions (Q1 to Q8). For example, in Q1, the PSM recorded were 30% of all the students for pre-survey and 50 % of all the students for the post-survey. This finding is consistent with the study carried out by Lee et al. [169]. They used 15 sixth-grade science classes taught by 12 teachers to find out the conceptual framework that students used to explain the nature and structure

of matter and molecules. They also assessed the effectiveness of two instructional units in helping students change those conceptions. They identified among other findings that students have three common patterns of misconceptions concerning the conservation of matter during physical changes. These are: (a) substances are conserved during physical changes, but not necessarily the mass; (b) substances transform into other substances during physical changes, rather than simply changing form; and (c) substances disappear and cease to exist, instead of continuing to exist but becoming invisible. They further reported that students' misconceptions about conservation of matter were a recurring problem and presented difficulties for students describing and explaining a number of phenomena. From the time they carried out their study to this present study is little over two decades, yet some students have such learning difficulties regarding the PNM. This means that we have not yet found a very potent teaching strategy to help students learn for a deeper understanding of the concept.

In finding out the origin of some of these misconceptions for Q1 in the pre-survey for example, 30% of all the students score is in the PSM category. It is suggestive to indicate that the 30% of the students did not understand the PNM properties as suggested by Johnstone [101, 102] and Gabel [7, 39] that learners are generally incapable of coping with the teaching of sub-microscopic, macroscopic and symbolic levels being taught simultaneously. From the interview questions, most of the students indicated that they learnt most of the PNM from middle through high school. Post-survey PSM results of Q1 was 50% of all students, meaning a 20% increase in alternative conception for Q1. In the analysis of the transcribed data from the interviews before and during the commencement of the lab courses, some students generally expressed a concern that they did not have

any prior idea of the theoretical background of the topics that were being taught at the teaching lab and that the lecture and the lab topics were different. That is, there was no correlation between what is being taught in class and in the practical lab. For example, a student wrote that "I learnt less in Chem 115 because…. the lecture did not correlate to the homework nor the test".

Also, using question 7 (Q7 below) as an example, most of the students show some level of misconceptions.

"In a pure sample of oxygen gas, what exists between the oxygen molecules?"
(a) Matter
(b) Air
(c) water vapor
(d) nothing
(e) atmosphere
"Your answer is": ________________

"Paragraph (or two) describes why you chose your answer and why you did not choose other answers".

A closer look at Table 4.4 for Q7 shows that the misconception measurement (PSM) was 20% and 25% of all the students, respectively for pre- and post-surveys. However, the NPU were 10% and 0% of all the students, respectively, for pre- and post-surveys while the PSU category had 70 % and 75% of all the students, respectively, for post- and pre-surveys. In this very instance, there was a 5% increase in both PSM and PSU group, while all the 10% that were in the NPU in the pre-survey reduced to 0% in the post-survey NPU. It follows to suggest that the 10% in the NPU (from pre-survey group) split, with 5% each being added into both the PSM and the PSU post-survey category respectively, or 5% of the PSM group from the pre-survey added onto the PSU group (post-survey) while all the 10% NPU (pre-survey) automatically joined the PSM (post-

survey) after the student used the analytical instrumentation. Whichever the scenario is, there was a reduction in the NPU, which is an overall positive impact.

The misconception about mixed gas had been reported by some researchers. Chung and Chiu [170] reported that students have difficulty forming correct mental models and the consistency of conceptions about a mixture of gases in the particulate model of an ideal gas. In this study, it is suggestive to indicate that some of the students may be having similar challenges. Chung and Chiu [171] suggested that to understand the difficulties students face when they learnt the concepts of gas particles microscopically, teachers should build a series of multiple-representation teaching models. Through understanding of students' mental models, science teachers can develop a proper teaching model to help students learn scientific concepts and change their conceptions [170-172].

Table 2 shows all the explanations given by the students for Q7 above. Below are some of the reasons/answers given by some of the students to Q7 above:

> "There is always a matter between oxygen molecules, just a guesswork" (Student A)
>
> "Matter is between the oxygen gases" (Student B)
>
> "Only thing between O-molecule is bond to hold them together " (Student C)

From the responses above, students A and B seem to not show better understanding on the concept of PNM, while student C gave a fairly reasonable and acceptable response (the answer was not totally correct). Some of the PSU students did not give all perfect explanations but due to the fact that they chose the correct option they were put into PSU category. Analysis of the responses of the students show some misconception in the PNM. The misconception of chemical bonding and familiarity with PNM had been

reported by Othman et al. [173] for 260 students between the ages of 15 and 16 years (Grade 9 and 10) in a secondary school in Singapore. The researchers' results suggested that some students do have limited understanding of PNM which also influenced their understanding in chemical bonding [173], and that the finding is a useful tool for challenging students' misconceptions about PNM. Are you connecting this finding to your finding in your study?

Overall, the total percentage of PSM across Q1 to Q8 is 310% for pre-survey, while that for post-survey was 250%. The overall difference between the pre- and post-survey percentages is -60% (i.e, 250% minus 310%). On average, the % PSM per question (Q1 through Q8) for pre-and post-survey were 38.75 (i.e., 310 divided by 8) and 31.25 (i.e., 250 divided by 8), respectively. We can therefore say that there was an average of 38.75 % alternative conception for the pre-survey while its 31.25% for the post-survey. It can be concluded that the PSM which is an indicator of alternative conception after the research per each question (Q1 to Q8) reduced by 7.5 % (i.e., 31.25 minus 38.75). The 7.5% reduction may be a positive impact (that is, assuming they were added to PSU category), negative impact (when they are added to the NPU) or mixed (i.e., some fraction of the joined the NPU and the PSU group). Table 4.4 suggests that the 7.5% were more of a positive impact, as the number of PSU increased significantly, while the NPU were reduced (Table 4.3).

Reasons for misconceptions may be many. Student conceptions are often inconsistent with the scientific conceptions they are required to learn or comprehend [174-176]. Misconception studies have largely shown that students develop different conceptions from those who teach or guide them in their learning [174]. These

misconceptions may be highly resistant to change [174, 177], and may further influence subsequent learning [174], and might lead to “conceptual trajectories”[174, 175] which had been shown to be rampant across many educational and cultural set ups [174] .

Research Question 3: What is the impact of instrumentation on mental model concerning particulate nature of matter?

The dynamics of the responses from students (for both pre-and post-surveys) in the various categories, NPU, PSM and PSU are well detailed in Table 4.3. The responses show an overall improvement from NPU to either PSM or PSU when the pre- and post-surveys were compared respectively. For most of the NPU category, the percentage reduced across board except for Q2 (0% pre-survey to 12.5% post-survey) and Q5 (10% pre-survey to 12.5% post-survey). Also, the PSM for Q2 also reduced from 50% in the pre-survey to 25% in the post-survey. However, the PSM Q5 shows an increase in the % of students that either selected the right answer with incorrect explanations or gave some acceptable explanations but selected the wrong answer choice (i.e., 20% from pre-survey to 25% in post-survey). Again, a closer look at Q2 in the PSU group shows an improvement from 50% in pre-survey to 62.5% in post-survey. Overall, for Q2, it follows from Table 3 that 12.5% from the PSM group (pre-survey) shifted to the NPU in the post survey while another 12.5% from the pre-survey PSM moved to PSU post-survey. This may account for the reason why the PSU for Q2 increased from 50% to 62.5% while the PSM reduced from 50% to 25% and the NPU increased from 0% to 12.5 %, respectively for pre- and post-surveys in each category. Even though not very likely, it is also possible that 12.5% of the pre-survey PSU group “got confused” and gave totally wrong answers and explanations and therefore added up to the NPU group post-survey while 25% of the

PSM in the pre-survey group improved their answers and explanations to add to the post-survey PSU to make the 62.5%. The total effect, however, for Q2 is that about 12.5% got everything correct during the semester, potentially due to their experience with the analytical instrumentation (the lecture and other activities may also be a factor for the improvement). However, in Q5, the PSU reduced from 70% pre-survey to 62.5% in the post-survey, a reduction of 12.5%.

In Q6, there was a significant increase of the PSU from 60% (pre-survey) to 87.5% (post survey), an increase of 27.5%. Furthermore, the PSM for Q6 also show a reduction of 40% to 12.5%, for the pre-and post-surveys, respectively. Since both the pre- and post-surveys of the NPU were both 0%, the observation in Q6 suggest that the 27.5% of the pre-survey PSM group improved their PNM, both correct answers and right explanations and therefore joined the PSU group after the post-survey. Similarly, for Q4, the PSU increased from 60% to 75% while the PSM reduced from 40% to 25%. Since the pre- and post-surveys NPU were also 0% each, the increased in the PSU category can be attributed to 'migration" from PSM to PSU, after the post surveys and the interviews. Same trend can be seen for Q8, where 10% migrated from PSM to PSU.

A 'bird eyes view' of the PSU column in Table 4.3 shows a general increment from Q2 to Q8 (Q1 was unchanged). In summary, the total percentage of PSU from Q1 to Q8 is 430% for pre-survey, while that for post-survey was 525%. The nominal average or the pre-survey PSU is 53.75 (i.e., 430 divided by 8), and that for the post-survey PSU is 65.63% (i.e., 525 divided by 8). This means that 53.75% of the students had very good understanding of PNM before taking their lecturers and the use analytical instrumentation in Chem 115L thus 9 (the lab), while 65.63% of the students showed sound perceptions

of PNM after they took their laboratory course in the Chem 115L at SDSU. The difference in % before and after the students did the experimentation with the analytical instrument is 11.88% (i.e., 65.63 minus 53.75). At least, here were about 11% of the students who had improvements in their perception on PNM after they used the analytical instrumentation in their chem 115L lab. Furthermore, the argument for the positive impact can be made from the definition that a decrease in % NPU (overall) followed by a corresponding increase in PSM and or PSU, or a % PSM reduction followed by increased in PSU (provided % of NPU remained the same or reduced), or a significant increase in PSU followed by deceases in NPU and PSM. Table 4.5 below gives a detailed summary for the overall observation for trends in NPU, PSM and PSU.

Table 4. 5. Overall Effect for the Categories for PNM at Pre-survey and Post-survey

PNM Category	% Total Pre-Survey (Q1 to Q8)	% Total Pre-Survey (Q1 to Q8)	[a] Interpretation (Net Effect)
NPU	60	25	35% decrease
PSM	310	250	60% decrease
PSU	430	525	95% increase

[a] Net effect is the difference between the % pre- and % post-survey.

In effect, there are decreases in %NPU (35%) and %PSM (60%) with a significant corresponding increase in %PSU (95%). Therefore, the impact observed was positive. The data in Table 4.5 suggests that the %NPU and %PSM categories actually migrated from their pre-surveys to the post-surveys PSU. The positive impact as observed in the surveys were also collaborated by the interviews, as shown in Figure 4.4 below. The interviews conducted were coded, and transcribed into NPU, PSM and PSU, with same definition as in the surveys. The data was subjected to intercoder reliability, and the reliability coefficient was 0.79, which is generally regarded as acceptable [162, 163].

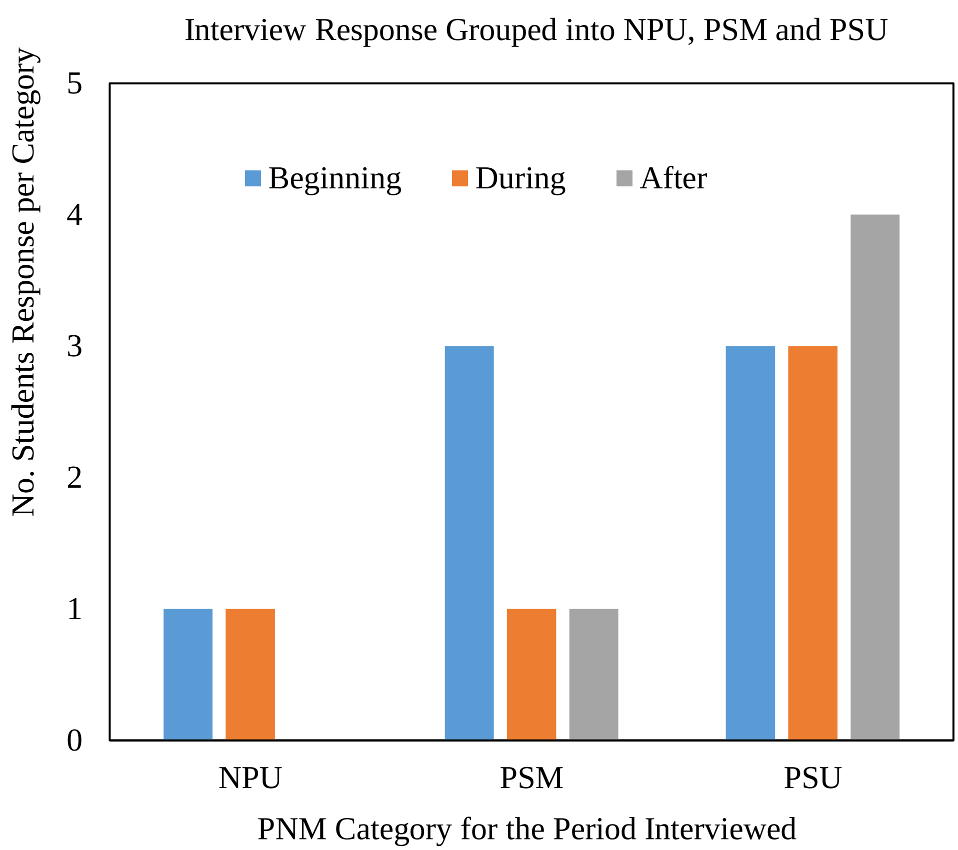


Figure 4. 4. Distribution of NPU, PSM and PSU at the beginning (N=7), during the semester (N=5) and after the semester (N=5).

At the beginning of the semester, 7 students were interviewed, and out of this, 1 student fell under the NPU (~14%), while the PSM and the PSU were 3 each (i.e., 43% PSM and 43% PSU, respectively). During the semester, the number of students interviewed reduced to 5. Out of this, we have 1 as NPU (20%), 1 as PSM (20%), and 3 as PSU (60%). After the semester, there was no NPU (0%), but the PSU was 4 (80%) while the PSM was 1 (20%). It is clear from this trend that the NPU totally reduced (from 14% to 0%) and PSM reduced drastically (43% to 20%) with an accompanying significant increase in PSU (43% to 80%), respectively. Even though the sample size was reduced during and after semester interviews, the observed trend in the interviews supported what was exhibited in the surveys. Thus, both the survey and interview results show a positive impact on PNM, an indication of better understanding of PNM after the students used the analytical instruments in their labs (Chem 115 L). A general question was posed to these students at the end of the semester (interview) about whether or not if the analytical instrument had helped in their learning and understanding of chemistry. The following are some of the summarized statements of the students transcribed from the interview:

“ I really like the lab work more than the lecture. The lab was fun, and made me to really love chemistry and some of the stuff sticks really good” …Student A

“I think the Chem 115L was helpful, because I love doing the practice than reading a lot and doing of assignments… Student B

“The Chem 115 Lab made me to see how instruments work for doing chemistry stuff. I like seeing the instrument and how they give the numbers for our solutions” …Student C

“In my group, we exchange ideas about the work we did with the chemistry instrument in the lab. Working with the instrument was really fun and help me to do more in chemistry for the first time”…Student D

“I like mixing of the solutions and how we measure them with the instrument. I really like doing stuff with my hands I am a handy person. The Chem 115L was very handy, and really good way to learn chemistry.”…………Student E

From the statements above, it is suggestive to generalize that analytical instrumentation played a role in helping the students to learn chemistry in the Chem 115L, and that the instrumentation in the Chem 115L had some positive impact on the understanding of chemistry. Some of the instruments used in the analytical lab (Chem 115L) during the semester were GC-MS, NMR, FTIR and UV-Vis. The positive impact of analytical instrumentation in teaching and learning of science (chemistry) had been one of the areas being looked at by some educators in recent times [58, 61-65, 125]. What is our finding here? Do we agree with the papers that you mention below?

Warner *et al*.(2016) [58] worked on the correlation of teaching and learning chemistry using laboratory instrumentation such as the balance, GC, GC/MS, IR, NMR, polarimeter, and UV−Vis. In this research, students were surveyed about their knowledge

and experience with this instrumentation for eight months plus, spanning over a five-year period using surveying tools as a means of data gathering for the pre- and post-organic chemistry students. The main goal was to verify the student's ability to use critical thinking and problem solving skills by making intentional choices about the type and nature of instruments required for solving particular and defined chemical problems, and also, gaining sound knowledge of facility and chemical instrumentation [58]. After the exploration, Warner *et al.* found out that the level of exposure to instrumentation in the lab can affect some changes in the student, and that upgrading the instrumentation does not necessarily impact the students' knowledge of instrumentation. The group also found that the provision of instrument intensive labs and continuous access to instrumentation helped in the technical competency of the student. Furthermore, the results suggested that the ability of students to use critical thinking in solving problems can be improved by increased exposure, and continuous and increased opportunities working with the laboratory instrumentation. Warner *et al.* [58] and his colleagues concluded that general chemistry students' ability of solving problems improved significantly (in statistical sense) when they were introduced to FT-IR and GC.

In 2007, Csizmar *et al*. [64] reported how beneficial the implementation of GC-MS and microscale distillation was for the understanding of intermolecular forces. Briefly, students were given some tutorials on distillation, gas chromatography and the trend of some selected chemicals in terms of molecular weight, polarity, etc. as well as the nature of Lewis structures. Students were required to go through the practical aspects of the microscale distillation and the gas chromatography practical. After the experiments and exchange of data for each student, a survey conducted show that 133 out of 149 students

that used the ‘GC-distillation’ experiment were helped to understand the relationship between the molecular structure, intermolecular forces, and boiling point. Overall, the response from a majority of the students indicated that the laboratory experiment with the ‘GC-distillation’ was highly informative, beneficial, exciting and enjoyable; thus, the response was very favourable, suggestive of significant contribution of the ‘GC-distillation’ for improved learning, and that experiment was beneficial to their learning.

In 2003, MacNeil and Volaric [61] explored the incomplete combustion phenomenon of candles and gas chromatography-thermal conductivity detector (GC-TCD) instrumentation to explain the concepts of incomplete combustion, thermodynamics and kinetics to first-year chemistry students, where they showed that the incomplete combustion is mainly due to kinetic processes, rather than thermodynamics. Essentially, the students were asked to write the chemical equations for the combustion, measure the amounts of oxygen and nitrogen gas with GC-TCD in a designed apparatus (in an inverted position) in a sealed spaced after the candle flame had been burnt to extinction. The students were able to estimate the levels of O_2 as well as ratios of O_2 and N_2 after post combustion from the enclosed space. After the experiment with the candle flame and the GC-TCD, the students were asked to re-take a pre-lab which they had previously taken prior to the experiment. Subsequently, their overall performance after engaging in experimental exercise rose from 33% to 79%, with the more scores about the knowledge of oxygen and nitrogen composition in the air, rising from 11% to 97%. This is an indication that the experiment with the GC-TCD instrumentation contributed to their overall performance.

In 2001, Reeves and Pamplin [62] incorporated hands-on GC-MS into their general chemistry lecture and laboratory courses, and found out that the introduction of GC-MS in their pedagogy helped students to not only gain mastery of the instrumentation but also improved their understanding and clarified isotopic abundance distribution and their relationship to the atomic mass. Their results also suggested that isotopic distribution can be inferred from their atomic masses based on the number of peaks that was seen in the mass spectrum by the students. The students were happy to have been able to confirm their results by way of calculations and comparing NIST library for the halobenzenes and carbonyl compounds and several transition metals that they studied.

PNM has been a major tool in accessing the effectiveness of teaching and learning science by many educational researchers. Analytical instrumentation has recently been used as a strategy for improving the learning and teaching science (chemistry). Both PNM as an evaluation tool or assessment and analytical tool as a catalyst for effective teaching and learning of chemistry has proven to give quite a positive feedback. In our research, we explored both the PNM and analytical instrumentation to gauge the understanding and perception of chemistry by Chem 115 students in SDSU, and we have shown that combining both approaches can be an alternative approach for accessing the teaching and learning of chemistry, even though this approach is not yet common.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the methodology (model) used in the research, the key findings and provides the conclusion and recommendations for future works.

Summary

One focus of the researcher was to explore Chem 115 students' understanding and conceptions of PNM. Another was to find if the use of research instrumentation in the instructional chemistry laboratory had any impact on their understanding of PNM. Finally, the researcher sought to identify student's correct and alternative conceptions concerning the PNM. The three research questions are provided again here:

- What is the Perception of students on particulate nature of matter?
- What are students' alternative conceptions relating to the particulate nature of matter before and after the use of instrumentation?
- What is the impact of instrumentation on mental model concerning particulate nature of matter?

Selective/purposeful sampling of 10 students in the Chem 115 lab of Fall 2018 allowed for a qualitative research design to be employed investigating students understanding and application of the PNM. The students' mental models on PNM and properties of matter were verified using eight (8) survey questions, given consecutively. The students' responses gave written reasons why they chose a particular response. Topics included properties of gases, changes of states, and differences between the solid, liquid and gaseous states of matter and the researcher investigated student PNM

particularly in how students view the arrangement of the molecules of each state of matter. The responses students gave under each of these were tallied as:

- the number of students who gave a correct reason (particulate and sound understanding) PSU,
- the number of students who gave an incorrect reason (particulate with some misconception) PSM, and
- the number of students who made no attempt (non-particulate with no understanding) NPU.

Data was collected by way of surveys (pre-survey at the beginning of semester, and post-survey after the semester), and interviews at the beginning, during and end of the semester. Seven (7) students were interviewed during the early part of the semester, 5 at the mid-semester and 5 after the semester was completed. The data were analysed in three different steps:

a) coding of survey responses,

b) transcribing of interview transcripts, and

c) coding transcribed interview responses.

Intercoder reliability was employed for consistency of transcribed data. The inter-coder reliability gave reliability coefficient of 0.79, which is generally regarded as reliable. Also, all the student’s written responses were quoted verbatim and analysed qualitatively. The data were used to address research questions established prior to the implementation of the study.

Research Question 1**:** What is the perception of students on particulate nature of matter?

Response to research question one was centred on the perception of students on PNM. Analysis of data was done by looking at the most popular answers chosen by students from the options provided and their written reasons given for selecting that particular option. A comparison of the most popular and expected answers were made, and the perception of PNM was gauged based on the expected (correct) answers. Direct quotations from students were also highlighted to reveal the extent of perceptions among the students who participated in the surveys.

Students' responses from the pre-survey (Table 4.1), showed a clear perception amongst the participants, except for Q3. Between 50% to 80% of students chose a specific answer, referred here as the most frequently selected answer, which was also the correct answer for each question (Q1, Q2, Q4, Q5, Q6, Q7, Q8), respectively. For Q3, the most frequently selected answer was selected by 50% of all the students, but was the wrong option from the multiple-choice answers given for Q3. From Q1 to Q8, 30% to 70% of the students who selected the correct answers also provided a sound explanation (sound and particulate) for their choice of answers.

Table 4.1 clearly shows that some students, if not all, had different levels of understanding to the PNM at varying degrees as seen from the responses for Q1 to Q8. Some students provided correct answers with a good explanation and are labelled as exhibiting PSU for these questions regarding the PNM. Other students were categorized as PSM, which means partially correct or partially incorrect. Finally, the remaining student responses were categorized as NPU as those whose answers were completely incorrect. Figure 4.2 outlined the description of perceptions upon grading the student responses as NPU, PSM and PSU for the pre-survey responses. In Question 1(Q1) for

example, 50% of all the students had a correct answer with sound understanding of PNM, while 30% and 20% of students were categorized into the PSM and NPU, respectively.

From the pre-survey as indicated in Figure 4.2, the NPU ranges from 10 to 20 % of all students, PSM ranged from 20 to 60 % of all students, and PSU was between 30 to 70%. Similarly, the post-survey responses (Figure 4.3), show that the NPU ranged from 0 to 12.5 % of all student as NPU, 12.5 to 50% of all students as PSM and between 50 to 87.5% as PSU, respectively. Overall, the data showed there was an alternative perception of PNM and that the students had different PNM concepts. From the data it can be concluded that for the NPU category for both pre- and post-survey responses, at least 10% of all students did not have any idea about PNM, while PSM group (for both pre- and post-surveys), that is, students with some understandings were at 20% of all students, and for the PSU category (for both pre- and post-survey) were at least 30%, indicating that at least 30% of all students had good understanding of PNM. For the same set of questions, a decrease (net) in the % of NPU (from pre- to post-survey) with corresponding increase (net) in % PSM and or PSU was an indication of positive impact (increased knowledge and understanding of PNM). Furthermore, a decrease (net) in % PSM followed by an increased PSU can be regarded as a positive impact (provided the NPU remained the same or reduced). A positive impact may also come about when there was a significant increase (net) in %PSU with a corresponding decreased (net) in %NPU and PSM, respectively. However, a negative impact was characterized by a significant decrease (net) in % PSU and or PSM with attendant increased (net) in NPU. Table 4.3 outlines the dynamics of these changes for each question (Q1 to Q8) for both the pre- and post-surveys. Taking the NPU category for example, there was slight decrease in that for

Q1, Q3 and Q7 but an increase in Q2 and Q5 for the pre-and post-survey analysis. Similarly, there was a general decrease for the PSM category for Q2, Q3, Q4, Q6, and Q8 with a corresponding increase in the PSU for all the selected question categories, respectively. Clearly, the data show that some of the students had different understanding for the same set of questions that was used to elicit responses from them.

Research Question 2: What are students' alternative conceptions relating to the particulate nature of matter before and after the use of instrumentation?

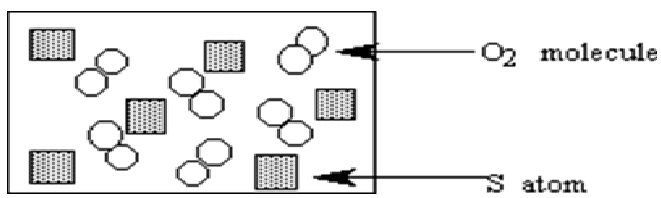
Response to research question 2 shows that students had alternative conceptions of PNM, and these are outlined in the PSM category (both pre- and post-survey). The PSM are the group of students whose responses were correct answers with incorrect explanations or vice versa. From Table 4.3, we recall that the % NPU category for the pre-survey was between 0 to 20 (i.e., the range, define as minimum and maximum % NPU). This implies that a maximum of 20% of all students piloted in the pre-survey were unable to give a correct answer and sound explanation, and the post-survey range was. 0 to 12.5 % of all students. The %NPU reduced in the post-survey considerably, and this is a very positive dynamic, since the overall PSU was increased and PSM was reduced (an indication that those NPUs migrated to PSU largely), as outlined in Table 4.4 (Chapter 4). With respect to PSM, which is an index of alternative conceptions, the % PSM range for the pre- and post-surveys were also 20 to 60 and 12.5 to 50 of all students, respectively.

Thus, up to about 60% of all the students either gave a correct answer with wrong explanations or gave a wrong answer with a correct explanation for the pre-survey while up to 50% gave correct answer with wrong explanations or vice versa for the post-survey.

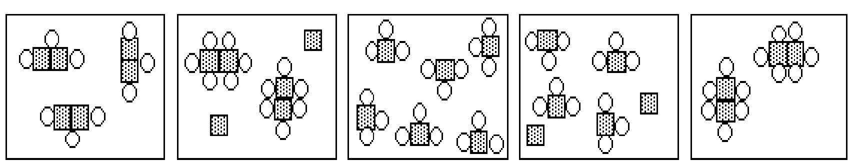
The alternative conception reduced in the post-survey, as compared to the pre-survey, which can be regarded as positive "migration", since the post-PSU data was observed to have increased (Table 4.4).

Both pre- and post-PSM data show there was alternative conception about the PNM in my study. In the pre-survey, some students selected correct answers but gave wrong explanation and vice versa. However, in the post-survey, most of these students improved in their explanations, in addition to selecting the right answers from the multiple-choice questions provided. Selected responses from the pre- and post-survey explanations of several students are shown here in response to question 3.

Question 3: The diagram represents a mixture of S atoms and O_2 molecules in a closed container



Which diagram shows the results after the mixture reacts as completely as possible according to the equation $2S + 3O_2 \rightarrow 2SO_3$?



a) b) c) d) e)

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

Student A

Pre-survey Statement: It represents 2SO3

In this response Student A shows several poor conceptions. First, the incorrectly written chemical formula indicates a lack of understanding of the representation of a molecule. Second, the student failed to evaluate the number of atoms of each element in both reactant and product situations, indicating a lack of understanding of the relationship between the number of atoms of an element involved in a chemical reaction. He/She referred only to the product from the equation (using an improperly written formula) without evaluating the number of reactants and the ratio to which they were combining.

Post-survey Statement: The O atoms are more than S atoms. There are 3 more O atoms than S atoms, so the O is a lot more than the S atoms

In this response Student A has improved in their response. During the pre-survey student A did not consider the number of oxygen and sulfur atoms, but in the post-survey they are considering that number. However, the student still lacked a full conception of the issue since the comparison of the number of atoms of O and S are not correct.

The student improved in their understanding as they began to consider the importance of the numbers of atoms of elements. Their PNM thinking has improved on this basis. This may have been due to the instrumentation labs but no direct connection can be made. While there was improvement, there still were some misconceptions.

Student B

Pre-survey Statement:2 molecule of S and 3 molecules of O

Student B response shows some understanding of chemical representation with

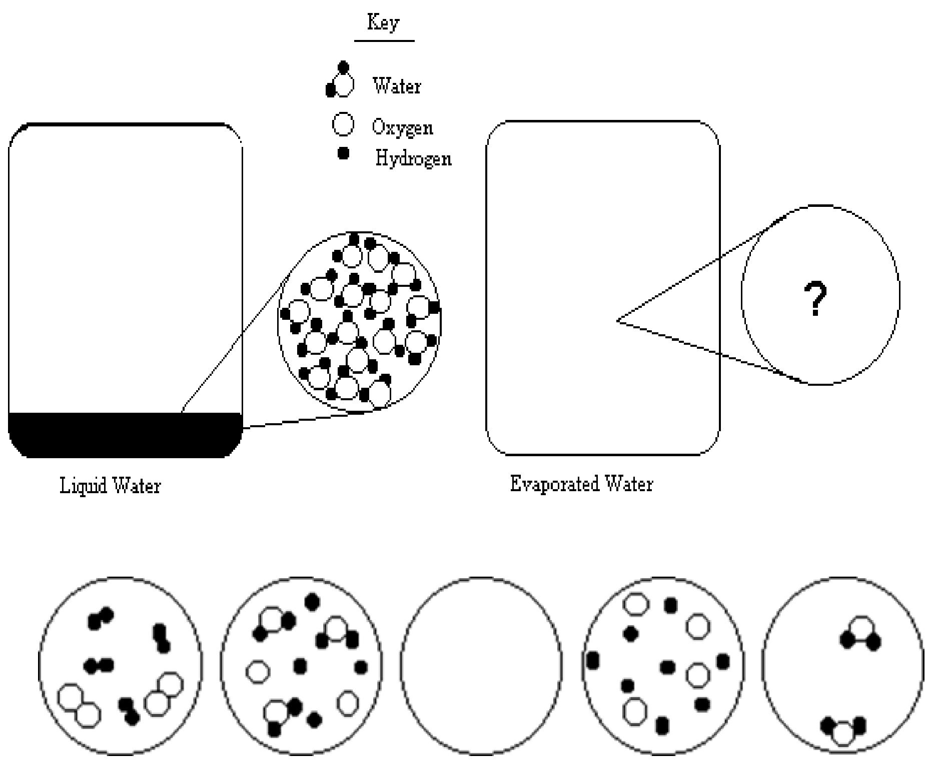
respect to the reactants, but he/she did not make any mention of the product, which is the import of the question, and this indicates a lack of understanding of relationship between reactants and products in chemical reaction. Also, the student failed to represent oxygen correctly in his/her description, as O_2, as exactly represented in the chemical equation, which shows lack of comprehension about representations of molecules with the chemical formula. Even if you consider student B's response as that for the product, he/she failed to represent the oxygen molecules correctly which is still a lack of understanding of how to represent molecules with their chemical formula.

Post-survey Statement: enough O2 for 4SO3 that is 6 O for every 2 S atoms and 2S atoms left

The post survey response of this student shows an improvement over the pre-survey response. In the pre-survey, student failed to show the ratios of reactants and products in the chemical reaction, but he/she did in the post-survey. There is some misconception about the representation of the chemical formula for both product and reactant description for the molecule. The student however, gave a correct ratio of atoms, that is "6O" atoms to every "2 S" atoms that was involved in the reaction.

The student improved in their understanding as they began to consider the importance of the numbers of atoms of elements. Their PNM thinking has improved on this basis. This may have been due to the instrumentation labs but no direct connection can be made. While there was improvement, there still were some misconceptions.

Question 4: The circle on the left shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after the water evaporates?



a) b) c) d) e)

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

Student A

Pre-survey Statement: All water is evaporated

In this response, Student A shows little evidence of PNM with this answer. Yes, all of the water has evaporated but the explanation provides no evidence that the student is considering the particulate nature, that is, what does the structure at the atomic level look like in the liquid versus gas phases. The student is not differentiating the differences between states of matter or changes of state with respect to particles that exist in the liquid state or gaseous state and how they are occupy space.

Post-survey Statement: The water molecules evaporate to gas which are moving in more space. The form hot water gas molecule is still the same water molecules.

This student had an improvement in the post-survey response. The student was able to demonstrate a correct understanding that molecules are in motion and the concept that there is a difference in the space occupied between states of matter. However, the statement of forming hot water gas molecules is interesting.

While this student shows an improved understanding of the states of matter and motion of molecules, their conception on PNM remains inadequate. Again, this improvement may have been due to the instrumentation labs but no direct connection can be made.

Student B

Pre-survey Statement: water split up and combine.

In this response, the student seems to be indicating that the water molecules were "splitting" into hydrogen and oxygen, and then re-combining. Or, the student is stating that the molecules of water separate then combine later in the gaseous phase. There is no clear indication of what the student believes in this statement. This indicates a lack of

understanding of what occurs at the molecular level when changes in states of matter occur.

Post-survey Statement: Gas molecule space up and spread further apart moving in random motion.

This student has shown some improvement as he/she no longer states that there will be any “splitting”. Additionally, there is a statement that molecules will be farther apart. But no mention that the change has resulted in any change in energy of the molecules and that the molecules will take up the entire space of the container. While there is clear improvement in the PNM, there is a lack of full understanding of the concept. This improvement may have been due to the instrumentation labs but no direct and explicit connection can be made.

Question 6: A wet dinner plate is left on the counter after it has been washed. After a while it is dry. What happened to the water that did not drip onto the counter?

(a) It goes into the air as very small bits of water.

(b) It just dries up and no longer exists as anything.

(c) It changes to carbon dioxide.

(d) It goes into the plate.

(e) It changes to oxygen and hydrogen in the air.

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

Student A

Pre-survey Statement: Water does not exist anymore

In this response, student A shows a lack of understanding of evaporation, and changes of state of mater from one state to the other. The student has not made a statement that the molecules of water are evaporating, therefore the student has shown little evidence that they understand concepts surrounding PNM. With no mention of molecules evaporating, it would seem the student does not have a molecular level of understanding. Additionally, stating the water does not exist anymore indicates the matter has been lost. This student has a lack of understanding of PNM.

Post-Survey Statement: It is a physical change stuff, the H_2O would just be evaporating

The post-survey response from student A is a good improvement from the pre-survey. The student demonstrated a better understanding of the situation by indicating that evaporation occurred and that this was a physical change. The student also correctly wrote the chemical formula for water, which is an indication of a correct understanding of how the hydrogen and oxygen are found in a specific ratio. However, again there is no discussion of water molecules evaporating, just that the water changed. There is no evidence that the student understands that the evaporation process is the breaking of intermolecular forces between water molecules in the liquid allowing the molecules to separate, creating a phase change. Overall, the student has a better conception but PNM remains lacking. This improvement may be due to the use of instrumentation in the lab, even though no direct connection may be attributed as such.

Student B

Pre-survey Statement: In evaporation water changes/separate into oxygen and hydrogen

Student B's response shows poor understanding of PNM. The student recognizes that water is oxygen and hydrogen which is a basic PNM understanding, but the student then suggests that the water molecules change, separating into oxygen and hydrogen, which shows a lack of understanding of evaporation and states of matter. The student's PNM knowledge is poor in this example.

Post -survey Statement: water does not change; it goes into the air in small bits

The post survey response from Student B is a slight improvement from pre-survey but does not indicate a change in the beliefs about separating into oxygen and hydrogen. Because this student stated originally that the water molecule separates into hydrogen and oxygen, their response her that "it goes into the air in small bits" might just mean it separates into hydrogen and oxygen. The student has not shown that they have changed this belief. There has been little change in PNM as we consider the student's responses.

Even though some of the post survey responses revealed inadequate understanding of PNM, there was a general improvement in post survey response that makes scientific sense as compared to the pre-survey. The improvements in the post survey response may be linked to the instrumentation, although no direct connection can be made. Other factors may such as lectures, maturity and student's own research etc may be responsible for the improvements. It may be important for us to explore this further in the future.

Overall, the total percentage of PSM across Q1 to Q8 is 310% for pre-survey, while that for post-survey was 250% (Table 4.5). The overall difference between the pre- and post-survey percentages is -60% (i.e., 250% minus 310%). On average, the % PSM per question (Q1 through Q8) for pre-and post-survey were 38.75 (i.e., 310 divided by 8) and 31.25 (i.e., 250 divided by 8), respectively. Table 4.3 and 4.4 shows that PSM category reduced in post-survey as PSU is increased significantly, while the NPU were reduced. The data is suggestive that student's alternative perception of PNM was enhanced to sound understanding after using the analytical instrumentation, that is the PSM group was reduced with a corresponding increase in the PSU.

Research Question 3: What is the impact of instrumentation on mental model concerning particulate nature of matter?

The impact on the instrumentation concerning the PNM was analysed from the overall data collected and the trends in the "migration" of NPU, PSM and PSU in the pre- and post-surveys as well as the interviews.

The % ranges of all students for the PSU categories for the pre- and post-surveys 30 to 70 and 50 to 87.5, respectively (Table 4.4). As can be seen there was a significant increase in the PSU group for the post survey as compared to the pre-survey. The overall trend and dynamics from the various categories are outlined in Tables 4.3 and 4.5, respectively.

Briefly from Table 4.3, a general increase of the % PSU of all students from Q2 to Q8 was observed in exception of Q1(remained unchanged). Table 4.5 summaries the NPU, PSM and PSUs, before and after the use of the analytical instrument. The total percentage of PSU from Q1 to Q8 is 430% for pre-survey, while that for post-survey was 525%. The

nominal average or the pre-survey PSU is 53.75 (i.e., 430 divided by 8), and that for the post-survey PSU is 65.63% (i.e., 525 divided by 8). This means that, on the average, 53.75% of the students had very good understanding of PNM before taking their lectures and the using analytical instrumentation in Chem 115L, while the average was 65.63% of the students showing sound perceptions of PNM after they took their laboratory course in the Chem 115 at SDSU. The average difference in % before and after the students did the experimentation with analytical instruments was 11.88% (i.e., 65.63 minus 53.75). Overall, there was 95% increase of all students for the PSU category (Table 4.5). Since there was an increase of 95% of all students for the PSU category with a corresponding reduction of the % NPU (overall reduction from 60% to 25% of all students from pre-to post survey), PSM (overall reduction from 310% to 250% of all students from pre-to post survey), the observation was regarded as positive impact. Thus, the analytical instrumentation utilized in the Chem 115 Lab did have a positive impact on their learning of chemistry, and could be described as positive impact. The data in Table 4.5 suggests that the %NPU and %PSM categories actually migrated from their pre-surveys to the post-survey PSU.

The participants (students) generally had a very good impression about the analytical instrumentation in their lab works. A general question was posed to these students at the end of the semester (interview) about whether or not if the analytical instrument had helped in their learning and understanding of chemistry. The following are some of the summarized statements of the students transcribed from the interview. Some of their direct quotations are reproduced below:

“ I really like the lab work more than the lecture. The lab was fun, and made me to really love chemistry and some of the stuff sticks really good” ………. ……………Student A

Comments: “*Student A” statement suggests that he preferred the lab work and he appears to understand some of the concept, which seems to imply that he /she got more understanding in the lab than the lecture.*

“I think the Chem 115L was helpful, because I love doing the practice than reading a lot and doing of assignments……. ……………………………………………Student B

Comments: “*Student B” statement is indicative that working in the lab made it easier in learning the chemistry as compared to reading and getting assignments done. It can be inferred the Chem 115 L may have gotten him/her interested more in chemistry, and that the lab in general, including the instrumentation played a major role.*

“In my group, we exchange ideas about the work we did with the chemistry instrument in the lab. Working with the instrument was really fun and help me to do more in chemistry for the first time” …………………………………………………………Student C

Comments: “*Student C” statements explicitly indicated that the instrumentation did help in understanding chemistry, and also saw improvement for the first time.*

The positive impact as observed in the surveys were also corroborated by the interviews, as shown in Figure 4.4 (Chapter 4). Specifically, the % NPU reduced from 14 to 0 of all students from the pre- and to post-interviews, respectively. The PSM category also showed a % reduction from 43 to 20 of all students for the pre- and post-interviews. However, the %PSU increased from 43 to 80 of all students. The interview data also showed a positive impact because there was an overall reduction in %NPU followed by a corresponding decreased in %PSM and an increase in the % PSU. The transcribed interview data was subjected to intercoder reliability, and the reliability coefficient was 0.79, which is generally regarded as acceptable [1, 2].

Conclusions and Future Work

From the observed trend in the data analysed and the verbal responses from the students, it can be concluded that students had positive impression about the use of analytical instrumentation in learning and understanding of PNM and that may have contributed to their overall positive performance and improvement in the post-survey, as compared to the pre-survey. Our research has shown that students do like to study with analytical instrumentation as this may help them in getting more interest in chemistry. One area that could be looked at in the future is to gauge if longer lab contact hours may be more helpful, as the students in this research appear to love the lab work. Also, our work provides some clue (evidence) of a directed impact of instrumentation on students' understanding of chemistry, showing that the laboratory work (practical) contributed toward enhancing the learning of chemistry for the Chem 115 students/participants. As with many studies of this kind, the limitation is in the sample size (participants/students). Without a large enough sample size, it is difficult to generalize this picture of the various dynamics. However, our research model is quite different in the sense that we looked at

two (2) variables namely instrumentation impact and knowledge of students during the semester. This helped to establish that data from different perspectives still yielded the same conclusions. In the future, it is highly recommended that the sample size be increased and the duration of the study prolonged. Specifically, this study could be done for at least 4 semesters over a two-year period, with more students and different chemistry labs (e.g., Chem 112, Chem 114, and Chem 326), if possible. With this wide representation from different courses and over a longer time, a general trend would be established for the effectiveness of analytical instrumentation for teaching and learning chemistry courses in SDSU, and not only Chem 115. Our study has provided some evidence and it is recommended that the use of instrumentation in undergraduate laboratories be continued as student learning will be enhanced from the use of these different types of technology.

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APPENDIX A…..Human Subjects Approval Request

Human Subjects Committee

South Dakota State University

__*___Exempt _____Expedited Review _____Committee Review

1. Principal investigator/researcher Bridget Klutse_______ Phone No. 605-688-6549

E-mail address of researcher _ bridget.klutse@sdstate.edu________

____Faculty __*_Graduate Student____ Undergraduate Student

____Not SDSU Researcher

If student, faculty advisor: Matthew Miller____________

College/School Graduate School Department Chemistry and Biochemistry______

(Please use an additional sheet to list names and contact information for others involved with the project.)

2. Project title College Students' Understandings and Conceptions of the Particulate Nature of Matter and the Influence of Research Instrumentation

3. Sponsoring agency ________None_____________________

4. Project period (contact with participants): From _08_____/_20_____/____18___ To __08/___15___/___19____

5. Location(s) of study _Chemistry & Biochemistry Department, Brookings main campus_____________

6. Number of human participants to be selected approximately 40 ___

7. Types of participants to be selected (check all that apply):

_*__Normal Adults ___Pregnant Women ___Prisoners

___Minors ___Mentally Disabled or Delayed

8. Exemption requested? __*____ Yes ______ No

If "yes", indicate basis for exemption. For complete descriptions of the exempt categories of research, see:

http://www.sdstate.edu/research/compliance/humansubjects/index.cfm

_*__Educational Research ___Educational Tests ___Study of Existing Data

__*_Survey/Interview Research ___Observational Research ___ Food Tasting

(The above do not automatically make a project exempt; it may require expedited or full committee review.)

9. Will any drugs, chemical or biological agents be administered to human subjects?

____ Yes __*__ No *If Yes, include documentation regarding safety from a source other than the manufacturer in METHODS.*

10. Will specimens or samples of tissues, body fluids, or other substances be collected from participants?

____ Yes __*__ No *If Yes, include details of collection, storage, labelling, use, and disposal in METHODS.*

11. Has each investigator involved in the study completed CITI on-line training and filed a copy of the certificate in the Office of Research and Sponsored Programs?

__*__ Yes ____ No

12. ***Research Protocol:*** Complete a description of the proposed study following instructions.

13. ***Informed Consent:*** Attach copies of all forms which will be used to obtain the legally effective informed consent of human subjects or their legal representatives, or justification why informed consent should be altered or waived.

14. ***Additional Materials:*** Attach a copy of all surveys, recruitment materials, and any other relevant documents.

Authorized Signatures:

Principal Investigator _Bridget Klutse_________________ Date 08/13/2018__________________

I Bridget Klutse, do not wish to appear before the committee

Advisor (if student project) _Dr Matthew Miller_____________ Date _08/13/2018_______

Department Head or Dean ___________________________ *Date* __________________

Research Protocol

A. **Objectives:** Is to explore Chem 115 students understanding and conception of the particulate nature matter and to find out if the use of research instrumentation in the chemistry laboratory has any impact on their understanding of the particulate nature of matter.

Research Questions

- What is the perception of Student on Particulate nature of matter (PNM)?
- What are students' alternative conceptions about PNM before and after the use of instrumentation?
- What is the impact of instrumentation on mental model concerning particulate nature of matter?

Pre-Post Survey

Week 1	8/20/18	Pre-Survey – Date and time to be determined
Week 2&3	8/27/18-9/3/18	Initial interview – Date and time to be determined
Week 6&7	9/24/18-10/1/18	Second interview– Date and time to be determined
Week11&12	10/29/18-11/5/18	Third interview– Date and time to be determined
Week 13	11/12/18	Post Survey– Date and time to be determined

B**. Participants:** The potential population of the study will be comprised of all CHEM 115 and

CHEM 115L students, of which the approximate number of students in these courses will be 40

C. **Time Required for Individual Participants:** 30 mins will be needed for the completion of the questionnaire during a time external to class time and 30 to 60 minutes will be necessary to complete each interview.

D. **Compensation to Participants:** For those students participating in both the pre- and post-survey questionnaire process, a pizza party will be provided before the end of the Fall 2018 semester. For each student participating in all three interviews, ice cream will be provided following the third interview.

E. **Benefits to Participants:** The study will help to determine if students' understandings and conceptions of the particulate nature of matter are influenced by their use of research instrumentation during their laboratory experience in CHEM 115. These findings will benefit future students and the curricular decisions made by the Chemistry & Biochemistry department.

F. **Methods:** Qualitative methods will be employed using a survey design which involves the administration of questionnaires and some interviews. The data will be collected using paper surveys, but data will be electronically recorded from these surveys. Interview will be digitally recorded and saved on a computer. During the first week of the fall 2018 semester, a pre-survey questionnaire (Appendix A) will be distributed to all of the approximately 40 students in CHEM 115. Students will be asked to complete the survey and return that survey to the research at the beginning of the next lecture period. The researcher will collect the surveys as they enter the room, so the instructor will not know which students are participating in the study. The data collected will be transferred to digital form and qualitatively analyzed to determine the level of their understanding of the particulate nature of matter.

As students return the pre-survey, they will be asked to voluntarily participant in a series of three interviews intended to monitor changes in students' conceptions of the particulate nature of matter resulting from the experiences during their fall 2018 semester. Approximately 3-5 students will be involved in the three-session interview

process. During each interview, students will be presented additional questions similar to those on the pre-survey regarding the particulate nature of matter (Appendix B) to determine if the research instrumentation has an impact on their particulate nature knowledge base. Interviews will be digitally recorded and then transcribed and saved on a computer. These transcriptions will be qualitatively analyzed.

A post survey (Appendix A; the pre- and post- will be the same) will be completed at the end of the course to determine the effect of research instrumentation on the understanding of the particulate nature of matter, the data collected, recorded digitally and qualitatively analyzed. Dates and time will be determined for all events in the research based on researcher and student availability.

G. **Risks to Participants:** There are no known risks to the students

H. **Risk Reduction:** The course instructor will not have knowledge of student participation and there will be no information provided to the instructor until the spring semester.

I. **Confidentiality**: Recorded data will be transcript and saved on a departmental computer and flash drive. All data will be destroyed following 3 months following the conclusion of the study.

J. **Recruitment:** All the students in Chem 115 will be asked to participate in the pre/post survey. From those students that participate in the pre-survey, volunteers will be recruited to participate in three interviews to be conducted throughout the Fall 2018 semester.

Informed Consent Letter Research Project – Fall 2018 Bridget Klutse

Dear CHEM 115 students:

I am conducting a research project entitled "College Students' Understandings and Conceptions of the Particulate Nature of Matter" as part of a thesis project at South

Dakota State University. The purpose of the study is to determine if students' understandings and conceptions of the particulate nature of matter is influenced during their experience in CHEM 115 and CHEM 115L courses. You as a student of CHEM 115/115L are invited to participate in the study by completing a pre- and post-survey and participating in three interviews. We realize that your time is valuable and have attempted to keep the requested information sessions as brief and concise as possible.

For those that complete both the pre- and post-surveys we will host a pizza party at the end of the Fall 2018 semester. It will take you approximately 30 minutes of your time to complete the pre-survey, 30 minutes to complete the post-survey, and 30-60 minutes for each interview session. The pre- and post-surveys will be distributed in class and you will be requested to complete that survey and return it at the next class period (CHEM 115). The submission of surveys will be done outside the classroom as you arrive so that the instructor does not know about your participation. Your participation in this project is voluntary and recognize that by participating in the pre- and post-survey sessions you are not required to participate in the interviews. Requests to participate in the interviews will be requested separately from the request to participate in the pre- and post-surveys. This will be done as you arrive for class and submit your pre-survey. If you decide to participate in the interview process and complete all three interviews, you will be provided one serving of ice cream from the Dairy Bar. There are no known risks to you for participating in this study and you may withdraw from the study at any time without consequence. Your responses are strictly confidential. When the data and analysis are presented, your name, title or any other identifying item will not be connected to the data. Upon completion of the study, all data will be destroyed.

Please assist us in our research and return the completed survey in the enclosed envelope.

<u>Your consent is implied by the return of the completed questionnaire.</u> When you return the completed questionnaire, you will be asked to participate in the interviews. Your participation in these interviews is separate from your participation in the surveys. Please keep this letter for your information. If you have any questions, now or later, you may contact us at the number below. Thank you very much for your time and assistance. If you have any questions regarding your rights as a research participant in this study, you may contact the SDSU Research Compliance Coordinator at 605-688-6975,

SDSU.IRB@sdstate.edu.

Sincerely,

Project Director – Bridget Klutse

Address: Avera 005,

E-mail Address – Bridget.Klutse@sdstate.edu Phone No. – 605-688-6549

This project has been approved by the SDSU Institutional Review Board, Approval No.: ___________

Information Sheet

Participation in a Research Project

South Dakota State University

Brookings, SD 57007

Department of Chemistry and Biochemistry

Project Director Bridget Klutse   Phone No. 605-688-6549

E-mail bridget.klutse@sdstate.edu   Date ___8/14/2018____

1. This is an invitation for you as student to participate in a research project under the direction of the Researchers Bridget Klutse and Matthew Miller.

2. The project is entitled College Students' Understandings and Conceptions of the Particulate Nature of Matter.

3. The purpose of the project is to determine if students' understandings and conceptions of the particulate nature of matter are influenced during their experience in CHEM 115 and CHEM 115L courses.

4. If you consent to participate, you will be involved in the following process: 1) the completion of a pre-survey which will take approximately 30 minutes of your time 2) the completion of a post-survey which will take approximately 30 minutes of your time 3) and for those that volunteer, participation in 3 interviews which will take approximately 30-60 minutes each time.

5. Participation in this project is voluntary. You have the right to withdraw at any time without penalty. If you have any questions, you may contact the project director at the number listed above.

6.There are no known risks to your participation in the study.

7.There are no direct benefits.

8. There is compensation (pizza for those participating in both surveys and ice cream for those participating in all 3 interview sessions) for your participation in this study.

9. Your responses are strictly confidential. When the data and analysis are presented, you will not be linked to the data by your name, title or any other identifying item. All data will be destroyed 3 months after the completion of the study.

10. As a research participant, I have read the above and have had any questions answered. I will receive a copy of this information sheet to keep.

If you have any questions regarding this study, you may contact the Project Director. If you have questions regarding your rights as a participant, you can contact the SDSU Research Compliance Coordinator at (605) 688-6975 or SDSU.IRB@sdstate.edu.

This project has been approved by the SDSU Institutional Review Board, Approval No.: __________

Appendix B – Pre and Post Survey Questions

Research Project – Fall 2018 Bridget Klutse

COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER

AND THE IMPACT ON RESEARCH INSTRUMENTATION

Pre-Survey

Directions: For each question, choose your answer AND write a paragraph or two which describes why you chose that answer AND why you did not choose other answers.

1. Which of the following must be the same before and after a chemical reaction?

   (f) The sum of the masses of all substances involved.
   (g) The number of molecules of all substances involved.
   (h) The number of atoms of each type involved.
   (i) Both (a) and (c) must be the same.
   (j) Each of the answers (a), (b), and (c) must be the same.

Your answer is: _________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

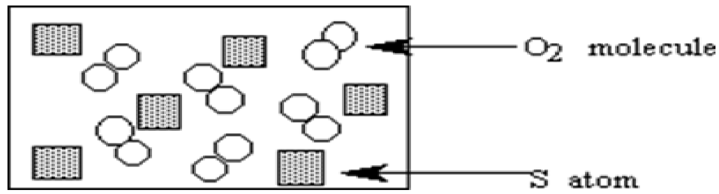
2. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

    (a) Air.
    (b) Oxygen gas and hydrogen gas
    (c) Oxygen.
    (d) Water vapor.
    (e) Heat.

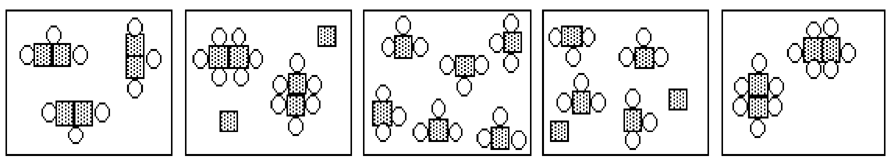
Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answer

3. The diagram represents a mixture of S atoms and O_2 molecules in a closed container



Which diagram shows the results after the mixture reacts as completely as possible according to the equation $2S + 3O_2 \rightarrow 2SO_3$?

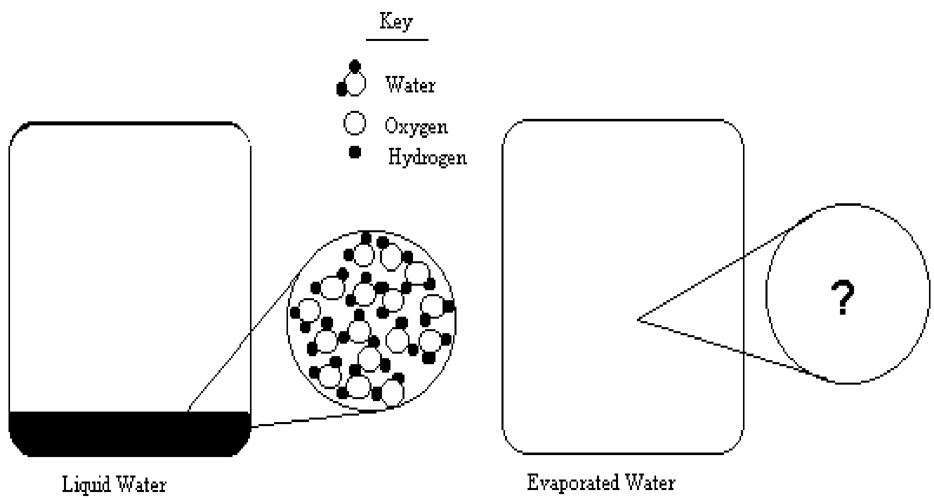


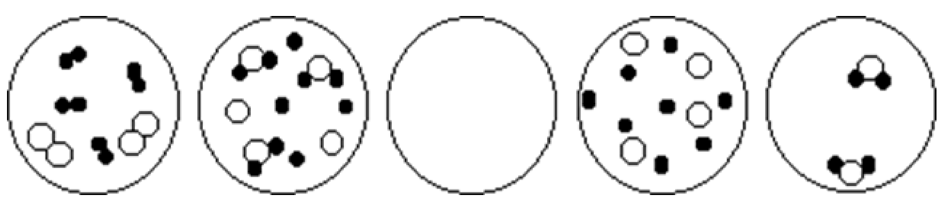
a) b) c) d) e)

Your answer is: _________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

4. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container. What would the magnified view show after the water evaporates?





a) b) c) d) e)

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

5. Figure 1 represents 1.0L solution of sugar dissolved in water. The dot in the magnification circle represents the sugar molecules. In the order to simplify the diagram, the water molecules have not been shown. Which response represents the view after 1.0L of water were added (as shown in Figure 2)?

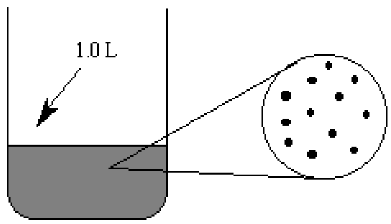


Figure 1

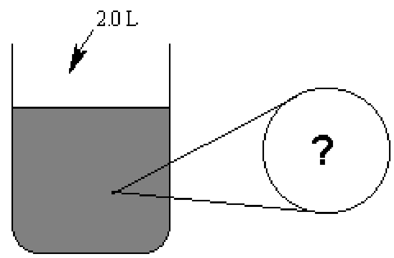
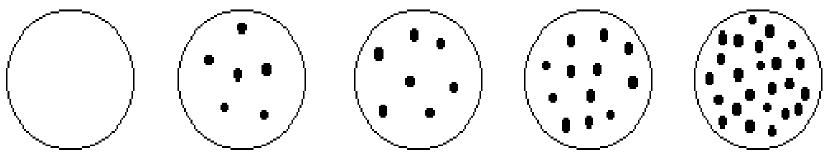


Figure 2



a) b) c) d) e)

Your answer is: ________________

Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

6. A wet dinner plate is left on the counter after it has been washed. After a while it is dry. What happened to the water that didn't drip onto the counter?

(f) It goes into the air as very small bits of water.
(g) It just dries up and no longer exists as anything.
(h) It changes to carbon dioxide.
(i) It goes into the plate.
(j) It changes to oxygen and hydrogen in the air.

Your answer is: ________________

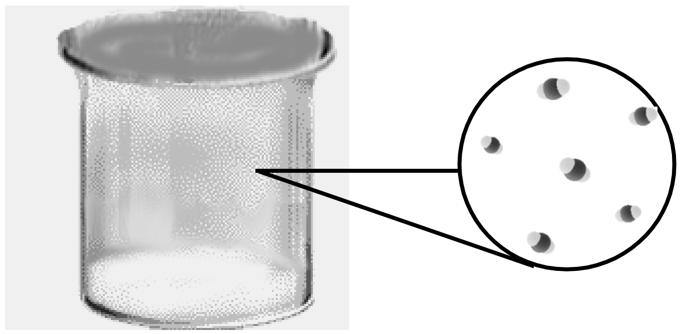
Paragraph (or two) describing why you chose your answer and why you did not choose other answers.

7. In a pure sample of oxygen gas, what exists between the oxygen molecules?
    (f) Matter
    (g) Air
    (h) water vapor
    (i) nothing
    (j) atmosphere

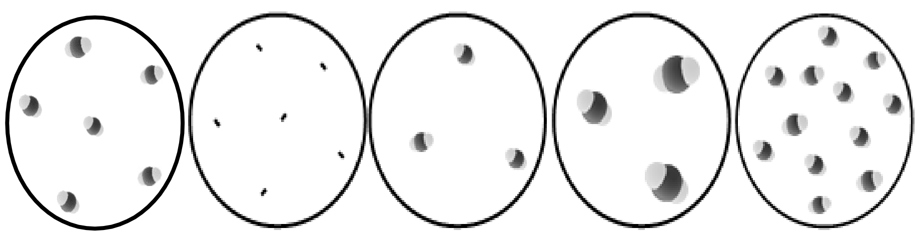
Your answer is: ________________

Paragraph (or two) describes why you chose your answer and why you did not choose other answers.

8. A magnified view of a sample of carbon dioxide (CO_2) gas at a pressure of 1.0 atm is shown below.



Which of the following diagrams best describes what you would “see” in the same area at a reduced pressure of 0.5 atm?



(a) (b) (c) (d) (e)

Your answer is: ________________

Paragraph (or two) describes why you chose your answer and why you did not choose other answer

Appendix C – Interview Protocols

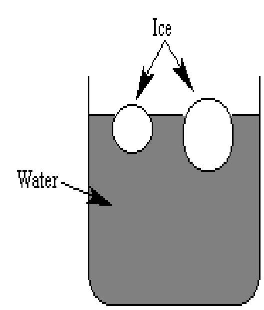
Research Project – Fall 2018 Bridget Klutse

COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER AND THE IMPACT ON RESEARCH INSTRUMENTATION

Interview #1 Protocol

Directions: For the question, choose your answer AND while answering the question, explain your thought process out loud as you answered the question. What are you thinking as you read and try to answer the question? Why did you choose the answer you chose? Why not choose one of the other answers?

1. Two ice cubes are floating in water:



After the ice melts, will the water level be:

(a) higher?

(b) lower?

(c) the same?

Interview Questions:

1) (If this was not done as they answered the question) How do you explain your

answer?

2) (If this was not done as they answered the question) On an atomic scale how is your answer explained?
3) Draw a picture of the atomic scale explanation you provided in question 2.
4) Where did you learn information that helped you explain this on an atomic scale?
5) How did this help you to understand concepts on an atomic scale?
6) How did your experiences in both courses CHEM 115 and CHEM 115L help you to more thoroughly understand the atomic scale concepts you used to answer this question?
    a. List and explain each experience and the impact.
    b. Are there any other experiences?

Research Project – Fall 2018 Bridget Klutse

COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER AND THE IMPACT ON RESEARCH INSTRUMENTATION

Interview #2 Protocol

Directions: For the questions, choose your answer AND while answering the questions, explain your thought process out loud as you answered the questions. What are you thinking as you read and try to answer the questions? Why did you choose the answer(s) you chose? Why not choose one of the other answers?

1. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

   (a) less than the nail it came from.
   (b) the same as the nail it came from.
   (c) more than the nail it came from.
   (d) It is impossible to predict.

2. What is the reason for your answer?

   (a) Rusting makes the nail lighter.
   (b) Rust contains iron and oxygen.
   (c) The nail flakes away.
   (d) The iron from the nail is destroyed.
   (e) The flaky rust weighs less than iron.

Interview Questions:

1) (If this was not done as they answered the question) How do you explain your answer?

2) (If this was not done as they answered the question) On an atomic scale how is your answer explained?
3) Draw a picture of the atomic scale explanation you provided in question 2.
4) Where did you learn information that helped you explain this on an atomic scale?
5) How did this help you to understand concepts on an atomic scale?
6) How did your experiences in both courses CHEM 115 and CHEM 115L help you to more thoroughly understand the atomic scale concepts you used to answer this question?
    a. List and explain each experience and the impact.
    b. Are there any other experiences?

Research Project – Fall 2018 Bridget Klutse

COLLEGE STUDENTS CONCEPTIONS OF PARTICULATE NATURE OF MATTER AND THE IMPACT ON RESEARCH INSTRUMENTATION

Interview #3 Protocol

Directions: For the questions, choose your answer AND while answering the questions, explain your thought process out loud as you answered the questions. What are you thinking as you read and try to answer the questions? Why did you choose the answer(s) you chose? Why not choose one of the other answers?

1. When water at 24ºC is cooled to 0ºC and freezes, the water molecules

    (a) become less organized.
    (b) move much faster.
    (c) stop moving.
    (d) break apart.
    (e) move much more slowly.

Interview Questions:

1) (If this was not done as they answered the question) How do you explain your answer?
2) (If this was not done as they answered the question) On an atomic scale how is your answer explained?
3) Draw a picture of the atomic scale explanation you provided in question 2.
4) Where did you learn information that helped you explain this on an atomic scale?
5) How did this help you to understand concepts on an atomic scale?
6) How did your experiences in both courses CHEM 115 and CHEM 115L help you to more thoroughly understand the atomic scale concepts you used to answer this question?
    a. List and explain each experience and the impact.
    b. Are there any other experiences?