Deconstructing the mole: A sociological narrative study that explores the mole concept experiences of science students' and lecturers', in the context of social justice.

By

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Declaration

This work has not previously been accepted in substance for any other degree and is not being concurrently submitted in candidature for any other degree.

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This thesis is the result of my own work, except where otherwise stated. Other sources are cited and a bibliography is appended.

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Abstract

The mole concept like mathematics has both an abstract and a concrete element, but unfortunately the abstract element pre-dominates the teaching and learning, which poses difficulties to both learners and instructors. These difficulties disproportionately affect learners from low socio-economic backgrounds. The aim of this study is to investigate the mole concept from a sociological standpoint, by exploring the teaching and learning experiences of science students and lecturers, in the context of social justice. The study views the mole as a socially constructed science currency, and thus involved the deconstruction of all its aspects, in order to uncover inequalities embedded within its instruction methods including assessment.

Twenty-five science students and three lecturers from London Metropolitan University responded to the questionnaire, which was also used as a recruitment tool. Nine students (5 in a focus group & 4 in a one-to-one) and three lecturers took part in narrative interviews designed to capture their experiences. The students ranged from foundation/access course, BSc to PhD, in subjects such as chemistry, biomedical, forensics, sports therapy, biology, human nutrition, cancer immunotherapy & pharmaceutical sciences. The three lecturers were all academic doctors with varying mole concept lecturing experiences, including post-doctoral work at Manchester, Oxford, and Open Universities respectively. Narrative interviews transcriptswere analysed through Bourdieuran prism, using an experienced based thematic approach. Four themes were identified: First degree socialisation (primary habitus), Second degree socialisation (secondary habitus), Field operators (actors' input) & Mole conceptual and procedural experiences.

The findings indicate that, students from lower-class background find the difficulties pose by the mole concept, much more challenging than the higher-class students. The higher-class learners are better equipped to deal with mole related difficulties because of their superior social context, which also includes the fact that, they had experienced the mole far earlier in their academic carriers, than lower-class students.This study recommends the conceptual teaching and learning of the mole in schools (primary, KS2 or 2nd grade), in tandem with the teaching of the other SI units of measurement (Meter (m) for length, kilogram (kg) for mass, second (s) for time). This will increase mole prior knowledge of all the learners, which is crucial for a broad and balanced science curriculum.

Table of Contents

List of Figures and Tables

List of abbreviations

AfL	Assessment for Learning (formative assessment)
A level	Advance Level
AoL	Assessment of Learning (summative assessment)
^{12}C	Carbon 12 (an isotope of carbon)
CBM	Curriculum Base Measure
CoP	Communities of Practice
EU	European Union
GCSE	General Certificate of Secondary Education
HE	Higher Education
ICT	Information Communication Technology
IT	Information Technology
IUPAC	International Union of Pure and Applied Science
KS	Key Stage (e.g. KS2, KS3 etc)
LEA	Local Education Authority
LA	Local Authority
PCT	Personal Construct Theory
RAM	Relative Atomic Mass
RMM	Relative Molecular Mass
SI	International System of units (Système International d'Unités)
UG	Undergraduate
UK	United Kingdom

Glossary of terms used in this study

Terms and definitions defined or used by the researcher

Analogies;

These are comparisons of other things, substances which only have the same similarity to the mole because they are either ‘uncountable’, or have smaller units that can be group together like the mole, for easy counting.

Avogadro;

This is an Italian physicist who added a different definition of the SI unit mole, by defining it in terms of number of particles through a mathematical constant.

Avogadro Constant;

6.02×10^{23} number of particles (ions, molecules, electrons) contain in one mole of any substance.

Bourdieuran;

This term relates to the works of Pierre Bourdieu.

Bourdieu’s theory of practice;

This refers to Bourdieus’ theory of Habitus, Field and Forms of capital.

Conceptual teaching;

This is the use of analogies in the teaching and learning of the mole.

Garri (Tapioca);

This is a West African fast food (uncountable noun) that is used in this research to illustrate the mole. Its scientific name is Tapioca.

Higher Class;

Participants who originate from the middle or upper social classes with a higher-than-average habitus and forms of social capital.

Lower Class;

Participants who originate from working class backgrounds, with a lower-than-average habitus and forms of social capital.

Mole;

This is an SI unit for the amount of substance coined by a German Chemist Oswald in 1900. It signifies the amount of any substance equivalent to 12g of carbon^{12}, and contains the Avogadro number of particles.

Procedural teaching;

This is the use of mathematical formulae in the teaching and learning of the mole,

Uncountable;

This term refers to uncountable nouns; things that we cannot count with numbers because they are too small, in this case ions, molecule and electrons, therefore can only be estimated. (Dewey, 1938)

Preface Personal Knowledge and Emotional Journey;

Completing this Doctorate thesis in science education has been an invaluable as well as challenging and emotional process. It has been a great learning curve, carrying out research of this magnitude, which is also in part, a reflection of my own habitus. From my student days, I have witnessed my peers' dropout of an applied chemistry course just after the first year, due to lack of mole concept mastery and several others struggled because they were non-traditional students who came in through access courses under the widening participation or equality of access scheme (Tarrant, 1989).

I also felt that I was socially constructed to serve as a local industry employee, working for both Coca-Cola and Britvic as an analytical chemist and as an industrial chemist for 'Industrial Chemicals', even though I had done a research degree (MSc analytical chemistry). I knew something was not right but could not work out exactly what it was. This study has been a revelation to me in several ways; firstly, it has opened my thoughts to how knowledge is organised and classified i.e., philosophical underpinnings which includes ontological and epistemological stance, theoretical positions which informs our research paradigms leading to research methodology and methods of data collections (research instruments) and analysis (Crotty, 1998).

I have had emotional setbacks not only because of the pandemic (covid-19), but also personal circumstances, as my country Southern Cameroons (Ambazonia) which has been illegally occupied by the Republic of Cameroun due to incomplete decolonisation by Britain and the United Nations. This has resulted into an armed conflict going on now for more than four years with my village and more than 300 other Southern Cameroons villages burnt down by French Cameroun forces. My mother's house was raised and my cousins killed, including one right inside my mother's house before it was set on fire. My elder sister only narrowly escaped with her life and lost all her belongings including money in the flames. My schoolmate and leader of our Southern Cameroons (Ambazonia) movement (Sissiko Julius AyukTabe) who was one of the guest speakers in a London Metropolitan University organised Political Summit in 2017 and other southern Cameroons refuges were abducted in Nigeria by the Cameroun government operatives, in complicity with the Nigerian authorities and flown to Cameroun where they were tried in a military court and given life sentences. The high court in Abuja Nigeria has since ruled that their abduction was illegal and against both Nigerian and Internal laws. The court also ordered that they be returned to Nigeria and paid compensation. This judgement has still not been implemented for more than two years now. However, the United States senate on January 2021 passed resolution 684 sessions 116, prescribing procedures to bring the conflict to an end, even today the 8th of June 2021, the US secretary of state for foreign affairs has issued warnings of visa and other sanctions against those who are working against a peaceful resolution of the conflict. It is in the backdrop of all these, that this thesis was put together.

CHAPTER 1 Introduction

1.1. Research aim;

Almost all the physical sciences are made up of scientific concepts that consist of both abstract and concrete elements. The gap between the abstract and the concrete must be a bridge, in order for learners to make meaning of the theories involved (Angello, 2017). The bridging of these two elements involves *scaffolding,* which requires the provision of prior knowledge that learners can apply to the new concepts (Angello, 2017). To acquire a good library of prior knowledge, requires a broad-based curriculum (Moore & Vaughan, 2017), which is not easily available in all the educational fields, due to cost. Learners from higher socio-economic classes are well adapted in the acquisition of a high degree of prior knowledge, due to certain social advantages. These sociological factors are Bourdieuran (habitus, field, and forms of capital).

The mole concept like mathematics has both abstract and concrete elements (Angello, 2017), but unfortunately the abstract pre-dominates the teaching and learning in both cases, which poses considerable difficulties to learners and instructors, according to other studies (Tullberg, et al., 1994). These difficulties may disproportionately affect learners from low socio-economic backgrounds. The aim of this study is to investigate the mole concept from a sociological standpoint, by exploring the teaching and learning experiences of science students and lecturers, in the context of social justice. The study sees the mole as a socially constructed science currency, and it thus involved the deconstruction of all its aspects, in order to uncover the inequalities embedded not only within its methods of instruction, but also the degree to which it affects the different types of learners, including those from the lower-class. The study further examines the role of sociological factors such as habitus, field, and forms of capital in shaping science students' experiences of the mole concept. The wider aim remains the deconstruction of all aspects of the mole, in order to uncover its complexity which turns to confuse both instructor and learner (Cervellati, et al., 1982; Niaz, 1985; Hawthorne, 1973; Bunce, et al., 1994); and the inequalities embedded in its teaching and learning (Reid, 1996; Leathwood & Hayton, 2002; Hutton, 1996), which are sociological. Even though the mole is a scientific concept, its teaching and learning occurs socially, hence the sociological theory applied in this study.

1.1.1. Rational;

This study highlights the social construction of science students' identities, as seen through the mole concept lens. The primary identities created are: research and local economy/factory workers students' identities. In addition, the study will examine the mole experiences of sciences students and lecturers from diverse science courses in a North London University. The research is born from the researchers' personal habitus (Bourdieu, 1973), which is informed by his experiences both as a mole concept learner and work in the local industries (Coca-Cola, Britvic, and Industrial chemicals) as an analytical and industrial chemist. These industrial experiences resulted from being socially constructed by the system to serve as a local industry worker (Walford, 1991). In addition, the study will examine the influences of the sociological factors which have helped in shaping these identities. These factors are external and mostly sociological.

The researcher started a chemistry undergraduate course in a renowned research-led university in central London, but could not continue beyond the

first term, due to immigration constrain at the time, but had admission the following year to study applied chemistry in a university that was a polytechnic, and later converted to a full university, (see 1.2.4). The “mole concept” was the topic that he experienced as a learner during the short period spent at the research-led University, so it forms the basis of this study. It is usually taught during the first sessions of UG chemistry (science) course due to the vital link it forges between theoretical and practical chemistry (abstract and concrete). This was also partly due to the ‘hidden curriculum’ which Bowles and Gintis (1976) talked about where the curriculum is made up of students learning experiences other than those stated by the written objectives of the school (see 1.2.5).

1.1.2 Research question;

The mole concept is a well researched topic, but most of the research is centred on the cognitive aspects of students learning (Surif, et al., 2012; Larson, 1997; Cervellati, et al., 1982; Tullberg, et al., 1994; Stromdahl, et al., 1994; Omwirhiren, 2015; Chiu, 2004; Chiu & Chang, 2005) . This is the constructivist perspective of learning, where the learners’ conceptual ecology is at play; therefore, they employed mainly a quantitative methodological approach. This study takes a different approach, by examining the external or sociological factors that governs science students learning experiences. It is widely reported that, students’ life/social experiences, affects certain outcomes, which includes; education, health, life span and general well-being (Jackson & Cameron, 2012; Brady & Gilligan, 2018; Berridge, 2012). Therefore, it would not surprise anyone that, the mole concept difficulties reported by other researchers, especially Tullberg et al., (1994) who reported that, the mole confuses both teacher and students, and disproportionately affects science students from low socio-economic backgrounds, most of whom access HE as non-traditional students. This study is insisting that, the mole concept problems identified by other studies, affects lower-class science students more than others. The policy of widening participation has rightly increased the number of non-traditional students in HE (Boeren & James, 2017), with the aim of addressing social inequalities. This has also led to the introduction of applied courses; in mostly LEA funded former Polytechnics turned universities, designed to supply workers to serve the local economies (Walford, 1991). This is the social construction of learners' identities, which is at the heart of this study, because students from lower tier universities (former Polytechnics) also called teaching-led universities, were socially constructed to serve as local industry workers, while those from higher tier universities (see section 1.2.5), also known as research-led Universities, are constructed to serve as research students (Walford, 1991). It is clear that University stratifications, correlated with learners' social classes, which is a reflection of their incomes and degrees of social capital (Reay, et al., 2005). Therefore, science students experience the teaching and learning of the mole differently, based on their habitus, field, and forms of capital (Bourdieu, 1993). For example, applied chemistry which is what the researcher experienced as a learner in a lower tier university, had a different watered-down syllabus to the traditional chemistry course taught in higher tier Universities. The researcher also briefly experienced the teaching and learning of the mole, in a higher tier University. Pierre Bourdieu's (1993) theory describes and explains how social and cultural inequalities are reproduced and legitimised through the education system. The capacity to benefit from and or invest in education is not equal (Bourdieu, 1986). Therefore, the first research question is designed to reflect on all the above.

How can we understand the socio-cultural influences that shape science *students' mole concept experiences?*

The second research question is important, because it seeks to understand how the different methods of teaching and learning the mole, influences the different ways that students experience it.

How does the teaching methods influence the way science students' experience the mole concept?

A sub-question to this question is;

Does the mole pose the same degree of difficulty to all students from the different social classes?

There are two principal methods of teaching and learning the mole (procedural and conceptual), and both methods should be taught in tandem (Surif, et al., 2012). But unfortunately, only the procedural method pre-dominates the teaching and learning of the mole, because according to some instructors, it is less time consuming and easy for instructors' accountability (Chiu & Chang, 2005). Whereas Ausubel (2000) pointed out the importance of conceptual teaching and learning by stating that, conceptual learning is meaningful learning. There is, however, lack of research in the area of conceptual teaching and learning (Taber, 2015). Procedural teaching and learning of the mole will require that science student have some degree of mathematical ability, which adds another layer of complexity especially for students with mathematics phobia. The assessment methods are equally important in determining how science students experience the teaching and learning of the mole. Cervellati et al., (1982) (see section 2.1.3) highlighted the fact that, science students' mole concept difficulties were due to certain instructional features like; curriculum content, instruction method and assessment. Therefore, assessment methods also determine how science students experience the teaching and learning of the mole, which includes summative and formative assessment (Black & Wiliam, 1998a; Black & Wiliam, 1998b; Miller, 2005), together with e-assessment (electronic assessment) delivered through e-assessor. Formative assessment is linked to conceptual teaching and learning, which encourages a broad and balanced curriculum (Hoover & Abrams, 2013)(Hover & Abrams, 2003; Moore, 2017), while procedural teaching is supported by summative assessment, which promotes the narrowing of the curriculum (Moore, 2017). E-assessor supports the integration of both summative and formative assessment (Sorensen, 2012, p. 172).

1.2 Other Influences;

1.2.1 Educational Inequalities;

One of the broader aims of this study is to address some of the persistent inequalities in science and chemistry education. Unfortunately, the British education system has not only been harbouring inequalities, but it has been reproducing and reflecting them as well. Such inequalities were highlighted by women's movements and trade unions (Leathwood & Hayton, 2002). Leathwood and Hayton (2002) noted that, despite efforts of the different governments to address the situation, which includes policies like; secondary education for everyone, comprehensive schooling, and raising of the school leaving age, inequalities persisted and even increased during the ten-year period (1978 to 1997) of Conservative government rule. Hutton (1996) pointed out that the policy which valorised the financial markets and encouraged individualism and hence inequalities were termed by the conservative party as the "New Right". The inequalities included educational and social, with achievements and educational opportunities reflecting gender, ethnicity, and class (Leathwood & Hayton, 2002).

It is this social inequality that is at the centre of this research. These inequalities result from governmental policies, which question students' educational abilities from economically deprived backgrounds. The new labour government came into office with a commitment to promote a challenging and positive educational experience for all students (Fielding, 1999). However, their care for a challenging student experience was not visible when they introduced policies that indirectly led to the watering down of mole concept teaching experiences for students from deprived backgrounds. These students mostly attend third-tier universities (see 1.2.5 university stratifications) where they gain access mostly as non-traditional students through access courses, with limited mole concept experiences.

1.2.2 Prejudice and Assumptions;

Blair's government sought to unite America's economic dynamism minus its inequities which already exist in UK, with the social solidarity of the European states, but without their rigidity (Blair, 2001b as cited in Leathwood & Hayton, 2002 p.140). His understanding of social justice was based on individuals of all backgrounds, races, creeds and capabilities have 'equal worth', while emphasising that the administration must 'act decisively to end discrimination and prejudice, with a widespread of equal opportunities, power and wealth (Blair, 2001b, as cited in Leathwood and Hayton, 2002 p.3). Most public policies are the results of assumptions and prejudice, like recently in England, assumptions were made about pupils and students' abilities, when their academic values were estimated as it was not possible to take public exams, these values were then fed into computer algorithms to determine GCSE and Advance level grades due to Covid-19 disruptions of the examination and school system. As a result, Lough (2020) reported in the Times Educational Supplement (TES) that '60% of "A" level grades were the results of statistical modelling, and that “students from poorer backgrounds are two times more likely to be downgraded than students from affluent areas”. These inequalities other than being the results of external influences that affect the way students experience learning and construct their future identities, also attracts social justice researchers, as it is clear from Leathwood and Hayton (2002) and Hutton (1996) that the inequality in England is persistent, so all a researcher needs to do, is to look for it.

1.2.3 Analogies;

The analogies used here are developed during this study and aim to highlight the conceptual method of teaching and learning the mole (Surif, et al., 2012), which can be acquired through socialisation (habitus and field). The conceptual method of solving mole concept problems is one of the two methods of dealing with mole concept problems. According to Surif, et al., (2012), conceptual knowledge is acquired through understanding ideas embedded in the chemical concept. It therefore, involved a deeper understanding of the concept, but research by Chiu (2004), revealed that a higher number of students could solve mole concept problems without an above-average understanding of the chemistry concept. For example, considering the ‘currency’ analogy, students learn to use money first, through home socialisation as they interact with family members (habitus) and subsequently with the public, which includes shops, banks, supermarkets (field). The bricklayer analogy is the same; students who lived in brick houses would have learned about bricks from family members, and from interactions with the broader public including hardware stores and building projects. The West African example of selling certain foodstuffs like rice and ‘garri’ in the open markets by using cups and glasses follows the same trend. Students would have learned how grain is measured using cups from family socialisations before extending the experience to the open markets, shops, and peers. Habitus is the outcome of family socialisation experiences, which can be modified through interactions with peers or other institutions/groups (fields) (Swartz, 1997, p. 102).

1.2.4 The Mole Concept as a Socially Constructed chemist 'currency';

Money and the concept of currency is an example of social constructionism as society and its peoples have accepted to give it value and importance (Pettifor, 2014). The mole concept, which is generally accepted by the science community as a unit of measuring of amounts of substance, mimics the currency concept (IUPAC, 1997). Every currency has an exchange value against other currencies, which in most cases is exchanged against the dollar ($) and is usually made up of smaller units, one hundred cents in the case of a dollar, and one hundred pennies for the pound. In any case, it would be easier to convert cents and pennies to dollars and pounds for ease of transaction. Therefore, instead of one thousand cents or pennies, it will be easier to say ten dollars or ten pounds, and so on. The currency analogy is similar to the mole, where all smaller units of substances (atoms, ions, molecules) are converted to moles for ease of counting, while the exchange unit is $Carbon^{12}$, and all the other 118 elements of the periodic table, are equivalent to the other currencies of the world. Imagine that there was no pound (£) or dollar ($) whole units, only pennies and cents; this would mean that shopping and other transactions will be tedious. The mole concept is similar, which makes counting easier instead of counting smaller units of matter. The next question is, 'how did people learn to use the currency?' For example,1) they can use a calculator to apply a formula and a computer programme for a more complex case (procedurally), or 2) they can learn the concept from others and apply it naturally (conceptually). The latter is achieved through socialisation constructed by interactions with families, friends, shoppers, and society. The mole is similar, as it is socially constructed within the science community with socialisation playing a vital part in its knowledge acquisition. This study seeks to understand the socio-cultural influences involved in constructing different mole concept science students' experiences. Another analogy is the relationship between 'sand/soil' particles and the 'Brick or Block' used for construction. If the sand particles represent "atoms", "ions", and "molecules", because after all, the sand or soil particles are of varying sizes and shapes, then the 'brick' or 'block' is the "Mole". It is easier to estimate the amount of material that goes into building a wall by counting the number of bricks or blocks rather than the billions and trillions of sand or soil particles. Nevertheless, the "Mole" is only an equivalent unit. One mole of any substance is equivalent to 12 grams of "Carbon^{12}", estimated by Avogadro to contain 6.02 x 10^{23}particles (The Avogadro's number N_A). For chemists, the mole is as critical as the pound to the banker or the brick to a builder. The banker would like to say one hundred pounds instead of ten thousand pennies, or the bricklayer/builder would say ten bricks per square meter if they are thinking of concentration. Likewise, the chemist would prefer to say one "mole" per litre instead of trillions and trillions of atoms, ions or molecules per litre. The West African analogy of retailing foodstuffs like rice and 'garri' is unique and relevant to the learners' experiences from that region. Rice and other uncountable solid foodstuffs are not retailed as in the west in kilograms. Instead, they are sold in cups or class measurements, measured from a larger quantity from a bag or large metal/plastic container. The grains represent the atoms, ions and molecules, while the cup or glass represents the mole. Analogies are important in conceptual teaching and learning, this study will highlight conceptual method as a means of addressing the persistent inequalities associated with the mole as it is based on knowledge quality and leads to deeper learning (Star, 2005). There are two principal methods of teaching and learning the mole; procedural and conceptual methods (Surif, et al., 2012), but only the procedural method is predominantly used.

1.2.5 University Stratifications;

The Neoliberal ideology has been at the forefront of 'Global Education Policy', where large multinational institutions like the World Bank, World Trade Organisation and other consultancy educational businesses like Cambridge Education are active in the sales and promotion of education policy worldwide (Haralambos & Holborn, 2013). The UK education policy framework from 1945 – 1997 was informed by this neoliberalism, laden with social justice initiatives, like equality of opportunity. Haralambos and Holborn (2013, p. 677), who further noted that the Education act of 1944 was heavily influenced by 'social-democratic principles', which led to a tripartite school system of grammar, technical, and secondary modern schools for the so-called academic, technical, and practical task 'ability' students. The Education act of 1944 led to the foundation that created the different types of students that eventually showed up at different universities. Thus, the comprehensive system for all 'abilities' and backgrounds of students born around the 1960s, as a remedy for the failure of the tripartite system, with the ultimate aim that it dampen social class bias (Haralambos & Holborn, 2013). The proportion of different types of students making it to higher education increased as a result. Haralambos and Holborn (2013) noted that families and school's habitus created different values of cultural capital (see section 5.5.5), which impacts students' university choices. In addition, Haralambos and Holborn (2013) pointed out that social class is crucial in determining someone's level of cultural capital, which has a huge impact on their Higher Education (HE) choices and impact their mole concept experiences. Pivotal to this research is the observation that middle-class students from private schools make full use of their cultural capital or the habitus they acquired in their families. Including awareness about top-tier universities, social confidence, and entitlement consciousness, which working-class students lacked (Haralambos & Holborn, 2013, p. 700). These external social factors have a great impact on science students' mole concept experiences.

1.2.5.1 Researchers personal experience;

Not coming from a middle-class background, the personal experience meant not experiencing any form of orientation on the different types of universities, nor developing any form of social confidence or entitlement consciousness. These would have been the experiences of the different types of science (mole concept) students. Personal habitus experience meant not knowing the differences between the first university that I started the undergraduate chemistry course (an upper-tier institution) and the South East London University (a lower-tier university). I instead studied and graduated in applied chemistry from the South East London University. At the Central London research-led university, where I gained access through an entrance test conducted in the office of the course coordinator, even though I had three GCE advance "A" levels, including chemistry, the test was based mainly on the mole concept. Thus, there was a sharp contrast to the South East London University (teaching-led), where no entrance test was required, and some students (non-traditional) gained entrance through an access course. There was also no distinct module or topic on the mole concept. However, being unaware of the different grades of universities or the social class stratification of UK society, 'self-exclusion as a process' could not apply in selecting the most appropriate university to study with. The increase in student's numbers in higher education, because all social classes' students can now gain access, meant that more degrees were issued. Thus, the value of degrees suffered in consequence (Bourdieu, 1993 cited in Haralambos & Holborn, 2013). Hence the stratification of universities and the degrees awarded, with those from certain top tier universities, defined as 'high-status, to act as a remedy for the dilution. Oxford and Cambridge were identified as elite universities, which attract middle-class privately schooled students. In contrast, Manchester, Liverpool and most old pre-1992 universities, attracting state schooled middle-class students, are considered middle ranking. The post-1992 mostly polytechnics turn universities, which attracts working-class students, were considered the least ranked university classification. (Reay, et al., 2005). Reay, et al., (2005) identified a correlation between 'the stratification of universities and students' social class and reflecting income levels (see section 1.2.5). Reay et al., (2005) highlight the social construction of more than one type of student, based on different forms and degrees of capital, and thus their degree of engagement with educational materials such as the mole concept. The different types of students make it possible for students' social construction to serve the local economy through a 'hidden curriculum' (see section 1.2.6). It is these different influences that this research explores.

1.2.6 Hidden Curriculum;

Bowles and Gintis (1976) highlighted the alienating and exploitative nature of work in a capitalist society such as Britain and the importance of a docile, *obedient,* and hard-working workforce, which must remain fragmented and divided to be easily controlled. The design of the education systems in these societies helps achieve this via the 'hidden curriculum'. The hidden curriculum is defined as 'knowledge that students acquired through their schooling experiences, which are outside the stated educational objectives of the academic institution.' (Bowles & Gintis, 1976). Therefore, the way schools are organised is far more critical than examinations or the content of lessons. The hidden curriculum can be seen in how government policy in England created third-tier universities, from former polytechnics, with applied courses, including applied chemistry. One of the aims was to supply workers to the local industries (Walford, 1991). Therefore, the government policy socially constructs the different types of science students found primarily in the lower-tier universities, hence different 'mole concept' students. Bowles & Gintis (1976) provided examples of the hidden curriculum shaping an uncritical, subservient, and passive future workforce. They cited a study of 237 senior year members of a New York high school and reported that personality traits, rather than academic abilities, accounted for the awards of their grades, with punctuality, consistency, dependability, and perseverance, attracted higher grades. In comparison, independence and creativity were related to lower grades (Haralambos & Holborn, 2013, p. 666). The emphasis in the lower tier polytechnic turned university, and applied science courses, was towards perseverance, with effort, rather than ability (Oates, et al., 2011) being the cornerstone of the course. Personal experience was that laboratory practical's, which relied mainly on the following of written instructions, were given a higher coefficient. The non-traditional (access course) chemistry students were motivated mainly by external rewards (Bowles & Gintis, 1976), considering that government policy was geared towards creating workers for the local industries (Walford, 1991). The hidden curriculum is also crucial in shaping science students' identities and hence influences their mole concept experiences.

1.2.7 Local Industries Influence;

UK government policy that socially constructed workers through higher education (Walford, 1991), targeted certain communities (including SE London), and class of learners (see 1.2.8). Watford (1991) highlighted the fact that applied courses were designed and run through the polytechnics/universities (lower-tier universities) and colleges, funded by the Local Education Authorities (LEA), intending to help the local economies. Industries constitute part of these local economies, which is how personally this led to working first, with Coca-Cola enterprises Ltd, then Britvic soft drinks Ltd, and 'Industrial chemicals', both as an analytical and industrial chemist. So, I became a product of UK government policy that socially constructs workers to serve the local economies / Industries. Most of the industrial work as an analytical and industrial chemist was based on the mole concept. The only difference was that, in the university laboratory, we worked with minimal quantities of materials. For example, we often used a quarter of a litre (250ml) or an eighth of a litre (125ml), whereas, at Coca-Cola and Britvic, we had to deal with eighty thousand litre tanks. However, most industrial processes have been automated, such that any layperson, with a few days of training, can operate the different types of equipment. Most middle managers were secondary school leavers' who have had on-the-job training, a similar parallel is most people who can drive, and do so without understanding how the internal combustion engine of a car works. So, the critical question that must be asked is, why would the government socially construct workers to serve the local industries (Walford, 1991), while school leavers can perform similar tasks? This research is also informed by my personal habitus which includes my industrial experiences. The applied science courses of the lower tier Universities included an industrial year. Students take a year out to spend in a local industry. Even though I never did the industrial year, but I can now see its role in the social construction of science students' identities as local industry workers, instead of the research scientist that most students are capable.

1.2.8 Social Class;

According to Reid (1996), ownership and access to social wealth are responsible for creating social groups or strata. '**Social wealth'** is defined as anything that has value and is scarce in society. These include property and income, influence and power, health and health services, education, and education services. Therefore, social class is a primary form of social division, resulting in other types of social inequalities. (Reid, 1996, p. 2). In the UK, class is generally seen in terms of membership of an occupational grouping; therefore, low skilled manual workers would attract comparatively lower social wealth. Therefore, access and ownership of social wealth are vital in identifying social class; thus, academic qualifications and even length of time spent in higher/further education and training serve as important indicators (Lahiff & Gould, 2001).

1.2.8.1 Social class as defined in this study;

Social class is one of the key themes in this study as we attempt to show that lower-class learners experience the mole differently from higher-class, especially when dealing with mole concept difficulties. Pierre Bourdieu wrote extensively about the impact of class in the education field. His theory of habitus, field, and forms of captal adds considerably to the complexity and different dimensions of the social class discuss (Wagner & McLaughlin, 2015) and can explains the replication of cultural and social inequalities in education (Bourdieu, 1993). According to Bourdieu, the HE field functions as a mechanism by which privilege is transmitted, as well as the allocation of status, to validate the active social order (Swartz, 1997). For Bourdieu (1986), the ability to invest in and profit from education, is not equal. That is why it is recommended that, in the HE field, students should deploy a variety of strategies in order to get the most out of their circumstances, to make good use of their academic capital (Bathmaker, 2015). This study if designed to help learners add to their strategies in HE. The organisation of education must be on the basis that, all students have the capacity to achieve their academic potentials (Bathmaker, 2003). It is on this bases that Bourdieus' theory of practice that dealt with social class, will be at the heart of this study. It is on this bases that Bourdieus' theory of practice that dealt with social class, will be at the heart of this study.

Pierre Bourdieu wrote about social class in relation to the French society which has a different structure from the the British class system, since the French Monarchy was eliminated during the French Revolution of 1848. Bourdieu therefore concentrate on the middle-class or the Bourgeoisies and the way the use education to propagate and reproduced their social advantages (Swartz, 1997; Bourdieu, 1986; Bourdieu, 1993). In Britain, the monarch sits at the top of the social classification, with the members of the aristocracy and clergy, sitting in the upper house of parliament (House of Lords), and the lower house of parliament (House of Commons), for everybody else. This was so until the Life Peerage Act of 1958. Before the industrial revolution, most Western European societies, were traditionally segregated hierarchically in a system that promotes the hereditary transfer of social status, political capital, and occupation. Industralisation had a huge impact in disrupting this social structure (Boundless Sociology).

Relatively recently in Britain, the Great British Class survey (GBCS) of January 2011, Identified seven classes in existence in the UK, which includes; Elite (privileged, wealthy, and possession of highest levels of all 3 forms of capital), Established middle class (2nd wealthiest and high levels of all 3 forms of capital), Technical middle class (prosperous, but scores low on social and cultural capital), New affluent workers (young, social and culturally active, with middle economic capital), Traditional working class (scores low on all forms of capital, but not totally deprived with some house value), Emergent service workers (Urban, relatively poor, but high social and cultural capital), Precariat (proletariat, poorest & most deprived, scoring low on social and cultural capital) (Savage, et al., 2011). The participants in this GBCS were asked questions about their house value, income, savings, leisure activities, culture, occupation, and friends. Due to the complexity in contemporary social class definition, it was important to simplify it to Higher and Lower class in this study. In other areas where we are referring to class in Bourdieuran terms, we have used middle and working class. Social class in this study was determined by student participants parents' occupation and academic qualifications, questions were also asked about their cultural activities, but was not significant in determining their class. It was difficult to allocate some student participants class, especially migrants who recently moved to the UK. This was the case with Mary, who moved to the UK from Poland, She described her fathers occupation as a sailor, then ship captain, it may mean something totally different, because she rated her mole concept understanding as 3 out of 5, even though she admitted she admitted during the interview that she had never heard of the mole, other than in that interview, and had never solved any mole problems. The lecturers were asked directly about their social classes, of which Dr Luke who has lectured in Oxford, described himself as working class, the rest said they were middle class.

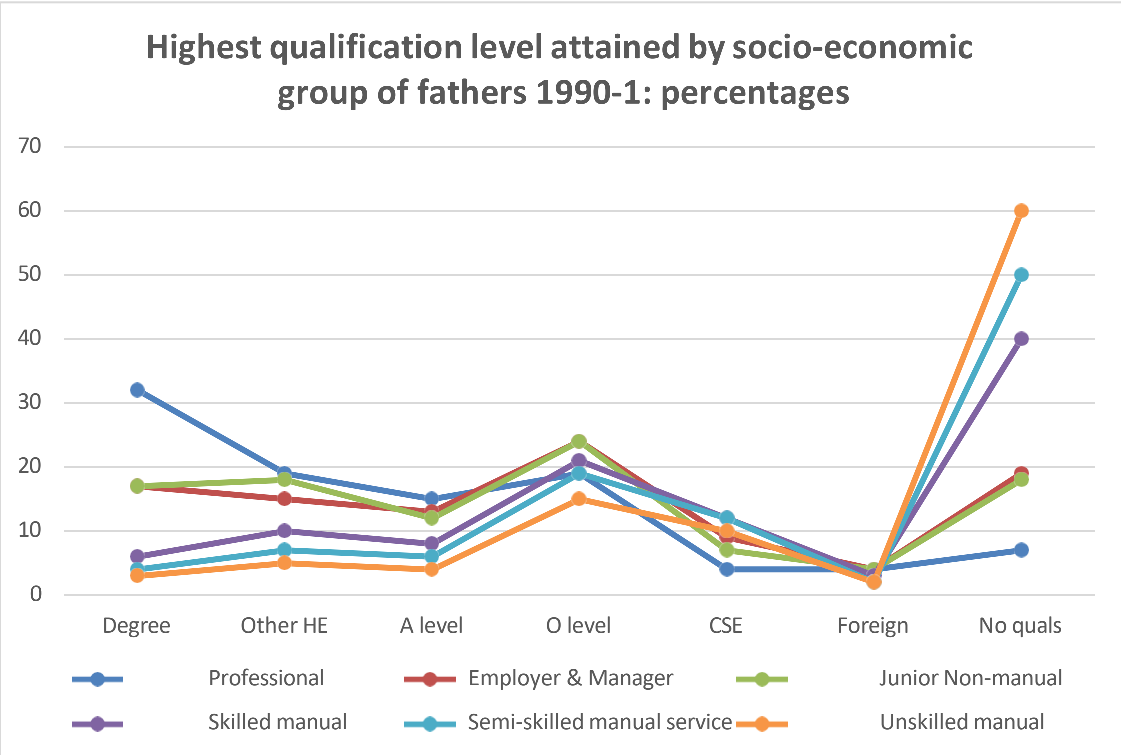

Figure 1. Highest qualification level attained by socio-economic group of fathers 1990-1: percentages (Adapted from Bilton, et al., 1996, p. 342)

Figure 1. shows the percentage of people with higher education qualifications reduces sharply across the social classes, which is reflected in the percentage rise of those with little or no educational qualifications across the social classes. There is, therefore, a correlation between social wealth (academic qualification), social class, and financial status (fig 1). The Kennedy report states that:

> *Studies consistently demonstrate that qualifications earned at 16, provide an excellent predictor of whether a young person will continue in full-time Learning… Those who enter higher education as full-time students, have already achieved academic success. Most will go on to achieve financial success too.* (FEFC, 1997, p. 21)

According to the Dearing Report (1997), students from working-class families, who enter post-compulsory education, demonstrated financial hardship compared to those from higher socio-economic groups. (Dearing, 1997, p. 29). Marx identified two classes in every society (the ruling and a subject class) that are always in conflict (Marx & Engels, 1950).This research may reflect where government policy (ruling class) attempts to socially construct workers (subject class) to serve local economies, succeeded to create different tiers of science students who would have different mole concept experiences.

1.3 Research Methodology

This study uses narrative inquiry method of the qualitative methodology, which is informed by the interpretive paradigm, where reality/truth is multiple (Slevitch, 2011). The ontological and epistemological stance that underpins the methodology is centred on the idealists' viewpoint and subject to individual interpretation (Patton, 2014). Semi-structured interviews in a one-to-one setting and focus group, was used to capture the narratives. Important ethical considerations which are significant in participants selection is discussed (see chapter 6.9.4).

1.4 Summary;

This research examines the sociological aspects of studying and the mole concept in particular. It seeks to understand that socio-cultural factors, including forms of capital, can influence how learners engage with the mole concept. Personal, educational experiences both as a learner and teacher, together with work experiences as an analytical and industrial chemist, has informed this research. The United Kingdom's government policy to socially construct workers to serve the local economies (Walford, 1991) seems to be at the heart of creating different types of science/mole concept learners. Perhaps, they aimed to increase social wealth in the working-class areas of the country and hence South East London (Reid, 1996).

CHAPTER 2: Review of Literature

2.1 Introduction;

This chapter investigates the history of research into the mole concept, its delivery to students principally between secondary, high school, and university, over the decades leading to and including the twenty-first century. There is also a review of the literature around the methodological research techniques used in this study.

2.2 The mole;

The mole is a chemist tool, the unit of amount of substance. The mole links the smallest particle (atom) and macroscopic or least workable amount of material used in the laboratory to a measurable tool. It enables the chemist to measure out equal amounts of substances, to obtain equal numbers of atoms. A mole is; *the mass of a substance containing the same number of fundamental units (atoms, molecules, ions) as there are atoms in exactly 12g of carbon^{12} (^{12}C)*. The current estimate of the number of carbon atoms in 12g of ^{12}C, is 6.022×10^{23} (The Avogadro's number (NA)) (Kolb, 1978). The "Mole Concept" is an essential concept both in practical and theoretical science because it is a fundamental unit of measurement, analogous to the "Pound" used as a currency counting unit, instead of the "Penny", which is smaller and difficult for counting. The concept is a social construct within the scientific community, classified under contextual constructionism, which recognises objective realism and its influences (Burningham & Cooper, 1999). The 'mole' is a unit of measurement for a physical quantity (Metcalfe, et al., 1986; Kolb, 1978), a bridge between the theoretical and physical (practical) scientific thinking, between the abstract and the concrete real and, therefore, vitally important in the understanding of the physical sciences. However, Bent (1985) had a counter view of the mole concept, arguing that it should be ‘X-rated’; since he claimed he did not need it, without offering any alternative. However, Gorin (2003) offers an alternative view to directly counter Bent (1985), by observing that;

> “*Virtually all practicing chemists must consider limiting reactions, theoretical yields in synthesis, formulas from composition data, titrations, the ideal gas law, balancing equations, deduction of equilibrium states, electrolysis, chemical kinetics, thermodynamic quantities,* and so on.*”* (Bent, 1985, p. 376).

2.2.1 Mole Concept Research before 1980;

Hawthorne (1973) carried out a documentary study involving one hundred chemistry textbooks in-classrooms use spanning the period 1891 to 1970 and uncovered a trend in the growing association between Ostwald’s (1900) definition of the mole and the Avogadro’s number (6.022×10^{23}) particles. Wilhelm Ostwald coined the word ‘mole’, from the Latin word “moles”, meaning “heap” (Kolb, 1978). Hawthorne’s (1973) study was aimed at addressing a three-decade-old concern within chemistry teaching to abolish a definition of the mole ‘as a mass of material that reacts with exactly 16 grams of oxygen’ with the pedagogical advice to use Avogadro’s N number of molecules instead. This research differentiates between the views of the mole preferred by the chemists (amount of substance equivalent to 12g of carbon^{12}) and that preferred by the physicist ($N=6.022 \times 10^{23}$ number of particles in 12g of carbon^{12}) Avogadro's number. To put it in layman’s terms, the currency (£) analogy can be used to illustrate the different viewpoints, as the chemists will prefer to use the pound, while the physicists like to work with pennies

(Avogadro's number). It should be noted that Lorenzo Romano Amedeo Carlo Avogadro was an Italian physicist, while Wilhelm Ostwald was a German chemist (Newell, 1926). To further illustrate this important point, I will use the West African market analogy, where the chemist will be interested in the cup of rice, while the physicist will be particular about how many grains of rice are in the cup. This illustration is crucial to this study because it does not only highlight conceptual teaching and learning, but it reveals why we had to deconstruct every aspect of the mole, to reveal its complexity and any possible inequalities associated with its teaching and learning which may affect how science students experience it.

The first definition referred to the oxygen atom (which does not exist in nature as a single atom) as the reference element for equivalency. Thus, twelve grams of carbon^{12} is the current equivalent element. Using the currency analogy, 12 grams of carbon^{12} is equivalent to using the US dollar as the reference currency against all other currencies. Hawthorne's (1973) findings pointed to the historical fact that the mole was introduced near the beginning of the twentieth century by Ostwald, and further shows increased usage of the N (Avogadro's) number in chemical education literature as the definition of a mole during the early 1930s, with a mild leap in the 1950s. In the 1970s, 4/5th of general chemistry text gave value to N, and 1/3rd only used it sparingly; 2/3rd of textbooks are not entirely stating it when discussing the mole, while 1/5th does not even mention Avagadro's number. This shows the conflicting views on the definition of the mole, between the chemists and the physicists, which has added to the complexity of an already abstract concept. Hawthorne's (1973) study also uncovers that there were chemistry text books in the sixties and seventies that did not link the Avogadro's number and the mole. At the same time, 1/5th do not even mention Avogadro's number. Hawthorne (1973) also differentiated the instructive use of Avogadro's number where 70% of text provided a numerical value, with 30% associating N with the number of moles around the 1950s and 1960s, with most of the use associated with Faraday's 96.494 moles of electrons (coulombs). As explained earlier, the chemist prefers to deal with whole numbers, with a preference for conceptual understanding hence the mole. At the same time, the use of N, the Avogadro constant, is a preference for physicists whose inclinations are towards procedural methods of dealing with the mole. Novic & Menis (1976) conducted a study on the mole's definition and uncovered that students' still have misconceptions of the mole concept. Some students associated the mole with the mass of a substance and gas particles. While some associate mole with the property of a molecule. Some mole concept studies relied on the psychological effects of learning base on Piaget, like Goodstein & Howe (1978). However, other earlier studies argued that most mole concept students have not yet reached the **formal operations** stage, hence the students' difficulties in grasping the concept, and suggested using concrete models during instructions (Herron, 1975; Furió, et al., 2002). Niaz (1985) identified that, most students entered university from secondary school, without having attained Piaget's level of formal operational, in terms of their cognitive abilities in processing the context of a mole concept task. This can also contribute to creating the different types of mole concept students (Niaz, 1985).

2.2.2 Mole Concept Research in the 1980's;

Vincent (1981) studied problems encountered by students during neutralisation reactions involving NaOH and HCl and uncovered the following errors;

- NaOH solution was regarded as a simple substance
- The proportion of ratio of moles was in the neutralisation reaction, equated with the ratio of proportion in volume
- The concentration (g/mol) equates with the number of moles

In an extensive literature review on applying the mole concept, involving bibliographical references covering a four-decade period Dierks (1981) used the I.U.P.A.C definition of the mole (1958 &1967) to discuss the problems of using the definition in teaching the mole concept. Dierks (1981) concluded that the principal problem was the abstract nature of the phrase “amount of substance” and the varied meanings attributed to the word “mole” (portion of substance, individual unit of mass, Avogadro’s number - number of particles). The research revealed the need to adequately explain the meaning of the phrase “amount of substance” in the definition context. Cervellati et al. (1982) carried out a quantitative study involving a large sample size of secondary school students; they found out that students did not envision the mole as a unit of an 'amount of substance', but as a mass (analogous to using "pennies" as a pound, and sand particles as a brick). Cervellati et al. (1982) attributed these difficulties to the student’s inabilities in solving stoichiometric problems, concluding that, the principal causes of the problems could be traced to instructional features:- curriculum content, assessment, instruction method, even teachers training. Students thinking of the 'mole' as 'mass' would mean a lack of conceptual understanding of the mole as in the above example. Some studies on students’ mole concept learning difficulties investigated the psychological aspects of their learning by employing Piaget’s cognitive distances of students’ stage of development, which highlights their intrinsic understanding (Goodstein & Howe, 1978). For example, in highlighting the cognitive difficulty of the mole concept, Gabel & Sherwood (1983, p. 176) identified that: '*A vast majority of high school students are not yet 'formal operational' because their proportional reasoning abilities still have to develop over time. Therefore, they suggested that students need to be taught problem-solving in ways that can enhance their experiences*'. Krajcik & Haney (1987) carried out a high school chemistry correlation study between achievement and reasoning skills study, and established that; success in chemistry, is directly linked to 'formal operational reasoning patterns. Niaz (1985), concluded that, secondary school students would rarely attain Piaget's formal operational levels of cognitive task processing ability before university, after researching first year students in a Venezuelan university studying Physics, Mathematics and Chemistry, which 75% repeated the course that had 50% of the content requiring formal reasoning skills. Niaz (1985) also stated that 80% of the students were at a concrete operational level of cognitive task processing and only 3.5% at the formal stage and recommended the teaching of mathematics and science in university introductory courses at the concrete operational level. Shayer & Adey 1984, cited in Furió, et al., (2002) stated that students' difficulties do not result from instructions or the lack of ability and effort to learn but instead reflect their stage of formal operations cognitive development. Niaz (1985), in evaluating the introductory chemistry, physics and mathematics courses in a Venezuelan university, found that 75% of students had to repeat a course whose content was made up of 50% formal reasoning (conceptual reasoning), while 80% were in the concrete operational level. Only 3.5% had arrived at the formal operational stage. Niaz (1985) concluded that mathematics needs to be taught as a supplementary subject. Johnstone and

El-Banna (1986), while examining the psychological aspects of learning the mole concept, also highlighted students' inability to solve mole concept related problems. Frazer & Servant (1986a) conducted a study where they revealed that out of 200 Advance "A" level pass students, not a single one of them relied on the expert method of dealing with the stoichiometric problems. In another study, Frazer & Servant (1986b) published the results of certain laboratory studies, which included; medical, industry, and metal laboratories, where 'normalities' and 'equivalents' mainly were used to describe concentrations. Frazer & Servant (1986b) concluded that the 'equivalents' concepts were preferred to abstract theories to express empirical data. Vygotsky (2012) highlighted the fact that students' learning could be in the correct zone of proximal development when tasks are set higher than their capacity. Phillips (1989), a chemistry high school teacher with 20 years teaching experience in South-eastern community school Florida, carried out a quantitative study to resolve students experiencing difficulties solving mole concept problems using computer-assisted instructions and reading skills strategies. It also involved using what he called "Frayer models, graphic organisers, and semantic mapping" to improve students' understanding of the procedural principle involved in solving mole concept problems. In addition, computer programs such as "COMPress and Knowledge Factory" were used by the participants to "review drill and practice" in relating their mathematical (procedural) understanding of solving mole concept problems. The study involved nineteen chemistry1 participants comprising three tenth-grade students, ten eleventh-grade, and six twelfth-grade students (6 female and 13 males). All the students had already taken and passed 1) the high school diploma test (state student assessment test part II) and 2) the algebra1 test. In addition, all the participants passed a first-year algebra course before enrolling. The research concluded that using computers for drills and practice was crucial in helping students relate mole concept principles to mathematical problem-solving methods, thereby increasing the students' overall ability to solve mole concept problems. The mathematics element of the mole concept teaching and learning will be crucial to this research as it is the principal method used in mole concept teaching and learning (Surif, et al., 2012). Later in the thesis will draw on studies involving the sociological aspects of teaching and learning mathematics as a guide to this study.

2.2.3 Mole Concept Research in the 1990s;

Mole concept studies in the nineties revealed that the quantity 'amount of substance' leaves both teacher and students confused about its clear meaning (Tullberg, et al., 1994). In this respect, Bunce et al. (1994) confirmed the above findings of students and instructors experiencing similar challenges. However, there have been differences in opinion amongst educators in the past 4 to 5 decades concerning instructors and students' difficulties in the teaching and learning of the mole, which prompted Dierks (1981) to conduct an extensive literature review on applying the mole concept, covering several decades. Staver & Lumpe (1993) also carried out documentary research involving twenty chemistry textbooks and uncovered two principal ways of defining the mole, which were the most popular, amongst which the cognitive aspect of the mole predominates. These include the fact that, in the first instance, it is important to ascertain the link between the mole with the Avogadro's number of particles. In contrast, in the second instance, it was the comparison of the mass of a substance contained in precisely 12 grams of ^{12}C that is necessary. Staver & Lumpe (1993) also found that the mole concept appeared in nearly all the chemistry textbooks they examined, as a method of counting very small particles that cannot be physically weighed. The use of familiar analogies of the mole was also highlighted in most of the textbooks, which introduces the conceptual teaching and learning. Garcia et al. (1990 cited in Furió, et al., 2002) conducted significant survey research covering secondary school to first-year undergraduate university students between 16 to 19 years old. As a result, they uncovered a significant proportion of incorrect answers concerning the International Union of Pure and Applied Chemistry (IUPAC) definition of the mole, hence concluded the superficial nature of students learning the mole concept. Duncan & Johnstone (1973) discovered that students find it challenging to understand when the reacting ratios were not 1:1. The difficulty also extended to dilution of an aqueous solution of a dissolved substance, failing to apply the correct expression in their calculations. Schmidt (1990) conducted an extensive study with 6000 secondary school age participants to determine their stoichiometric calculations skills and concluded that students turn to equate the number of moles of reacting species to the masses of reacting substances. They also equate molar masses to the proportion of reacting masses, neglecting the molar coefficients of the equation. The students did not appreciate the fact that an atom of different elements exhibits different masses. Janiuk's (1993) study segregated chemical concepts into two categories: 'Concrete-operational, which relates to experiential (hands-on) learning, and 'formal operational concept, where the mole concept belongs, meaning developing the concept through **position within a postulatory-deductive system.** Janiuk's (1993) research aimed to find the best conditions and methods for students' learning chemical concepts such as the mole. The theoretical approach was a range of tests, which varied in complexity, to measure student achievements, followed by interviews to determine specific processes, then a psychological test. The study concluded that learning chemistry concepts such as the mole is complex and still developing. However, I do not entirely agree with the concrete operational aspect of it, especially when dealing with gasses. For example, the ideal gas law (PV=nRT) is a mathematical formula used in the calculation of the number of moles (n) of a gas at a given temperature (T), volume (V), and pressure (P) of the gas. It would be very challenging to deal with such a problem through the deductive inference reasoning method alone, especially from the standpoint of high-school students. Krishnan & Howe (1994) developed a "paper-pencil test" instrument including a concept map to help instructors diagnose students' conceptual understanding of the mole concept. According to their literature findings, the test instrument was vital because students learn through knowledge accumulation to already existing knowledge, according to cognitive psychologists. Students developed misconceptions if their prior knowledge is wrong, which will become problematic, as instructors will find it challenging to identify their misconceptions. Krishnan & Howe (1994) identified the Piagetian individual interview method (Osborne & Freyberg, 1980; Watts, 1981) as one of the ways of understanding learners' conceptions. The methods used were diagnostic tests comprising of four stages:

1. Detailed study of some mole concept definitions from popular chemistry textbooks
2. Redefinitions of mole concepts into statements that have variables
3. Identifications of means of using sub-concepts already defined to solve problems

4. The use of a concept map to validate the already derived mole concept definitions

Krishnan & Howe (1994) concluded that their paper-pencil-test instrument would be helpful to chemistry instructors in teaching the mole concept and any other chemistry concept. Schmidt's (1994) research dwelled similarly on stoichiometric mole concept calculations aimed at uncovering students' errors. He concluded that difficulties are attributed to the challenging nature of the mole concept. Students did not rely on conceptual reasoning, even after being instructed to. Stromdahl *et al.* (1994) examined the mole concept amongst educators and discovered that 11% identified the mole as a unit of "amount of substance". Most of them (61%) identified it with Avogadro's number and 25% with mass. They concluded that students' conception or misconception of the mole concept correlates with that of their instructors. Tullberg et al., (1994) also concluded that instructors often neglected some of the taken granted facts, like the differences between molar mass and atomic/molecular mass, possess the most problems. They also found that instructors did not know the historical facts of the mole concept origin. Staver & Lumpe (1993) investigated the mole concept understanding of secondary school students regarding problem-solving, with some recognising number of particles, while others mass in grams. Staver & Lumpe (1993) identified two learner difficulties: inability to reconcile meaning between actual and sub-atomic quantities and differences in concept understanding, equating grams to a unit of atomic mass. Larson (1997) conducted ethnographic research on the mole concept in an American High school located in a military base in Japan. It was a participant observation method study, which took place in a high school chemistry classroom for one year. Larson's study highlighted the mole as a "unit of a physical quantity, an amount of substance", the interphase between abstract theory and practical laboratory chemistry, which bridges some physical quantities (volume, mass, & particles), that can be derived using proportionality constants; (Larson cited Stromdahl, et al., (1994). Larson concluded that many students were at the margin of understanding the concept (1997). Stromdahl et al. (1994) conducted a study on teachers understanding of the mole concept. They identified that eleven per cent recognised the mole as the 'unit of amount of substance', 61% identified it with Avogadro's number (6.0×10^{23}), and 25% identified it with the mass. They concluded that students' understanding of the mole is influenced by their instructors, which are different from the standards prescribed by the international system. Tullberg et al. (Tullberg, et al., 1994) highlighted that student find it difficult to differentiate between atomic mass, molar mass, and molecular mass, even though educators assumed that students are already competent in this knowledge. In these examples, the teacher and teaching methods were at fault; nothing was said about the 'field', 'Habitus' or 'Cultural Capital' (Bourdieu, 1986) of the learners. A complete discussion of Habitus, field, and cultural Capital will follow later. Bourdieu identified 'the position of individual agents in a field, the outcome of interactions between the explicit rules of the field agent's habitus and the agents social, economic and cultural capital,' and that 'the social order is progressively inscribed in people's minds' through 'cultural products', which includes language and education (Bourdieu, 1986, p. 471). It is therefore essential to consider the social positions and interactions of the learners.

2.2.4 Mole Concept Research after the year 2000;

Omwirhiren (2015) conducted a quantitative study involving n=120 upper secondary school students in Zaria (Nigeria) to examine students' errors in dealing with mole concept problems, and concluded that lack of initial understanding of the mole concept leads to subsequent lack of engagement in other topics, especially those involving 'stoichiometric' calculations since it involves dealing with molar quantities (Musa, 2009 cited in Omwirhiren, 2015). Omwirhiren (2015) also pointed to the fundamental and abstract nature of the concept while highlighting its importance. Ahiakwo's (2015) study of quantitative chemistry performance by secondary school students highlighted their poor performance in chemistry calculations due to similar reasons. (Omwirhiren, 2015; Ahiakwo, 2015). Considering the mathematical approach to the teaching and learning of the mole concept, some studies relating to the above approach have concluded that students demonstrated errors in calculations and misconceptions (Kousathana & Tsaparlis, 2002). Other recent studies tried to link students learning complexities of the 'mole' to misconceptions and errors associated with the phenomena. (Ahiakwo, 2015; Fang & Fang, 2011). Surif et al., (2012) conducted a quantitative study to investigate students understanding of the two main methods of solving mole concept problems (procedural and conceptual methods). They concluded that 'to solve a chemistry problem effectively, students should acquire a high degree of both procedural and conceptual knowledge. Where conceptual knowledge would be the knowledge acquired through the understanding of ideas embedded in the chemical concept, whilst procedural knowledge relates to the degree of understanding in the application and algorithmic (problem-solving/mathematical) application of the concept (Surif, et al., 2012). However, Chiu & Chang (2005) have shown that, students mostly can solve problems without an above-average understanding of the chemistry concept. Teachers, therefore, concentrate their efforts on the mathematical (procedural) approach of teaching and learning the concept because this may not only be less time consuming but is vital for problem-solving ability, and instructors' accountability (Chiu & Chang, 2005). There are lots of parallels between the study of the mole concept and mathematics (Ahiakwo, 2015; Niaz, 1985; Phillips, 1989) and there are limited studies on the sociological aspects of mole concept learning. Therefore, a sociological study of mathematics is included here, which will inform some aspect of the basis of this study. Malcolm et al., (2018) carried out a collaborative and iterative study called "the learning Study" (LS) which aimed at monitoring the performances of physical science instructors through a topic-by-topic framework. The conceptual application of the mole concept was the topic chosen by the researcher, to investigate three science instructors and their supervisors as they apply the Learning Study method. The mole concept lesson involved grade 11 (year 12 or sixth form) students revision lessons to improve their conceptual application of the mole concept, which act as a prelude to the stoichiometric topic. The study which involved three different schools in Southern Africa used the LS method which included pre-testing and post testing of the students for formative reasons. The study highlighted the fact that the instructors require PCK (Pedagogical Content Knowledge) which the possibility/ability of instructors to adapt their content and pedagogical knowledge into an awareness of how particular topics are organised (Shulman, 1987). The study therefore relied on topic specific PCK, which in this case was the conceptual teaching and learning of the mole, which formed a framework for their lesson planning. The instructors from each school conducted a two-hour revision lesson on the topic, with a break after one hour, with students working in groups of four. The findings showed an overall improvement especially in identifying molar volumes. Nevertheless 10% of participants failed the test in cycle 2, after passing in cycle 1. It was further reported that there was no significant improvement in answering the mole conceptual question relating to molar volumes as there was no significant difference in the scores (Malcolm, et al., 2018). This outcome is expected, because the instructors did not use any mole concept analogies which I think is at the centre of conceptual teaching and learning of the mole. Analogies encourage meaningful learning and leads to deeper understanding (Ausubel, 2000). This study has developed three analogies to that effect.

2.3 Linking the mole concept to educational social constructs;

From the articles reviewed, the emphasis has been on researching the factory/industrial model (Shaw, 2016) of teaching and learning the mole concept, characterised by quantitative methodology aimed to investigate the procedural (mathematical/formulae) methods of solving mole concept problems. This model was the trend in the eighties and late nineties, where according to Walford (1991) there was a political decision that socially constructs workers to serve the local economy. As a result, most post-1992 universities, which were former polytechnics, are located in economically deprived areas. This situation is in direct contrast to the incentives for research by top tier Higher Education (HE) institutions located in more affluent areas (Bathmaker, 2003). This was achieved through funding mechanisms (see section 5.3 political perspective). Research into the late nineties started looking into both the conceptual and procedural methods (Larson, 1997; Janiuk, 1993) of solving mole concept problems, but still skewed towards the quantitative approach, with minimal studies using qualitative methodologies or the sociological aspects associated with the mole concept, and science in general. The trend of using a predominately quantitative methodology in researching the mole concept continued into the millennium. However, some studies looked into both the procedural and conceptual methods of solving mole concept problems (Surif, et al., 2012). Even though Kolb (1978) stated that "*there is probably no concept in the entire first-year chemistry course more important for students to understand than the mole and one of the main reasons the mole concept is so essential in the study of chemistry is stoichiometry.*" The trend also reveals the application of Information Technology (IT) in the teaching and learning of the mole concept in the late eighties and into the millennium. This thesis will examine the differences between procedural/mathematical and conceptual methods of addressing mole concept problems. For example, considering the pound (£) and pennies (P) analogy (see section 1.2.3), it is easier and natural to buy goods and services, using the conceptual knowledge of the relationship between the pound and pennies. However, one can still use a formula and a calculator (procedural) method to work it out. For example, pound (£) is equal to X (pennies), divided by one hundred (£ = X (p) / 100), where pound (£) is synonymous with the mole.

2.4 A research comparator:

Sociological aspects of mathematics study, in the context of school transfer

(Noyes, 2004): Noyes (2004) looked at the different influences that have impacted the mathematics learners’ experiences in the context of school transfers. Some of these influences include; government policy, school culture, family attitudes and so on, described using the term "learning landscape metaphor" by Noyes (2004, p. 77). Its research was a qualitative study, with case study as the methodology of choice, which centred on participant observation of two classes of about sixty students and a semi-structured interview of six 10 to 11-year-old students. Noyes' thesis examines the socio-cultural factors that define learning and schooling and explores the comparative influences of these different cultures on mathematics learners. It also seeks to comprehend the mechanisms of 'social reproduction and positioning in education, as applied to mathematics, in the context of school transfers. More parallels between Noyes (2004) research and this thesis can be drawn, not only because the mole is defined mathematically by Avogadro via a mathematics constant, but because it can be determined procedurally (Niaz, 1985; Cervellati, et al., 1982), and the study highlights the same socio-cultural aspects of studying the mole concept.

2.4.1 Research Methodology Preferences from literature reviews;

Most of the research on the mole concept that was reviewed relied on scientific methodology, with survey and other quantitative methods as the research instruments. We took a different approach. This study uses narrative inquiry method of the qualitative methodology, which is informed by the interpretive paradigm, where reality or truth is multiple (Slevitch, 2011). The ontological and epistemological stance that underpins the methodology is centred on the idealists’ viewpoint and subject to individual interpretation (Patton, 2014). Semi-structured interviews in a one-to-one setting and focus group, was used to capture the narratives. Important ethical considerations which are significant in participants selection is discussed (see Chapter 6 Methodology).

2.5 Summary;

Amongst the papers reviewed, according to the papers covering about forty years, there was no clear trend that separates the decades other than that, from the late eighties onwards, there was the introduction of Information and Communication Technology (ICT) in the mole concept studies. Prior to this, especially in the late seventies and early eighties, there were attempts at researching the psychological aspects by employing Piagets' cognitive distance of students' stages of mental development. Such research focuses more on their intrinsic mole concept understanding (Goodstein & Howe, 1978; Niaz, 1985; Gabel & Sherwood, 1983; Krajcik & Haney, 1987; Shayer & Adey, 1984 cited in Furió, et al., 2002). Some studies concluded that students' difficulties in solving mole concept problems were not the results of instruction but because they have not yet attained Piagets' formal operational levels (Niaz, 1985; Shayer & Adey, 1984 cited in Furió, et al., 2002). Prior to these dates, most studies on the mole concept carried out in the pre-sixties and early seventies centred on documentary research. For example, Dierks (1981) carried out a biographical study covering four decades, investigated the use of the IUPAC definitions going back right into the sixties, and concluded that the definition and word "amount of substance" was responsible for the abstract nature of the mole concept. Hawthorne also carried out a documentary study involving one hundred chemistry textbooks (Hawthorne, 1973). A vast majority of the studies reviewed used quantitative methodology, with very few qualitative studies.

Therefore, to maintain a balance in the investigation, research into mathematics studies that use qualitative and social aspects of mathematics were reviewed, considering the parallels that exist between mathematics and the mole concept (Noyes, 2004); "A sociological study of school transfer and the learning of mathematic".

CHAPTER 3; Conceptual Teaching and Learning

3.1 Introduction;

The mole concept has two main methods of experiencing it: the procedural (mathematical) and the conceptual method, which explores ideas embedded in the concept (Surif, et al., 2012).There is a marked distinction between knowledge type and knowledge quality in the context of procedural and conceptual knowledge (Star, 2005), which can further throw more light on how chemistry students can experience the teaching and learning of the mole concept. Both forms of knowledge are perceived as knowledge types, usually in the social world, whereas in the science / mathematic world, they are qualities of knowledge (Star, 2005). Procedural knowledge is defined in terms of two kinds: familiarisation with individual symbols of a system and rules or procedures in dealing with problems, whereas conceptual knowledge is more relationship loaded, with a well-connected web. Understanding knowledge quality is significant since it will highlight the influences of science students' mole concept learning experiences. In addition, it defines how well something is understood or known. Knowledge quality can be observed at two extremes, superficial and deep levels, and anything in-between, with the latter associated with flexibility, critical thinking and understanding. In contrast, the former is associated with inflexibility, rote learning and knowledge reproduction (Glaser, 1991). It is, therefore, clear that procedural knowledge is superficial knowledge. From the literature review, it is apparent that the procedural method has been the dominant method used in both teaching and learning of the mole concept (Niaz, 1985; Larson, 1997; Phillips, 1989). Therefore, social justice implications arise due to inequalities associated with a lack of conceptual mole concept knowledge. Taber (2015) supports the conceptual method, insisting that conceptual teaching and learning should be a significant focal point of chemistry and general science education. Taber (2015) highlighted the lack of research in this crucially important area and recommends that it be given urgent attention in research and teaching and learning. The three analogies developed during this study will be utilised where possible to explain the phenomena. A crucial issue in science and chemistry education is to enable learners to translate ideas in the sub-microscopic sphere of electrons, ions and molecules (which the mole concept attempts to quantify) to the observable world of objects. Conceptual learning in science reflects the nature of science itself, which is becoming a fundamental curriculum aim. The fundamental nature of chemical knowledge is derived through categorisation, models, and typologies, which offers the learner distinct descriptions (Kiste, et al., 2017).

3.2 What are Concepts?

Gilbert & Watts (1983, p. 64) refer to concepts both as "an individual's psychological, personal, knowledge structure and to the organisation of public knowledge systems". This thesis explores how science students experience the teaching and learning of the mole concept, using a sociological theory, and highlights the social justice implications. Bourdieu's theory of practice (habitus, field, and forms of capital) applies. An individuals' psychological, personal and knowledge structure is first acquired from their home through socialisation within the family (habitus), 'an embodiment of culture and personal history' (Bourdieu, 1973).Their public knowledge organisation is the 'field' because it is where they practice their dispositions by relating the strategies of habitus to those of other actors in those public institutions (Bourdieu, 1985). In contrast, forms of capital will influence their social class and choice of university, influencing their mole concept experiences. Taber (2015) pointed out the importance of conceptual science learning as a distinguishing factor of the learners' different conceptions from what he called 'canonical concepts' in the curriculum.

> "*Concepts are mental features – Mental objects (categories) or actions (discrimination) – that are part of how humans make sense of the world*" (Taber, 2015, pp. 375-76).

Take the example of the analogies I developed (see analogies; 1.2.3) consider the concept of 'currency' as a mole concept analogy. Learning to use money starts from family interactions (habitus), where practical learning occurs, then this is extended by social interactions with public institutions like shops, banks, supermarkets, schools, and so on, ('fields'). A calculator with an inbuilt algorithm can procedurally experience the currency/money concept to work out money change and percentage reductions tasks. In this example, the currency concepts remain a mental entity available for recall in an individual's mind. Taber (2015) argued that the concept of acids exists only in minds and not part of the physical world, but strangely deviated from adopting the idealists' position of the material world as a construct of the human mind (p.376). Additionally, Taber (2015) attempts to agree with a realist counter position of the material world existing independently of the human mind, which backs the natural science position. Taber (2015) concluded that whatever the case, our thinking about the material world is structured through concepts based on mental constructions. The idealists' position of the material world being a construct of the human mind is similar to that held by 'divine science', as Eddy (1875) stated in her book *Science and Health with key to the scriptures*, that all objects/entities are spiritual ideas because they existed first as a 'blueprint' or thought in the minds that created them; therefore, she identified an infinite Mind that created and governed all. This study sees concepts like the mole and the currency concepts as socially constructed. They, however, existed first as an idea or blueprint in the minds of those that constructed them. For example, Ostwald coined the word ‘mole’ in 1900, with his definition of ‘amount of substance’, appealing to chemists. In contrast, Avogadro’s definition via a mathematical constant appealed to physicists (Kolb, 1978; Hawthorne, 1973). Their social construction meant that they could be transmitted socially and influenced by social factors. Sjoberg (2000) pointed out the regularities in the natural world, sees the creation of conceptual schemes as a means of making sense of those regularities, and concluded that the perception and conceptualisation of the regularities takes place in the minds of the individuals. People’s conceptual development is interpretive, as humans make sense of their experiences by building on current understanding, such that over time, they turn to see in relation to their concepts (Taber, 2015, p. 377) Over extended periods of engagements, concepts become grounded or automated, like in the experience of learning to ride a bicycle. Notably, new learners rarely have vital 'conceptual structures' of the experts (teachers), therefore requiring more conceptual thinking. The instructors will have to share their conceptual thoughts with their learners, especially those examples that relate to their learners’ experiences. This study adopts a social constructivist perspective that knowledge is situated within the scientific / chemistry community and is socially transmitted, not necessarily only in books and scientists’ minds (Taber, 2013).

3.3 Conceptual Assimilation;

Concepts must be assimilated into a consistent and correlated structure as they do not exist independently in a child's mind but requires coordination of thoughts (Vygotsky, 1934/1986). The Personal Construct Theory (PCT) explained the existence of structures in concepts, where constructs have the same connotation as concepts, which form the basis of discrimination, with hierarchical structures (Kelly, 1963). The PCT theory assumes a bipolar construct as a perception and cognition fundamental unit. Kelly (1963) identifies discrimination in terms of white–black, good–bad, acid–base. His conceptual thinking reflects the way he researched a person's constructs, which involved a two-stage process, one of which will involve, for example, learners arranging figures representing chemical structures like molecules, ions and atoms. Curriculum developments and schemes of works planning has dramatically benefited from the conceptual analysis since concepts or constructs can be viewed as hierarchical in a treelike order (Herron, et al., 1977). Similar arguments on the way students conceptualise reality as one origin of resolute conceptions, were further developed by Chi et al., (1994), expanding concepts with the example of students interchanging process for substance and vice versa, like treating heat as a substance instead of the process of heating. Aspects of people's inherent knowledge have demonstrated the usefulness of Kelly's (1963) methodology, but it is debatable if the hierarchical structures can capture the full degree of individual concepts. They are often commonly seen as fixed within 'propositional networks', similar to illustrating students' knowledge, using concept maps (Gilbert & Watts, 1983). However, this has a cognitive and subjective connotation as they described how peoples' conceptual meaning is dependent on relating it to their other previously understood concepts. Gilbert & Watts' (1983) work supports the importance of the three mole concept analogies (currency, bricklaying, and West African retail cup) described in this research, which are all relevant to the mole concept students' experiences. The important message for teachers is to explore the links students already have for the concepts under instruction and highlight the critical links concerning the new concept. Taber (2015) established that allocating enough time in establishing students' conceptual links will go a long way in not only dispelling misconceptions but will help learners to develop different conceptions and reinforced conceptual science/ chemistry structures.

3.4 Science and Conceptual Integration;

Science comprises a vast field including sub-fields, with a wide range of activities making it a fertile area for conceptual integration, with diverse possibilities for a wide range of analogies (Kuhn, 1996). Furthermore, the broad specialist areas offer different concepts and theories suitable for modelling. Losee (1993) stated that science is constructed on the bases of certain assumptions, which historically has assumed a realist/positivist position and currently adopting a post-positivist stand as the legitimate nature of science. Ontologically speaking, the scientific reality is based on external objective truth, whereas individual natural scientists may hold subjective views from the physical world, they interact with. Furthermore, the physical world appears to demonstrate a certain degree of stability, allowing research, influencing the way we interpret change (Glasersfeld, 1989). A common argument is that humans' comprehension of the world makes science possible. There is general agreement that psychology and cognition can provide indirect knowledge of the world, in contrary to conclusions reached through scientific methodology. There are however significant differences between different scientific principles, which limits human understanding. The most valuable ideas are those with broadly relevant frameworks for interpreting different phenomena, for example the theory of evolution not being easily accepted by certain students, even though evolution is fundamental to contemporary biology, which poses a deep problem (Long, 2011; Dobzhansky, 1973). The way in which the different fields and disciplines are related to each other is complex, with the view that eventually chemistry will be condensed to physics, and biology to chemistry, but may not be the case since all biological and chemical concepts can be viewed through the lens of physics (Taber, 2015). For example, the mole concept has a physics definition in the Avogadro's constant (Hawthorne, 1973), and a chemistry definition based on amount of substance, and the photosynthetic electron transport chain (cytochrome) and Krebs citric acid cycle, which links biology and chemistry (Ostwald, 1900; Kolb, 1978; Alabduladhem & Bordoni, 2021).

3.4.1 Diversity in Chemistry Modelling:

Conceptual models are not always consistent as their theories, and most often only reflect loosely the theories they try to represent (Taber, 2015). For example, the three analogies developed during this study can be easily challenged, if taken out of the mole concept context. Taber (2015) identified two distinct types of models that can be easily encountered by chemistry learners, which comprise for example, the definition of oxidation in terms of oxygen addition may be limited, since it will exclude other oxidation cases that may not involve oxygen. Whereas oxidation defined as loss of electrons covers everything. Another example where the Lewis model of defining acids covers more ground (including non-acids), than the Bronsted – Lowry model of defining acids which is not wrong, though it does not include all acids (Taber, 2015). The two definitions of acids (Lewis and Bronsted-

Lowry) are not erroneous but simply a human construct, of which we can rightly say that the definition of the concept of acids is socially constructed within the chemist community based on the different substances under examination in their characteristic reactions. Modelling of chemical structures especially at the sub-microscopic level presents a different position all together, where students will encounter multiple ways of representing and modelling atoms, ions, molecules etc. Some are outdated models, with differences between entities that cannot easily be represented at a macro level. For example, the solar system atomic models representing molecules compared to line-bone bonding structures linking atomic centres, with both models not fully representing all the features of a molecule (Justi & Gilbert, 2000). Taber (1995) pointed out how instructors maintained their different models as their conceptual lockers, where models can be pulled out to fulfil defined cognitive tasks, citing examples of crystals model showing close-packed structure, whereas it may not be necessary in other situations. Most limitations of conceptual models are only noticed by instructors, especially their ontological significance as incomplete illustrations, and their epistemological significance as tools to construct learners' thoughts and essentials of theories under examination (Taber, 1995). Learners can only be conscious of their limitations if the instructor brings it to their attention, especially to dispel misconceptions. The use of different models representing the same concept can be problematic, instructors must make the attempt to compare and explain their limitations, strength and application range of the novel model against the alternative that learners are already used to, with the aim of not confusing the students (Taber, 2015).

3.4.2 Conceptual and Integrated Learning;

The importance of conceptual integration in learning especially in the way students make sense of teaching and learning, is crucial (Taber, 2015), this makes learning relevant to the learners' lived experiences, and is what is often described as meaningful learning, as the learning material must be relatable to the current cognitive structures of the learners (Ausubel, 2000). It is clear that once instruction is not meaningful as when the learning material is not related in any degree to the learner's cognitive structures, or their existing knowledge, it leads to rote learning or learning through memorisation and repetition (procedural). Meaningful learning is associated learning because it can be associated to the learners' existing knowledge, but it remains fragile according to Alverez & Squire (1994). Learning materials can be easily activated and accessible by the learners if linked to previous mental representations through meaningful learning, because it gives the learner multiple routes to accessing the precise mental representation, which leads to more flexibility and deeper understanding. Meaningful learning is conceptual learning which can be applied in different context (Taber, 2015). It should be noted that, from constructivists viewpoint, an individual learner is the one who must recognise meaningful teaching, as it is associated with their previous understanding embedded within their "conceptual ecology", thus bringing relevance (Bodner, 1986). An important aspect of teaching, therefore, is to "make the unfamiliar familiar" by making the connection between new material and previous, and associating analogies, examples and metaphors to explain new ideas introduced in a lesson (Taber, 2002).

3.4.3 When Conceptual Teaching Impedes Learning (Misconceptions);

It is generally observed that conceptual teaching has positive effects in students' learning, and teachers should help students build conceptual maps and systems to aid their understanding. Nevertheless, it is also noted that huge conceptual change may introduce inconsistencies if inadequate conceptions are used (Thagard, 1992; Vosniadou, 2008). Learners may develop misconceptions or alternative conceptions away from established knowledge. Taber (2015) noted that some students may harbour the notion that metals are all hard substances, and all acids being dangerous substances. Another example included the "octet" rule in chemistry, which is a common conceptual framework, where students believe that atoms "want" or required eight electrons on the outer shells, and how chemical change takes place for atoms to fulfil this requirement (Taber, 1998). A key misconception of the octet rule is the human attributes associated with atoms, as students' seem to think that atoms may have feelings or desires (affinity) for electrons, with a good proportion of students believing that atoms are alive (Griffiths & Preston, 1992; Taber, 2013), which highlights the learners face in conceptualising sub-microscopic level theoretical abstract models to explain chemical concepts (Griffiths & Preston, 1992; Taber, 2001). Teachers are therefore advice to use anthropomorphic language with care, when introducing analogies and metaphors in making abstract and unfamiliar theories, familiar (Taber, 2015).

Other misconception that impedes learning includes:

- NaOH solution was regarded as a simple substance
- The proportion of ratio of moles was in the neutralisation reaction, equated with ratio of proportion in volume (Vincent, 1981)

- The concentration (g/mol) was equated with number of moles (Furió & Ortiz, 1983).

Vincent (1981) also highlights the fact the phrase “amount of substance” in the definition of the mole, confuses both instructors and students. Cervellati et al. (1982) also arrived at the same conclusion as students did not envision the mole as a unit of an “amount of substance” but rather as mass. Staver & Lumpe (1995) also found that students could not differentiate between molar mass and atomic mass.

3.4.4 Teaching Implications;

Conceptual teaching is closely linked to constructivist narrative (Driver & Oldham, 1986), instructors are advised to identify aspects of their previous knowledge which might help in constructing their conceptual structures of new learning materials, while repeating new materials using different conceptual structures, and knowledge from other topics where necessary (Taber, 2011). Teachers should help students “meta-cognitive development”, to help figure out the extent of their own knowledge structures and complex thought patterns. They are also advised to highlight the central role of conceptual models, with less emphasis on alternative models, since learners often treat scientific models as real (Treagust, et al., 2002). Instructors should also learn to be clear about conceptual models’ limitations, including tolerance of ambiguities in the modelling (Taber, 2010).

3.5 Conclusion;

The aim of this chapter was to explain the significance of conceptual teaching and learning within the context of mole concept, in order to highlight the inequalities embedded within the teaching and learning of the concept, especially if only the procedural method is used. Conceptual teaching and learning of the mole concept would have greatly enriched chemistry students' experiences of the concept, through meaningful learning (Ausubel, 2000), especially students from low socio-economic backgrounds, and non-traditional student who may not find the procedural method on its own accessible. Surif et al. (2012) quantitative study of the mole concept identified both the procedural (formula), and the conceptual as the two main methods of solving mole concept problems. They recommended that students should acquire a high degree of both methods, but Chiu & Chang (2005) found that teaching is centred on the procedural method only, with students solving mole concept problems without even an above average understanding of the concept. Meaningful teaching and learning is that which is made relevant to the learners' lived experiences (Ausubel, 2000), and this is what conceptual frameworks offers, which most students are not receiving and which is especially crucial for students from low socio-economic backgrounds. Cervellati et al. (1982) quantitative study of secondary school students highlighted the fact that students' inability to solve stoichiometric mole concept problems can be traced to certain features of instruction, which included; content of the curriculum, instruction methods, teacher training and assessment.

From the above information on Cervellati et al. (1982) findings, I will be devoting chapter four to mole concept assessment, to highlight how it impacts on science/chemistry students' mole concept experiences, and to highlight possible inequalities embedded within.

CHAPTER 4: Assessment (Mole Concept)

4.1 Introduction;

Assessment methods (summative and formative) influences how learners experience teaching and is identified as one of the factors responsible for students' inability to solve mole concept problems (Cervellati, et al., 1982); therefore, it has a significant impact on how science students experience teaching and learning mole concept. This chapter highlights how it impacts students' experiences and some of the inequalities embedded with the assessment framework. Research by Martinez & Lipson (1989) identified two types of assessment; assessment of learning (summative assessment) and assessment for learning (formative assessment) and suggested that assessment for learning should take priority over the assessment of learning (see sections 4.3.1 & 4.3.2). Assessments (e.g., examinations, tests) are often conducted at the end of a course of study. They are principally separate from the educational process aims to measure what the student has learned and what they are capable of doing. The resulting qualifications are the primary means that most people (students) are categorised and labelled in society. It also determines the type of tertiary institution (tier of university) that the student attends, determining how they will experience the mole concept (see 1.2.5 university stratifications). This view of assessment is problematic because it creates the discourses of intelligence and ability, which introduces the inequalities in the education system and hence has social justice implications.

4.2 Historical;

It is vital to examine the historical context of assessment to highlight its conceptual understanding and reveal how it impacts students in general and science students' mole concept experiences in particular, together with the inequalities embedded within it. Before the 18th-century, assessment was mainly carried out in universities by public oral examination, which only changed with the 'Senate House Examination', which introduced written tasks and distinct grades in the form of marks. This form of assessment, is predominantly summative, continued throughout the 19th century and was characterised by a written 'Closed book Examination' except for languages and medicine (Stray, 2001). Senate House Examination resulted from the need to examine individual cognitive progress and address the corruption associated with the oral examination system. This system of examination (summative assessment) dominated until after mid 20th century. Its effectiveness in measuring learners' ability and its restrictive character of assessed skills started coming into question (Stray, 2001; Cox, 1967; Heywood, 1977). Mass examination (summative assessment) is the product of mass education, which itself is a recent phenomenon of the 19th century, responsible for elevating and rewarding the 'able', and separating students into trades, vocations and professions, fulfilling a "mild eugenics function". It was also established that the prosperity of nations would depend on "the disciplined intelligence of the bulk of the community" (Devine, 1999, p. 401; Humes & Bryce, 2003). Therefore, examinations and the resulting qualifications are used as instruments to socially construct individuals in society after determining the 'field' (institution) where the mole concept students will practice their dispositions (Bourdieu, 1995). Oates et al. (2011) identified a distinctive feature associated with countries with 'high-performing educational systems, which was a distinctly different approach to 'pupil progression and differentiation. All learners are encouraged to achieve sufficient understanding before progressing to the next topic area. Oates, et al., (2011) stated that learners' "achievement is interpreted in terms of the power of effort rather than the limits of ability", where the emphasis on effort is a distinctive feature of countries like China, Singapore, South Korea, Taiwan, which are all Confucian-heritage countries. It is assumed that deeper understanding can be achieved through deep engagement with the learning material, including systematic memorisation. Whereas, in western countries such as England and the USA, there has been a different assumption, where the "*capacity to learn, and achieve, is determined by an innate endowment of fixed intelligence (**ability**)*" (Oates, et al., 2011, p. 45). The discourse of 'ability' versus 'effort' will determine how science students experience learning in general and mole concept in particular. The assumptions about children limited capability in learning are responsible for the 'negative influences and expectations of achievements and impact on the organisation and assessment of learning (Oates, et al., 2011, p. 45). Oates et al., (2011, p. 9) recommended that, "*resources should be prioritised for pupils who have either fallen behind or are identified as at risk of falling behind the rest of the class*", where they termed the approach '*high expectations for all*'. Currently, this is not the case since chemistry and science students are socially constructed as factory or local industry workers from teaching-led and research students from research-led universities, based on their tier of university, which is a direct outcome of the assessment process (Walford, 1991). The mole concept is assessed mainly through summative assessment or assessment of learning, which aims to separate 'able' from 'less able' learners. Its method of teaching and learning is predominantly procedural (Surif, et al., 2012).

4.3 Assessment of Learning;

There was a mistaken belief in the English education system that children's intellectual powers can be determined accurately at an early age through the use of an intelligence or ability test (Moon, et al., 1989).

4.3.1 Summative Assessment or Assessment of Learning (Ability Testing);

Academic work assessed to determine the extent of a student's learning outcome towards a degree, including presentations, essays, examinations, dissertations, is the definition of summative assessment (Harvey, 2004). Summative assessment is also thought of as testing at the end of school terms or courses, intending to provide information on students' levels of comprehension and an indication of how well the programme was taught (Wojtczak, 2002). Some studies have highlighted the definitive character of summative assessment by pointing to its validity and reliability as the principal debating points, including criterion and norm-referenced testing and assessment designs (Miller, 2005). While other studies on summative assessment especially on Higher Education (HE) assessment practices, have emphasised that grades and marks which are the outcome of the summative process are its strengths. However, it does not reveal much about the entire learning process or material covered, which is vital information for those wishing to appraise the vigour of an achievement (Knight, 2002).This lack of vigour and coverage and the limitations of the concept of ability make summative assessment an unfair or unequal test, making its utility questionable. Furthermore, some studies have concluded that summative assessment is a poor or moderate indicator of specific achievements, including career achievements. However, it may somehow indicate reliability on specific achievements at certain periods in the undergraduate course of study (Knight, 2002). If summative assessment is the principal method of mole concept assessment (Cervellati, et al., 1982), and also a poor indicator of achievements (Knight, 2002), therefore the whole notion of academic progression based on 'ability' alone, which determines science students' tiers of university (field) and hence their mole concept experience, is problematic.

4.3.2 Formative Assessment or Assessment for Learning;

Formative assessment is defined as a process aimed at amending ongoing teaching and learning by teachers and students during instruction to improve students' understanding and learning outcomes (CCSSO, 2008). It is also defined as a system of obtaining information and observations concerning students' abilities and skills with the aim of informing and facilitating practice and the learning process (Black & Wiliam, 1998a; Black & Wiliam, 1998b). A key feature of formative assessment is feedback, a feedback loop or iteration (Vai & Sosulski, 2011). This feedback loop introduces the concept of effort to formative assessment and can influence how students experience learning in general and mole concept in particular. The relationship between "effort" and "ability" will be further explored (see 4.4 Meritocracy). Studies on formative assessments by Shute et al. (2008) examined an assessment for the learning process called Adaptive Content with Evidence-Based Diagnosis (ACED), which involved a student based diagnostic procedure. ACED is aimed at uncovering gaps in the learners' skills, knowledge and understanding, but lacks reliability and validity, which confirms the importance of feedback mechanism. Another study based on enhancing learning using formative assessment, involved students with diverse educational experiences from an extended HE degree course, and relied on a specific virtual framework created for participants on a biology module. The study comprised a weekly on-line test that gave participants the flexibility of completing the assessment task at their own convenience. The results showed a higher student engagement and improved grades, with student feedback indicating more than 80% approval of the assessment tool (Jacoby, et al., 2014). Similar highlights came from a study that looked into the effects of blended learning technologies as it impacts students learning/performances in a biochemical science HE course (Heugh, 2015).

However, some drawbacks of formative assessment were also highlighted, including the fact that it is usually non-standardised in procedure and outcome because the assessment data is usually non-reliable. The study by Shute et al., (2008) also highlighted psychometric difficulties, which included 'modelling of different students' characteristics and their diverse abilities' (Shute & Zapata-Rivera, 2008). Another diagnostic or formative assessment study of mathematics concluded that formative assessment is an integral part of instructional decision-making (Katterlin-Geller & Yovanoff, 2009). Katterlin-Geller & Yovanoff (2009) highlighted students' ongoing misconceptions in particular knowledge areas, which helps bridge learners' knowledge gaps by designing extra tuition. It is envisioned that diagnosis furnishes important data about learners' competencies of vital prior knowledge and skills, including misconceptions or preconceptions of the learning material. Katterlin-Geller and Yovanoff (2009) study discussed current methods of diagnosis and identified the pros and cons of each technique of making instructional decisions in mathematics. Please note that mole concept teaching and learning is predominantly achieved through procedural or mathematical methods

(Surif, et al., 2012). Katterlin-Geller & Yovanoff. (2009) techniques included; 1) cognitive diagnosis assessment (which identifies persistent misconceptions and the further tuition intervention as a solution), 2) error assessment (identifies the error learners are making when dealing with a particular problem and corrected through repeat tuition), and 3) skills analysis (which determine skills that may be hard to design repeated review activities), (Katterlin-Geller & Yovanoff, 2009). With skills analysis, Ketterlin-Geller & Yovanoff (2009) suggest that instructors have to determine students' mastery of certain sub-skills. While Fuchs et al., (1990) stated that, “skills analysis is becoming more popular as a method of diagnostic understanding of ‘Curriculum Based Measure’ (CBM). CBM has an excellent history as a calibration instrument for assessing special needs students’ and a near-perfect means of organising authentic information about all students' progress. CBM is a widely used system beyond mathematics to include spelling, reading, writing, and screening tool to address underachievement (Katterlin-Geller & Yovanoff, 2009). If applied or not applied, formative assessment will influence how science students experienced the teaching and learning of the mole concept.

4.3.3 Summative (Ability) and Formative (Effort) Assessment;

The application of both methods of assessment will enhance science students’ experiences of the mole concept. Studies that highlighted the use of instructional summative assessment data in formative assessment ways, using evidence based/instructional decisions concluded that it has become vital in the instructional process (Hoover & Abrams, 2013). The fundamental difference between formative and summative assessment is in the way assessment data is used. Summative assessment data is used principally in governmental departments, school administrators, local authorities, parents and teachers. On the other hand, formative data is predominantly used by instructors and learners (Hoover & Abrams, 2013). Hover and Abrams (2013) suggest that a combination of formative and summative assessment can be valuable and practical. Summative assessment has a secondary formative function in addition to the primary summative or ability testing (Bennett, 2011). Data gathered through summative assessment, if used by instructors to improve their pedagogy such that students' understanding of the learning material is improved, then its nature becomes formative (Black & William, 2003). The notion of using summative and formative assessment methods, especially if both methods are related to specific teaching goals and practices, was supported by Brookhart (2010).

A study conducted by Guskey, et al (1990), as reported by Hover and Abrams (2013, p. 220), involved a group of 'at risk' primary school pupils with mild learning disabilities under monitoring by their instructors through 'mastery learning'. The data from summative tests at the end of a learning task was analysed to administer formative feedback to the learners about their conceptual understanding of the learning materials. In addition, the entire assessment outcome data enabled tutors to offer pupils instructional requirements. 'The scores pupils attained in the treatment group rose by 13.6%, and an increase of over one standard deviation, in contrast to 3.8% in the control group'. Hover & Abram (2013, p. 220) argue that the vast amount of data accumulated since the beginning of state-mandated testing, from summative assessments at the end-of-course exams or grade-level ability tests, has not been helpful to current researchers. Hence, it was difficult to arrive at any conclusion about students' achievements to the application of assessment data. However, an explanation was attempted by Hamilton et al., (2009) when they suggested that the difficulty identified by Hoover & Abram (2013) is linked to the elusive nature of experimental/research designs which involved the use of data. Hover and Abram (2013) concluded that regardless of the difficulties linked to assessment data by teachers and its predisposition to influence student accomplishment, there is an increasing body of knowledge on how teachers should use assessment data. There are similarities in advantages when the procedural and conceptual methods of mole concept teaching and learning are combined (Surif, et al., 2012), and the summative plus formative assessment combined (Hoover & Abrams, 2013). All of these can have huge impacts on how undergraduate chemistry students experience the teaching and learning of the mole concept. The use of an electronic assessor tends to bring both methods of assessment together.

4.3.4 E- Assessor (electronic / digital / online assessment);

E-assessor is electronic or digital assessment (Vai & Sosulski, 2011) also known as computer-based or online assessment. The application of Information Technology (IT) to the assessment process (Sorensen, 2012) also influences the way students in general and science students in particular experience the teaching and learning of the mole concept. A study by Sorensen (2012) on e-assessment with Chemical Engineering students as participants, confirm overwhelming student support and approval of e-assessment. An online survey revealed that most learners prefer electronic assessment methods and wish them to be utilised across other curriculum areas. E-assessor supports the integration of formative and summative assessment. MCQ's can be set easily with the incorporation of feedback elements for the formative mode and in-depth essay and problem-solving mode questions for the summative element (Sorensen, 2012, p. 172). The integration of summative and formative assessment using e-assessor will be important, especially when using the procedural method of mole concept teaching and learning. E-assessment has to be varied and ongoing and linked to learning outcomes, with appropriate instructor and peer-to-peer feedback (formative), together with clear grading (summative) element (Vai & Sosulski, 2011). Ongoing online assessment has the added benefit of providing the students with 'multiple opportunities to understand and improve their knowledge, skills, & underline and locate the learners' levels of understanding (Vai & Sosulski, 2011). E-assessor's role in linking summative and formative assessment is crucial in assessing the learners' 'powers of effort rather than only the limits of their ability' (Oates, et al., 2011). Therefore, online assessment can improve the procedures and methods of assessment due to advantages that include; immediate feedback, time-saving, excellent use of resources, convenience and records saving. The instant feedback element of formative e-assessment enables students to deal with their misconceptions or gaps in knowledge (Jordan & Mitchell, 2009). Almost all online courses and systems now provide essential support for assessment, especially in evaluating and creating multiple-choice tests (Sorensen, 2012). Aravinthan and Aravinthan (2010) investigated the learning outcomes of an electronic self-assessment test designed as a formative assessment instrument for two engineering courses. They identified a significant correlation between students who attempted the test and their general performance determined by their exam scores (Aravinthan & Aravinthan, 2010). Some other study investigated the online testing of first year physics students' and revealed a huge students' satisfaction and participation. The students recognised that the test facilitated their study, as it provided them with further problem-solving tasks and immediate feedback (Swan, 2004). These results are consistent with the assessment of effort applying both the formative/summative assessment elements and enriching science students' experiences. Nevertheless, Swan (2004) argues that 'the tests also helped identify 'weaker' students', which is problematic as assessment can only draw attention to gaps in students' knowledge, which does not mean they are weak students. All learners can learn at a very high level (Oates, et al., 2011). Another quantitative study highlighted the importance of e-assessor in summative assessment, which employed a survey method to gather data from distant learners (Jordan, 2011). Jordan (2011) concluded that, the learners interacted more with the online questions when marks were allocated, with students' wanting their online scores to be included in their final grades. Another significant aspect of formative online assessment is peer-to-peer e-assessment. Lu & Law (2011) investigated the effects of online peer assessment. Their study included peer-to-peer feedback with grading and employed 181 high school students via an 'iLap' online system. The research reported significant effects on both the assessors and assesses when the data were analysed using multiple regression (Lu & Law, 2011). An 'Apache' e-assessor server using Javascript & PHP and MySQL as the database system was created and implemented to update and simplify the examination process. The system was user friendly and easily edited using an administration module teachers can add and remove questions or amend the entire exam make-up and even observe students' participation. The multiple-choice type questions enhanced the formative element of the test, especially as the test is marked instantly, with re-evaluation and feedback (Petrisor, et al., 2011). In addition, E-assessors can save significant amounts of resources since the costs of paper and ink with other related stationery will be eliminated. Equally, a large number of students can be examined simultaneously and repeatedly (Petrisor, et al., 2011). However, e-assessment critics highlighted conventional e-assessment task could encourage superficial learning (Jordan & Mitchell, 2009). Other disadvantages of e-assessor include; the need for a powerful server with internet access, the cost of computer equipment and student access to appropriate resources to practice (Petrisor, et al., 2011). Assessment practices, especially summative assessment, determine merit, which determines the types of universities that science students will attend and influence their experiences (Wojtczak, 2002; Knight, 2002). This, identifying these differences highlights the necessity to examine the concept of meritocracy.

4.3.5 E-assessment and blended learning;

E-assessor can encourage blended learning, as evident from research by Heugh (2015), where blended learning incorporating e-learning (System Management Program) innovative method was used asynchronously with traditional classroom, to study the achievements, progression, satisfaction, and retention of students in four biomedical modules. Through formative assessment, significant difference was found, between the intervention group of students and the non-intervention cohort (Heugh, 2015).

4.4 Meritocracy;

A meritocratic society is one in which intellect and merit is the central theme of society. This was supposed to have replaced social class stratifications with distinctions between a merited powerful elite and powerless underclass of little or no merit (Allen, 2011).

Young’s equation that defines merit includes ability plus effort;

Meritocracy= Ability + Effort (Young, 1979; Allen, 2011)

Key: for this research, “**ability**” will signify the tendency to memorise facts such as mole concept related equations (mol = mass (g)/RMM) where RMM is Relative Molecular Mass, and (conc. = #moles/vol.), including the ability to rearrange and substitute values into the equations and solve stoichiometric problems. It is the ability to understand the procedural method of mole concept teaching and learning and its evaluation by summative assessment. The ‘**effort’** would mean attempting conceptual learning by applying prior knowledge through concept maps and feedback interactions/iteration or loops between learner and instructor (Hoover & Abrams, 2013). It is related to conceptual teaching and learning described in chapter 3 and formatively assessed. The introduction of a meritocratic society to replace a class-based society (Young, 1958 cited in Allen, 2011) has not addressed societal inequalities in England; otherwise, this research would not have been necessary. Furthermore, summative assessment which determines students’ university tiers (Knight, 2002) and hence social rank, is itself problematic, without the inclusion of “effort” (Young, 1979).

4.4.1 Meritocracy and this study;

A class-based society breeds inequalities which are legitimised and reproduced through the education system (Bourdieu, 1990). The legitimisation is achieved through educational qualifications which are the outcome of mostly summative assessment method. These qualifications not only determine the type of HE institution that the learner attends, but determines merit. Meritocracy is the supposed antidote for a class-based society, but it still propagates inequalities because it is not equally applied. For example, meritocracy includes both ‘effort’ and ‘ability’, but academic credentials or qualifications are mostly dependent on examinations which are based mostly on summative assessment (ability testing). Predominantly, the mole concept is evaluated by summative assessment (ability testing), where learners’ ‘limit of ability’ is tested and the outcome used to label or select students for academic progression (Oates, et al., 2011; Knight, 2002). Summative assessment or ability testing is problematic because it lacks ‘vigour and coverage’ (Knight, 2002). Summative assessment as applied to the mole, only measures students’ abilities to memorise and manipulate equations. Chiu (2004) found that, students can solve mole related problems without having an above average understanding of the concept involved. On the other hand, formative assessment is linked to the evaluation of learners ‘power of effort’ (Oates, et al., 2011), as it includes feedback between learner and instructor, which can be repeated, leading to the effort in addressing gaps in the learners understanding (Hoover & Abrams, 2013).Procedural teaching and learning of the mole, is linked to summative assessment which encourages the narrowing of the curriculum, hence disadvantaging lower-class students. Whereas formative assessment will introduce the element of ‘effort’ in the meritocracy equation, and will encourage a broad based and balanced curriculum, which will include all class of students (Moore & Vaughan, 2017) (also see sections 4.3 & 4.4).

4.5 Assessment and this study;

The assessment methods are equally important in determining how science students experience the teaching and learning of the mole. Cervellati et al., (1982) highlighted the fact that, science students’ mole concept difficulties were due to certain instructional features like; curriculum content, instruction method and assessment. Therefore, assessment methods also determine how science students experience the teaching and learning of the mole, which includes summative and formative assessment (Black & Wiliam, 1998a; Miller, 2005), together with e-assessment (electronic assessment) delivered through e-assessor. Formative assessment is linked to conceptual teaching and learning, which encourages a broad and balanced curriculum (Hoover & Abrams, 2013; Moore & Vaughan, 2017), while procedural teaching is supported by summative assessment, which promotes the narrowing of the curriculum (Moore & Vaughan, 2017). E-assessor supports the integration of both summative and formative assessment (Sorensen, 2012, p. 172). For this study, Dr Kan (not his real name) uses both formative and summative assessment and e-assessment, in evaluating his student. The general trend is that, most science lecturers depend on summative assessment in delivering the mole, which is the case with both Dr Paul and Dr Luke. We would have expected Dr Paul to assess his learners using both summative and formative assessment methods, since he teaches using both conceptual and procedural methods. Dr Kan who uses all three methods of assessment, does not teach the mole conceptually, which is strange.

4.3 Summary;

Assessment is one of the critical factors influencing science students' inability to solve mole concept problems (Cervellati, et al., 1982). Assessment comprises two vital components; summative, also termed assessment of learning, and formative, which is termed assessment for learning, (Martinez & Lipson, 1989). Predominantly the mole concept is evaluated by summative assessment (ability testing), where learners' 'limit of ability' is tested and the outcome used to label or select students for academic progression (Oates, et al., 2011; Knight, 2002). Summative assessment or ability testing is problematic because it lacks ‘vigour and coverage’ (Knight, 2002). On the other hand, formative assessment is linked to the evaluation of learners ‘power of effort’ (Oates, et al., 2011), as it includes feedback between learner and instructor, which can be repeated, leading to the effort in addressing gaps in the learners understanding (Hoover & Abrams, 2013). The use of both assessment methods can address the inequalities and disadvantages of the summative assessment process, leading to learners’ deeper understanding (Hoover & Abrams, 2013; Brookhart, 2010). The effective amalgamation of summative and formative assessment is an advantage of an E-assessor (or similar tool), allowing for varied and ongoing assessment opportunities (Vai & Sosulski, 2011; Sorensen, 2012). Both procedural and conceptual methods of mole concept teaching and learning can be linked to summative/ability testing and formative/effort assessment respectively. Meritocracy should include both ‘ability’ and ‘effort’ (Young, 1979); otherwise, the inequalities of the class-based society will persist (Young, 1958 cited in Allen, 2011).

4.4 Conclusion;

The procedural method of mole concept teaching and learning relates to summative/ability testing with all its limitations, while the conceptual method is related to effort via feedback / formative assessment. E-assessor can facilitate the use of both methods in mole concept assessment. All these factors operate in the Bourdieurian' field' of tertiary educational institutions where science students (mole concept students) and instructors practice their dispositions (Bourdieu, 1985), impacting their experiences.

CHAPTER 5: Theoretical Framework

5.1 Introduction;

This chapter offers an outline and essential examination of the theoretical framework that governs this study. It commences with an overview of the importance of using a theoretical framework, followed by an introduction to Bourdieu’s theory of practice, habitus, field and forms of capital (Bourdieu, 1984; Bourdieu, 1990). The theoretical framework specifies the general space in which the study is situated and defines the parameters, used to maintain and interpret the research findings (Pearson & Li, 2005). In qualitative research, the theory does not typically shape the study from the beginning. The goal is not to test theory as in scientific research but more to build theory and interrogate emerging ideas that shape the research's principal aim. (Pearson & Li, 2005). It is vitally important that the study does not employ theory to "mine" data and only highlights the information that backs the theory. Instead, it uses it as a means of understanding the data better (Webb, et al., 2017). It is often said that, in the absence of concepts or theory, the study is empty and narrow, while research without concept/theory is blind or an “armchair contemplation” (Silverman, 2017). However, Swedberg (2016) noted that understanding and knowledge are created through deliberately and unconsciously, tapping onto existing concept/theory and producing an intricate interplay between research, concept/theory, and practice. Some science students and especially students from low socio-economic backgrounds who are usually non-traditional, demonstrate great difficulties in HE access, participation and outcomes. These students remain targets for social construction, to serve as local industry workers

(Walford, 1991).

Ontologically / epistemologically speaking, reality could be objective, subjective, or constructed (Crotty, 1998). Berger and Luckman (2011) visualised society as existing in multiple reality mode, objectively; by people's engagements with the social world. This, subsequently impacts on them, giving rise to fixed routines, and an accumulation of knowledge, which becomes objective knowledge to future generations. On the other hand, subjective reality experiences in society is accomplished through different degrees of socialisation, which includes, being ascribe an identity and position in society. This view is also confirmed by Burr (1995), who insisted that, identities are externally ascribed from our social realm, and not from within the person. This study is underpinned by the social constructionist theory, which is of the interpretive paradigm, as it seeks to understand not only the social construction of the mole, but also how it shapes and influences the mole concept identities of learners, through its teaching and learning. This research will begin by defining social constructionist theory, and differentiate it from social constructivist theory, as it is often used interchangeably, for example by Charmaz (2008) as reported by Andrews et al., (2013).

5.2 Social Constructionist theory;

Social constructionism asserts that most entities, especially those regarded in society as normal or natural such as the perception of class, race, disability, and gender are socially constructed, therefore does not precisely reflect reality. It should be noted that these constructs are usually produced within certain cultures and establishments, and comes to light in certain historical periods, and their dependency on political, economic and historical conditions can engineer their change and evolution (Vinney, 2019). Social constructionism originated in the sixties from a group of thinkers who added to Mead's theory of symbolic interactionism which holds that, social interactions are vital for the constructions of identities (Berger & Luckmann, 2011). The theory holds that, all meaning is socially produced, and might be so deep-rooted that they appear natural or objectively real, which is not the case, as they are the product of a given society in history, without a true reflection of reality (Vinney, 2019). The mole concept can be viewed via the social constructionist lens, as it originated in the 1900's during the beginning of the modernist period where science was replacing the church, as the dominant mode of thought (Kolb, 1978). This research uses the following three main points of social constructionism (knowledge is socially constructed; language is central to social construction; & knowledge construction is politically driven), to situate the mole.

One of the three fundamental beliefs of social constructionists is the notion that knowledge is created because of human interactions or relationships, the outcome of social processes that occurred in cultural and historical contexts (Vinney, 2019). This was further highlighted by Vinney (2019) by stressing the fact that in the scientific sphere, where objective truth can be acquired within the boundaries of a certain discipline, there is no universal truth that is more valid than the others. So, the truth about the mole concept is not as rigid and objectively true as it appears to be, even though it is a scientific concept, especially when we consider its cultural and historical context. The 'mole' was socially constructed in the early twentieth century (1900) by a German chemist Ostwald (Kolb, 1978), who defined it as "an amount of substance", to help estimate the amount of reacting substances. An Italian physicist Avogadro, also contributed in defining the mole from a physicist point of view "Avogadro constant" (Hawthorne, 1973) This is significant because it highlights two modes of thoughts at play in the social context of the mole. The social construction of the mole is similar to the social construction of money and the concept of currency (Pettifor, 2014). Money/currency only has value in the exchange mechanism, because people and society accept to give it value (also see section 1.2.4, the mole concept as a socially constructed chemist / scientist currency). This is equivelant to the mole, as the entire scientific community has decided to accept the mole as the unit of measuring “amount of substance”, even though with different angles of looking at it (Avogadro constant, milli-moles, nano-moles). Recently, in 2018, the 26th General Conference on Weights and Measurements (CGPM in French) holding France, voted to change the definition of the mole from Oswald the chemists’ “amount of substance equivalent to 12g of Carbon^{12}”, to an “amount of atoms/molecules given by the Avogadro constant”. This definition is more of a physicists’ viewpoint. So, we say the mole is socially constructed, at least within the scientific community.

A second fundamental belief of social constructionists’ theory is the fact that, language is central to social construction, as it obeys certain rules which shapes how we understand the world. This makes language not neutral, as it can limit our expression or perception of what we know and experienced (Vinney, 2019). The social construction of the mole is influenced by language. The word “mole” is a Latin word meaning “heap”, and was coined by a German chemist Oswald (Kolb, 1978). Equally, Avogadro’s constant, which also defines the mole, was introduced by Avogadro, an Italian physicist (Hawthorne, 1973). We also have different aspects of the mole “milli-moles” defined using the French language, as “milli” is derived from the French word “mille”, meaning a thousand. In this case, “milli” signifies a thousandth (1/1000), similar to the other metric units’ millimetre and milligram. So, we have an interplay of Latin, which was the main language of science at the time (Porzucki, 2004), English and French. These three languages are involved in the social construction of the mole, with German and Italian influences from the key architects (Oswald & Avogadro). Another fundamental belief of social constructionists is the fact that, the resulting knowledge generated in a society, has social, political and cultural significance, as individual members of the society, accepts and propagates the societal understanding of some vital realities, values and truths (Vinney, 2019). Vinney (2019) further pointed out how when new members of that society recognise the resulting knowledge; it is further propagated until it can become policy and or ingrained in that community for privilege and power. The socially constructed ideas then develop into social realities, which if not addressed, will start to appear fixed and may become embedded. It is these embedded ideas in the scientific community about the mole, which come as a result of its social construction, that this study seeks to deconstruct, in order to uncover the inequalities if any, embedded within its structures. The social construction of the mole had a political connotation from its origin, which is not separate from the language construction. The mole was introduced in 1900 by Oswald a German chemist, but why was a Latin word "mole" used, instead of a German word? The scientific community was heavily influenced by the political atmosphere leading to and beyond World War One (WW1). Old European powers (Russia, Germany, France, Italy, Britain, Austria & Hungary) had started forming military alliances as early as 1892 with France and Russia. Germany, Austria-Hungary & Italy, and the Triple Entente alliance of France, Britain & Russia in 1907; seven years after Oswald established the mole. Despite the political tension, the mole was constructed in Latin, because Latin was the dominant language in Europe, even though German was the dominant language of chemistry (Porzucki, 2004). This was important because most scientists will prefer their papers read by the wider scientific community, instead of a small number of scientists. At one point, the language influence in the science community was in the proportion of 1/3 German, 1/3 French & 1/3 English until after WW1, where the British, Belgian, and French scientists, planned an embargo of German and Austrian scientists, from attending conferences, and were barred from publishing their works in Western European Journals. This action produced two scientific societies, with one German and the others English/French (Western European), which later lead to the formation of the International Union of Pure and Applied Chemistry (I.U.P.A.C). This body now defines the mole as an S.I unit of measuring “amount of substance”, measured using the metric system which is French. German which was the dominant language of chemistry was eliminated (Porzucki, 2004). Had Germany won the wars, the mole and the way it is expressed or experienced, would have been very different. German would not only have remained as the dominant language of chemistry, but it would have been the dominant language of the world, including the whole of the scientific world. Porzucki (2004), citing Michael Gordin (Professor of the history of science), reflected on the fact that, after the USA entered the war in 1917, anti-German frenzy took precedence in the USA where a significant proportion of the society was still speaking German. German speaking was criminalised in at least 23 states. Porzucki (2004) further noted that, even though the English adopted the word “oxygen” which was coined by French scientists from Greek, meaning “acid-maker”, the German scientists did not. They instead translated the word “acid-maker” word-for-word in German, “Sauerstoff” (acid-substance). This indicates that most scientific words or units of measurement like the metric units would have been done differently, had Germany won the wars. Currently most scientific words are not translated out of English language, such as microchip, transistors & online. It is therefore important to deconstruct all aspects of the mole, to uncover elements of its social construction, which may promote societal inequalities. Another aspect of the political and cultural influences of the social construction of the mole, can be found in section 5.3 (Political Perspective), which examines the social construction of two types of mole concept students (traditional & non-traditional). Vinney, (2019) made a distinction between social constructivism and social constructionism. The former is involved with what is happening at the cognitive level of the individual's interaction as they create structures to comprehend the world, while the later deals with individual's interactions within their environment in a group or society, to construct new realities. Parallels can be drawn between these and other systems, for example, an individual's behaviour and traits are believed to be caused solely by genetics, according to biological determinism theory, while social constructionism insists on environmental factors on individual behaviour, creating social realities (Vinney, 2019). Nevertheless, social constructionism has its critiques, as some scholars claimed that it is anti-realist, as it does not wholly subscribe to positivist view of reality which is based on observations (Vinney, 2019). This positivist view can be applied to the mole, as it is a scientific concept. It has been demonstrated above, how the mole is socially constructed. Therefore, to fully understand the nature of the problems it posses to both students and instructors as revealed by previous studies (Tullberg, et al., 1994), an understanding of its social construction is necessary, hence the deconstruction. Pierre Bourdieu's theory is appropriate in this respect because the aim is to examine the external factors that govern the teaching and learning of the mole, which are mainly sociological.

From the University stratifications (see section 1.2.5), it is clear that students are socially constructed for different types of universities (Bathmaker, 2015). Consequently, such students will have different mole concept experiences. In the context of equality of access and widening participation, the study emphasises investigating current mole concept/educational practices and policies that continue to reproduce social inequalities in the science/academic field (Webb, et al., 2017). Webb et al., (2017) highlighted social formations, transformations, and causations, thus making Bourdieuran theory appropriate and central to this study. Bourdieu (1993) significant contribution in the education field was in developing a broad theory to describe the reproduction of social and cultural inequalities throughout education and the effects of non-recognition in legitimising these. As a result, the education system was more associated with specific classes' social cultures, which reflects and justifies these qualities as individual abilities. In addition, he highlighted the importance of understanding the laws of reproduction to lessen, even in small degrees, the reproductive outcome of inequalities in the education system (Bourdieu, 2008). Bourdieu’s interest in the role of education in promoting inequalities accounts for the author's interest in his theory. Equally, it has attracted the interest of other researchers as they insisted that Bourdieu’s theory provided a useful framework for them to understand aspects of Higher Education, which comprised unequal access and experiences of the system (Murphy & Costa, 2016). Changes do not match the high degree of change in the social world in the legitimisation of inequalities in the education system; hence Bourdieu’s theory offers a vital asset for researchers in this field (Gale & Lingard, 2015). Bourdieu's theory is underpinned by social groups' constructs, not merely the collection of individual behaviours but is shaped by tradition, culture, and objective structures in society (Rhynas, 2005). Bourdieu (1984) refused to offer a clear definition of his theory of practice, neither did he admit that it was a theory at all, but he generally referred to it as a principal feature of social life that requires explanation (Rawolle & Lingard, 2008), which is given by the equation;

"[(habitus) (capital)] + field = practice]" (Bourdieu, 1984, p. 101).

According to Webb et al., (2017), the above equation defining Bourdieu's theory of practice, is conceptualised as a complex interface of the social space, reflecting the social and cultural norms constructed between individuals and institutions (fields). Alternatively, in another sense, the relationships between habitus, field, and capitals produce social practices where subjective perception and objective structures affect human action (Suminar, 2013). Ontologically speaking, reality could be objective, subjective, or constructed (Crotty, 1998). For example, Berger and Luckman (2011) visualised society as existing in multiple reality modes, objectively; by peoples' engagement with the social world, which subsequently impacts on them, giving rise to fixed routines, and an accumulation of knowledge, which becomes objective knowledge to future generations. On the other hand, subjective reality experiences in society are accomplished through different socialisation degrees, including ascribing societal identities and positions. Burr (1995) affirms this view, insisting that identities are externally ascribed from our social realm and not within the person. Contextual and strict constructionism was suggested by Burningham & Cooper (1999) ascribing objective reality and its influences to contextual. At the same time, strict constructionism is more inclined to multiple realities, taking a relativist stance, responsible for criticism from social constructionist’s' formed around a superficial conceptualisation of realism and relativism. Fleetwood & Ackroyd (2004) identified four modes in which things/entities can be real; social, material, ideal and artefactual. This research is classed under social realism and is guided by social constructionist theory, which is associated with post-modernity and qualitative methodology (Andrews, et al., 2013). Initially, we differentiate between social constructionism and constructivism. Charmaz (2008) uses both terms interchangeably, as reported by Andrews et al., (2013). Young and Colin (2004) noted that constructivism assumes that individuals construct mental experiences of the world through cognitive processes. In contrast, social constructionism relies on the social influences created through groups interactions. They view knowledge and reality/truth as mental processes created, not discovered (Young & Collin, 2004). However, language has emerged as a problematic medium of transmitting feelings and thoughts within social constructionism, where language is responsible for making thought and concept possible (Burr, 1995). For example, the word ‘mole’ comes from the Latin word ‘moles’ meaning ‘heap’ and tends to confuse both learners and instructors (Kolb, 1978; Hawthorne, 1973), as the historical context is not often taught. Another criticism offered by Craib (1997), pointed out that social constructionism is anti-realist, as it refuses the fact that ‘knowledge is a direct perception of reality’. The subsequent discourse will examine how certain social factors conspired to socially construct different approaches to science students' mole concept experiences. Bourdieu (1985) highlighted the relationships between factors and systems especially how factors combine to form systems. The essential part of this thesis dwells on habitus, field and forms of capital, for example, the habitus of science students’, parents’ and lecturers. A sociological view of how students experienced the learning of the mole concept is imperative and will reflect on Bourdieu's theoretical framework.

5.3 Mole Concept Learning Experiences;

It is already clear from discussions in sections (1.2.5) university stratifications and (1.2.8) social class, that different categories of students were created based on different university tiers and social classes. So, it is essential to look at the learners' different socio-cultural relationships. The different learning cultures are unique for most learners, therefore influences them in totally different ways.

5.4 Political perspective;

This section highlights how the political system created an increased number of traditional and non-traditional undergraduate science/chemistry students, resulting from the expansion of Higher Education (HE) and the evolution of the learning culture from elitist to mass education model (Trow, 1973). A thorough examination of the Higher Education (HE) system was initiated by the United Kingdom (UK) government, which Lord Dearing published in 1997, Dearing's focus was to improve on the "Committee on Higher Education 1963 report and forge a way forward into the future of HE. Dearing's outlook was that HE should be at the forefront to develop a "learning society" (Bathmaker, 2003, p. 1).

> "*Over the next 20 years, the United Kingdom must create a society committed to learning throughout life. That commitment will be required from individuals, the state, employers and providers of education and training. Education is life enriching and desirable in its own right. It is fundamental to the achievement of an improved quality of life in the UK*." (NCIHE, 1997, p.1, cited in Bathmaker, 2003).

Watson & Taylor (1998) noted that the Dearing's committee had to deal with an urgent financial problem in HE, which according to them, was the thrust behind the inquiry, which then resulted from both the effects of “expansion and underfunding”. The aim was to change the system which was based on elite institutions and traditions to one that promotes social inclusion through widening participation. The Dearing (1997) report was responding to the changing nature of HE, which must change the socio-economic context (Technology, economic and social change), which should lead to the emergence of a “knowledge-based economy”, characterised by the “production, distribution and use of knowledge information” (Clarke, 2001). The knowledge-based economy requires that a vast majority of workers needs the know-how to use and engage with different forms of knowledge (Jarvis, 2000). In addition, the notion of “competitive advantage” or “global knowledge war”, (Halsey, 1997; Brown & Lauder, 1995) to gain an advantage over other nations in a global economy has led to educational expansion (Halsey, 1997). The urge for competitive advantage, was accompanied "by the general belief of a limited pool of talent", which Bathmaker (2003) countered by highlighting the fact that, this was no longer acceptable as the organisation of education and training must rest on the basis that all learners are capable of attaining their highest potentials in practical and academic achievements (Bathmaker, 2003, p. 5). Brown and Lander (1995) further believed that ‘a sizable proportion of the population (80%), can attain degree level instinctual standards. Trow (1973) had defined elite, mass and universal education in terms of the percentages of the eligible participation of the population in HE (elite 15%, mass 15-40% and universal 40% and above). These are the reasons that have contributed to the expansion of HE through the government’s policy of equality of access and widening participation, as they aimed at attaining mass education. Halsey (1997) reported that by the start of the 1990s, all three major political parties in the United Kingdom (Conservatives, Labour and the Liberal Democrats) believed that mass education was unavoidable in the 21st century (Halsey, 1997). After the Robbins report of 1963, HE student numbers expanded, doubling between 1963 and 1970 (Walford, 1991), but the system remains elitist (Trow, 1973). The Conservative government in the 1980s due to the limited resources that resulted from the financial crisis of the 1970s, instigated a stagnation of HE expansion, which went on until the end of the decade, before Kenneth Baker, the then minister of education, approved an increase in students' numbers, which saw a rapid rise from 1988 to 1992, accounting for 30% of school leavers going HE. There was a further cap at 33%, especially on public-funded full time HE student numbers for the remainder of the decade (NCIHE, 1997). Nevertheless, within a decade, the rise in student numbers from 17% to 33% between 1987 and1997 ushered the beginning of mass education from an elitist model (see Fig.2).

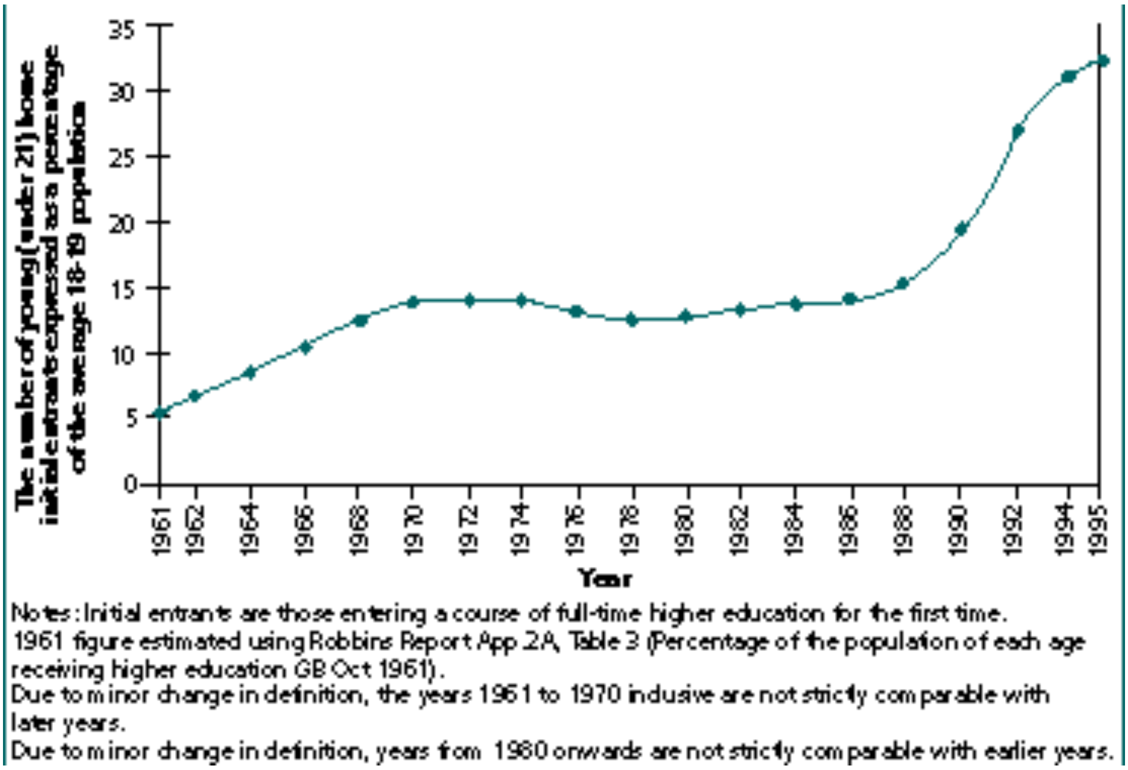

Figure 2. Higher Education Age Participation Index (API) – GB Institutions (Source: NCIHE, 1997, paragraph 3.9)

After the Robbins report of 1963, a binary system was created, with the Universities (self-funding) on the one hand, while the polytechnics and colleges (local education authorities 'LEA' funded) on the other, to assist the local economies through the design of **applied courses** (Walford, 1991). Universities funding was based on a block grant system issued by the University Grant Committee (UGC). The amount linked directly to students' number and a good proportion (30 to 40%) was allocated for research. The funding differentiated between research-led universities and teaching-led polytechnics and colleges (Walford, 1991, p. 167). I studied applied chemistry (BSc Hons) at a local university (teaching-led former polytechnic), and later worked at some local industries. So as the researcher, I am a product of the social construction, based partly on political decisions and influences. It should be noted that applied courses operate a narrower curriculum as they focused more on hands-on activities, whereas the academic courses operate a much broader curriculum, as they rely on abstract reasoning in the teaching and learning (Walford, 2011). These differences affect the way students experienced learning and the mole concept.

As stated already in this section, the Conservative government of 1979 were determined to reduce HE spending, by make it more relevant to industry needs, and to increase overall efficiency (Walford, 1991), therefore 1981 saw a significant reduction of HE spending, without affecting the amount of money spent on each student. As a result, student numbers were reduced in the universities but continued in the polytechnics and colleges, despite reducing the amount of the central government's contribution and the amount the LEA are allowed to spend on HE. The expansion of students in the polytechnics and colleges was a general worry that quality was being compromised for efficiency, affecting the standards and approaches to teaching and learning (Walford, 1991). Issues of overcrowding, with staff-student ratio pressures and teaching resources, had an overall impact on lowering academic standards (Halsey, 1997, p. 645).Therefore, the funding mechanism was one of the political tools used to socially construct the different types of science/chemistry mole concept students. The political decision to widen access thus increase participation in higher education, especially the expansion in polytechnics and colleges, resulting from the Robbins (1963) and the Dearing report (1997), is at the heart of the creation of the different science students, with different mole concept experiences which this research is based. The university (research site), where the participants were recruited from, was formerly a polytechnic. Hasley (1997) suggests that these changes resulted in a lowering of academic standards due to overcrowding. The lowering of academic standards and the introduction of applied courses narrowed the subject content (curriculum), hence creating the different mole concept science students seen between the research-led and teaching-led universities and therefore varying mole concept experiences. So, it was a political decision to create workers to serve the local economies (Walford, 1991), as was the decision to introduce the mass education model, supported by three major political parties (Trow, 1973; Halsey, 1997). The mass education model contributed to the creation of different types of students, and hence students' experiences. The political decisions result from the UK government's reaction to international comparisons as Apple (1993) noted, under "conservative restoration", and the notions of "global knowledge war" or "competitive advantage" (Halsey, 1997), which ushered in the mass education model and created the different students' and experiences.

5.5 University, Home and Peer/Friend cultures;

The different cultures impact science/chemistry mole concept learners in totally different ways; therefore, the tendency is to explore their interactions and relationships to these cultures, explaining their varied experiences (Dierks, 1981). Figure 3 shows some socio-cultural fields that interact to influence the mole concept learning experiences of undergraduate chemistry students.

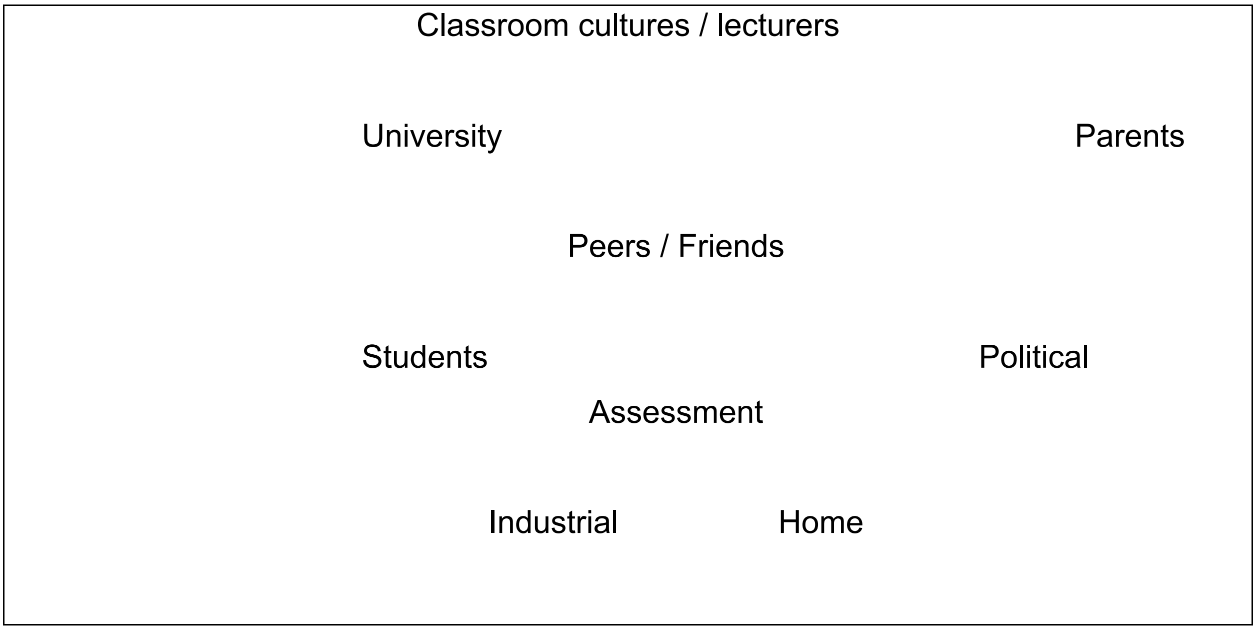

Figure 3. Socio-cultural Influences of teaching and learning the mole concept. (Concept developed by Heugh from Noyes 2004 p.67)

These social interactions are complex, Figure 3 gives a holistic picture rather than specifics, but it could be explained in both terms (Heugh, 2015). Influencing how undergraduate chemistry students experience the mole concept. Harker (1984, p. 18), insisted that most of these cultures, are embedded within most people's constitutions.

Political decisions that constructed the different types of students as mentioned in section 5.3, and hence their varied experiences and decisions, represents what Bourdieu terms “the field of power”. These, according to Bourdieu, are constantly changing, but have a defining role in shaping students’ experiences (Bourdieu, 1986).

5.5.1 Universities;

The tripartite school system (Grammar, Technical and Secondary Morden) discussed above under university stratifications (see 1.2.5) sets the stage for the different types of students that eventually gets into the universities and would have notably different experiences (Haralambos & Holborn, 2013). Reay et al., (2005) reported that the different tiers of universities would mean that the students would experience science/chemistry and the mole concept differently. The top tiers were Oxford and Cambridge, which predominantly attracts upper and middle-class privately schooled students. The middle tier comprises predominantly pre 1992 universities, such as Manchester, Liverpool and Kings College mainly attracting state schooled middle-class students. While the post-1992 mostly polytechnics turn universities, which have primarily working-class students, are the lowest tier (Reay, et al., 2005). Reay et al., (2005) further noted that the university stratification correlated with the students' social classes, reflecting their household income levels and degrees of capital. These different types of universities will socially construct students with varying mole concept experiences. Personally, as the product of the above experiences, I attend a middle-tier/research-led university initially and latter, a lower-tier teaching-led university, with mole concept experiences from the former and almost no mole concept experiences from the latter. These varied student experiences, leads to different educational outcomes which mostly favour students from middle-class families, as stated below;

> *"The Institute of Fiscal Studies (IFS) & Crawford* (2014)*, found out that, "students from higher socio-economic backgrounds are 3.4 percentage points less likely to drop-out, 5.3%, more likely to graduate and 3.7% more likely to graduate with a first class or second class upper, than those from lower socio-economic backgrounds."* (Crawford, 2014, p. 3)

'University environment and lecturer cultures influence the immediate atmosphere of science/chemistry students learning experiences. Diverse cultures and sub-cultures within a university environment may distinguish themselves, for example, those of the students, lecturers, administrators, and parents, which may congregate around interest groups including class and economics/financial, may tend to nudge the institution into different directions' (Stoll & Fink, 1996, p. 87). The students, lecturers, administrators, and parents' cultural influences constitute Lave & Wenger's (1991) "Community of Practice" sub-set. There are, therefore, diverse cultures at play in a science/chemistry mole concept classroom, which are external to the learner and influence their learning experiences. Nickson (2000) identified the same multicultural mathematics experiences in a mathematics classroom (Nickson, 2000, p. 148). There are significant similarities between mathematics and the mole concept, not only because both rely on procedural and conceptual teaching and learning methods, but the mole concept contains a mathematical constant (the Avogadro number; 6.0×10^{23}). Avogadro number can be derived from a gas equation $PV = nRT$ (P = pressure, V = volume, n = number of moles, R = gas constant, & T = temperature). Some formulae govern mole concept calculations. The different university environments will have different teaching and learning cultures of the mole concept, based on the institute's ethos, research-led or teaching-led (Walford, 1991). The lecturers' role is equally vital in shaping the learning cultures and students' experiences, which is shaped by the institution's ethos. For example, from personal experiences, the lecturers in the research-led Central London middle-tier university I initially attended taught the mole concept in detail. In contrast, there was very little or no mole concept teaching at the teaching-led, third tier South East London university. I also had a similar experience during my teachers' training program (PGCE), where I observed a chemistry lecturer who taught only some basic aspects of the mole concept from a SE London Community college but neglected the calculations aspects of the concept. The lecturers' habitus, social status and cultural capital (see sections 5.2, 5.3, 5.4), can influence how they interact with the learners, and shape their experiences. The type of parental support is a vital factor that influenced the learning culture of science/chemistry students. Bourdieu (1974) discusses “the learning attitudes of the different social classes, including children and parents and their views about particular institutions, based on their attachment to particular social classes, which also shapes their outlook on the job market (Bourdieu, 1974, p. 33). As mentioned previously (1.2.5), we have already seen how the stratification of universities correlates with their students’ social classes and hence cultural capital, which influences students’ university choices and, thus, their mole concept experiences (Reay, et al., 2005).

Assessment methods and peer influences can also shape how science students experience the mole concept in that formative assessment can have the most effect. It is defined by the Council of Chief State School Officers (CCSSO, 2008) as;

> “*a process involving feedback, used by teachers and students during instruction to amend ongoing teaching and learning aimed at improving students’ achievement of intended outcomes”* (CCSSO, 2008, p. 3)

The feedback element, couple with students’ collaborative work, is crucial in this type of social learning. It is also viewed as acquiring information and observing learners’ abilities and skills, to inform practice (Black & Wiliam, 1998b). Social learning occurs within collaborative group work, which may include direct and indirect collaboration. Group tasks may be direct collaboration, while indirect collaboration may include participating from the periphery (Lave & Wenger, 1991). The non-traditional students were learning from the others through observation, *legitimate peripheral participation (LPP)* (Lave & Wenger, 1991).Formative assessment is the principal method by which non-traditional (mature) students gain access into Higher education (HE) through access courses. Higher Education Statistics Agency (HESA) defines mature students as;

> *"Students who are aged 21 or over on the 30th September of the academic year in which they started a degree course"* (HESA , 2020)

Mature students constituted a significant proportion of students in HE, with an increase of 21 – 24 years old first year students from 1015/16 to 2018/19-, and first-year students age 30 and above had an overall increase in 2018/19 (HESA , 2020). Most are predominantly concentrated in former polytechnic/colleges which have now converted into full Universities. The traditional HE institutions, admit students through selection based on a 'summative' testing of students' abilities (GCSE and GCE "A" levels results). However, the different teaching and assessment variations experienced for different qualifications contribute to creating the different student experiences of the mole concept. The Expert Panel for the National Curriculum Review had warned that segregating students on ability alone leads to social injustices. They identified a common feature of the countries with high performing students (Singapore, China, Japan, South Korea, and Finland): is the presumption that; 'all students can learn to a higher standard, with the assessment of learning, achieved through "the power of effort", rather than "the limits of students abilities (Oates, et al., 2011, pp. 44-45). "Effort" here is related to the input from the field and Communities of Practice, which includes; students, parents, teachers, school administrators and government/policymakers (Lave & Wenger, 1991; Bourdieu, 1995). The above have established the existence of complex relationships between diverse-layered cultural experiences and the mole concept student. Bourdieu's work will now be reviewed in the context of sociological forces that impacts friendships, education, and family.

5.6 Pierre Bourdieu's Theory of Practice;

5.6.1 Positioning Bourdieu;

This study is about the social construction of knowledge and identity. Pierre Bourdieu attaches higher value to cultural and economic aspects of class (Bourdieu, 1984). We have seen how interrelated class, type of university, economic and cultural capital are linked these have a direct impact on how science students experience the mole concept. Bourdieu was concerned with showing how different social fields similar in nature, could reproduce structural inequalities without the actor's awareness or influences. Bourdieu (1984) wrote on diverse subjects, covering education and critical analysis of sociological concepts. Swartz (1997, p. 5) noted that, Bourdieu also critically analyses concepts such as; structuralism, positivism and grand theory. Bourdieu (1985), habitus was instrumental in helping to bridge the divide between objective and subjective realities, which is more of uniting Burningham and Coopers' (1999) contextual and strict constructionism. Bourdieu and Wacquant (1989) and Burr (1995) agree that language was a problematic medium in transmitting thoughts and feelings when he warned new sociologists to watch out for words

> *"....beware of words. Language poses a particularly acute problem for the sociologist because it carries along a "spontaneous" social philosophy which constitutes one of the most formidable "epistemological obstacles" to a rigorous science of society* (Bourdieu & Wacquant, 1989, p. 54)

Bourdieu (1985, p. 39) considers 'speech and accent as slight indicators of class signs', indicating the position in society and similar social origins rather than ability or intelligence. On the other hand, Jenkins (2002, p. 39) criticises Bourdieu's writing as complex and obscure. One would incline to agree with Jenkins because why would he warn new sociologists about language, then only to deliberately increased the complexity of his use of language just for the sake of it or to gain social recognition at the expense of other French intellectuals. So, Bourdieu identified an obstacle according to his own words, and then deliberately placed the obstacle there. Important to this study is the relationship between school (university) and home culture (habitus), which Bourdieu had provided in a theoretical perspective (Bourdieu, 1974; Bourdieu, 1989; Bourdieu & Saint-Martin, 1974). The study hopes to draw parallels between the findings here and the way science in general and the mole concept in particular has been socially constructed. Next, we consider details of the various parameters of Bourdieu's theory of practice.

5.6.2 Habitus;

Habitus is the outcome of a person's history; where the circumstances of their reality are internalised and transformed into a disposition that creates authentic practices and meaning giving perceptions (Bourdieu, 1984). Therefore, cultural and social information influence individuals' actions and thoughts processes (Suminar, 2013). Bourdieu (1985) thought of habitus as a process where the social reality in the individuals' experience becomes their contribution to the external social life, such that past experiences inform the present, which in turn informs the future and has the tendency of reinforcing the status quo (James, 2011). This is viewed as the key ideology of Pierre Bourdieu's theory of habitus, where the body relates to the social world and vice versa the social world to the body (Reay, 2004). Habitus is a robust concept that produces practices throughout history but develops in relation to social context, including the combined history of class and the family (Bourdieu, 1984; Reay, 2004). According to Rawolle & Lingard (2008), habitus is a set of dispositions that allows agents to connect with and contribute to practice and functions as a prior requirement for consuming and producing practice. Bourdieu dismissed the existence of distinct boundaries between the classes, which has resulted in criticisms about his concepts being unclear and at the same time being praised for their malleability (Murphy & Costa, 2016). The flexible nature of class gives rise to social change through social mobility, with education being the engine of the change, thus making his concepts relevant to this study. Considering the issue of social class discussed (see 1.2.7), highlights the influence, according to Bourdieu, of diverse lifestyles acquired different social status, which therefore produced expressions of social class (Weininger, 2002). As a result, the interface of social class, experience and status of science students from deprived/socio-economic disadvantaged backgrounds are inherent characteristics of Bourdieu's theory of practice. Therefore, they help consider the mole concept teaching and learning outcomes of science students as members of the UK society. Suminar (2013) described habitus as more than a habit, arguing that humans have internalised and personified social structures that often operate voluntarily and limits what individuals think they are capable of and incapable of doing, making them and their social reality bounded. Social reality is claimed to be socially structured, resolute, and limited (Bourdieu, 2004) Bourdieu's theory of habitus would have been influenced by Aristotle, whose theory of hexis elucidates the functions of education in determining individuals' actions via the gaining of capabilities, skills and positions (Rawolle & Lingard, 2013). The effect of this is that students from deprived backgrounds who are usually non-traditional and working-class may well demonstrate internalised assumptions about studying science in university as not for them (Burnell, 2015). Burnell (2015) described primary habitus as the socialisation originally developed in the home surroundings, as parental and family practices and values, including their social positioning during childhood, shape the child. Bourdieu refers to the phenomenon as ‘habitus de classe’ (Bourdieu, 1984), pointing out that it is not only limited to social status but includes the different tastes, interests, and lifestyles between social classes. Between and within families, the interconnections of habitus and economic & social capital, plus culture, produce outcomes commonly referred to as family habitus (Archer, et al., 2012). Family structures teach children their place in society in relation to specific cultural norms and forms, including the education system as it applies to those who attached more value to it and those who do not (English & Bolton, 2016). Thus, primary habitus will have an impact in the way science students experience the mole concept. Secondary habitus will have a similar impact as primary habitus. Burnell (2015) describe secondary habitus as the socialisation derived through interactions with external institutions from home like schools and universities, including life experience. Reay's (1998) investigated the influence of secondary habitus who described how secondary habitus is determined by the school experiences, though his work was centred on key stages one and two. An important aspect of secondary habitus includes the function of educators as custodians and facilitators to knowledge acquisitions. Institutional habitus determines the way students think and shapes their aspirations (Reay, 1998). Secondary habitus will influence students’ higher education and post HE experiences and thus their mole concept experiences. Reay's (1998) work further highlighted the fact that different habitus’ might exist for different students within the same field (institution) due to cultural biases (traditional and non-traditional students) and prejudice. Bourdieu's theory has been criticised for extending habitus to include secondary habitus, which operates within institutions. It is claimed that it shades the contradictions within the institutions and, it is also applauded for identifying the association between the individual and the collective (Stahl, 2016).In terms of educational outcomes, Bourdieu’s theory identified huge inequalities based on the class system as access and participation are easily attainable by certain social classes. In contrast, the reverse is true for others, such as the working class, as they have limited habitus (Burnell, 2015). The mole concept is socially constructed within the science community, and it is transmitted through primary and secondary habitus’. Wacquant (2004) identified how habitus is transferred across various consumption modes, including foods, sport and music, which regularly occurs between and within the same social group, embedding similar lifestyles and promoting particular social orders (Rawolle & Lingard, 2013).

There are conflicting arguments about the malleability or rigidity of habitus; if can it be developed further or changed? Some see it as porous and changeable (Reay, et al., 2009), while others think habitus cannot be changed; instead, fresh layers can be added over what exists (Grenfell & James, 1998). Primary habitus cannot be subjected to change easily and is described as a 'memory pad', which can create a different habitus when subjected to diverse social environments. It protects itself against crises and resists change by adaptation (Bourdieu, 1990). It is claimed that the primary habitus is second nature as humans are trained to behave in similar ways in the same situation, thus influencing secondary habitus (Bourdieu, 1990). The ‘fish in water or out of water’ analogy was used by Bourdieu (1990) to explain the second nature of primary habitus - when someone experiences the social of which they are a product of or used to, it becomes second nature to them, unlike if they are in a social environment which they are not accustomed to, they may not feel that they belong, therefore there is a conflict, leading to them acting in strange ways. Habitus may be a difficult concept to define by sociologists. However, Haralambos and Holborn (2013, p. 699) think it points to 'the dispositions, tastes and expectations of the social groups to which individuals belong, citing the example of the school/university and family'. The thought supports the notion that the school/university structuring experiences are governed by the family's habitus (Bourdieu, 1973). Some examples of the habitus acquired from the family include; educational standards awareness, especially of the different tiers of universities, social confidence and entitlement consciousness. Lack of educational standards awareness would mean that students from low-income groups (working-class) would exclude themselves from top tier universities because it is out of their reach (Haralambos & Holborn, 2013). The different tiers of universities construct science students with varying mole concept experiences, as discussed in section 5.4.1. Reay (2015, p. 354) defined habitus as "a deep, interior, epicentre containing many matrices"; this highlights significant aspects of the concept as it points out the importance of appreciating personal histories. The word 'habitus' in my opinion, is derived from the French word "Habitat", according to the Collins French/English dictionary, which means; housing environment. It may signify culture, the environment in which one has been raised, which shapes one's experience, or how one sees the world. Swartz (1997, p. 102) noted that "habitus is the outcome of family socialisation experiences, which can be modified through engagements with peer groups. This study examines the socio-cultural influences that impact science student's learning of the mole concept, the habitus, which defines where and how they acquire their dispositions, is relevant in this respect. Nash (1999) offers criticism of Bourdieu for refusing to define habitus. Bourdieu refusal has encouraged others to attempt their own definitions, including myself. Habitus in this study is where participants acquire their disposition through vertical (family) and longitudinal (peers/friends) socialisation. Habitus influences the way students experience the world (their disposition), which they acquired through ‘vertical’ socialisation (the social and cultural capital they acquire through their immediate families by socialisation).

5.6.2.1 Conclusion;

One's habitus directly impacts the way they experience the world through their disposition and the political decisions made, which in turn affects their 'field'. Therefore, it directly impacts the way they experienced the teaching and learning of the mole concept. In addition, students' habitus directly influences their university choices, which impacts how they experience the mole concept, as already explained above.

5.6.3 Field;

Fields are primarily structural and social spaces that affect or shape habitus and influence what counts as significant capital (Meuleman, et al., 2015); fundamentally fields have common characteristics other than independent (James, 2011) therefore, field is directly associated or linked to habitus and forms of capital, and according to Bourdieu, they should not be treated separately (Bourdieu & Wacquant, 1992). Therefore, habitus owns and trails capital, which can only be measured in terms of the field (Bourdieu & Wacquant, 1992). Fields are large social spaces where individuals practice their dispositions. Competition occurs with the actors employing different tactics to consolidate their advantages/positions or improve them (Bourdieu, 1990). Field borders are porous; however, each is unique by rules or logic whose knowledge is associated with field success (Ignatow & Robinson, 2017). Rawolle and Lingard (2013) highlighted that there is unequal access to the competition for capital within the social fields and how the field agents are in the end characterised by positions within the field (Bourdieu, 1986). Additionally, Bourdieu did not offer a clear and definite definition of field. Rather he elucidated principal qualities, including: 1) every field is portrayed by competition between agents who have different forms and degrees of capital, 2) the performance of the field depends on agents who are prepared to play the field game, 3) the make-up of the field is a position of power, 4) every agent in the field holds deep interest and is devoted in the importance of playing the game, all of which is often unintentional (Bourdieu & Wacquant, 1992). The games metaphor refers to the regulations of the university field and the students' place within it (Bathmaker, 2015). In the university field, students must use a range of strategies to get the most out of their situation in a competition to preserve or maximise their academic capital (Bathmaker, 2015). The importance of playing the game and attempting to fit into the field, is associated with the intrinsic value of university education, where even those who made a great effort to access and fit in the field, embrace a collective belief in its importance and authenticity (English & Bolton, 2016). Considering this research, what is significant is that the notion of a porous field concept, which may enable reflection on significant change within the education field, is in line with what Bathmaker (2015) talked of as 'thinking beyond Bourdieu'. Studies conducted by Surif et al., (2012) highlighted the fact that there are two main methods of teaching and learning the mole concept, but instructors depend solely on the procedural method. In contrast, the conceptual method makes the concept relevant to the science students' experiences and leads to deeper understanding (Ausubel, 2000). Perhaps the porous field concept will lead to more conceptual teaching and learning of the mole concept and widen participation and increase social mobility (Blake, 2018). The fact that there is an unequal access to the competition for capital within the social field (Rawolle & Lingard, 2013) highlights Bourdieu's claim that the capacity to invest in and benefit from education is not equal (Bourdieu, 1986). For Bourdieu, education, instead of being a field for only social change, also functions as the instrument by which the existing class system is socially reproduced (Harman, 2017). Non-traditional and working-class students, to a large extent and others will have a disadvantage in science educational access, participation, and outcome, because of their field limitations, habitus, and forms of capital (English & Bolton, 2016). James (2015) highlighted that in western societies, social reproduction is symbolic, as social agents are unconsciously contributing to their very oppression which is in line with Bourdieu's misrecognition approach. In relation to this study, the fact that science students with very little habitus and cultural capital (mostly mature and non-traditional students) are engaging in science HE studies, they are therefore unconsciously taking part in their own oppression, through supporting a false sense of social mobility and widening participation (Harman, 2017). Bourdieu, pointed out that personal achievement has the effects of cementing and increasingly disguising the existing inequality of the HE system by giving the impression of meritocracy, thus diminishing the need to address it (West, et al., 2013). However, there remains the prospect of personal agency, with the most disadvantaged students habitually ending up with less valued qualifications. They may be socially constructed as local industry workers with very few research-oriented science opportunities, compared to success stories from first-tier UK universities, which defeats the concept of social mobility and widening participation (Reay, et al., 2009). Nevertheless, some critics disagree with the degree to which individuals are ignorant about their oppression and suggest that agency can be exercised, and choices made irrespective of existing structural inequalities (English & Bolton, 2016; Burnell, 2015; Reay, 2015). For individuals who eventually gain access to higher education, Bourdieu's (1990) parable of 'fish in or out of water' students' experience highlights the out of place experiences expressed by some students. In imbibing or reconciling their habitus with that of their field (university), habitually traditional students who are primarily middle class achieve this with relative ease (West, et al., 2013). Some students are naturally more secure with the routines and rules of the higher education game acquired via the primary and secondary habitus' and therefore have social capitals nearer to the HE institution's habitus. In contrast, frequently, non-traditional students might well struggle, mostly in first and second-tier universities, since the cultural, social and educational capital they possess is alien from what is standard and valued in those institutions (West, et al., 2013). Learners effortlessly form groups and social networks with peers that have similar life experiences, which may be based on specific cultural attributes like, gender, social class, age, disability, and ethnicity. These connections may help students adjust to university experience (Keane, 2010). However, the over-representation of white upper and middle-class students in HE, especially in the top tier universities, and the underrepresentation of students from lower-class and minority backgrounds, meant that underrepresented students are less able to adapt seamlessly to the HE environment and may experience “a fish out of water experience” (Keane, 2010). The concept of counter-habitus was proposed by Stahl (2015) which is, based upon a make-up towards fitting-in and self-accountability; a practice of integrating aspirations and existing economic and social inequalities and improving the central values of higher education field of achievement with values produced by primary habitus (Stahl, 2015). This research draws parallels with the Keane’ study (2010), since most participants are science students who had gained access to HE via access courses and foundation routes (non-traditional/working-class), mostly with limited primary habitus and social inequality experiences. Drawing on Bourdieu’s theory, the changing application of forms of capitals across fields which assist the middle-classes to effectively navigate the HE fields, and the intricacy of working-class, other minorities and non-traditional students face in doing the same. Tensions can exist between the alternating habitus, which allows non-traditional students to adapt to and accept the rules of the field (university environment) to succeed academically with contrasting primary habitus of commonness and limited ideas (Stahl, 2015). Habitus does not surrender to the field but is in regular negotiation even though beliefs of tension between the novel field and primary habitus can influence the perception of self and how identity is constructed (Stahl, 2015). As habitus does not surrender to the field (Stahl, 2015), and the field is porous, thus subject to change; therefore, changes in the education field in general and HE, can enrich the mole concept experience for all science students. Stahl (2015) suggests that the concept of 'fitting in' or integration is reductive because it presumes a particular mode of adjustment to the academic field. Learners mainly give in when they may have various adjustment modes to associate with standards within and without the university field (Gilardi & Guglielmetti, 2011). It is claimed that because of the above, Bourdieu (1990) may have failed to see the importance of individual agency, personal experiences and attainments of learners who do thrive even though operating outside the established standards (Patiniotis & Holdsworth, 2005). For learners who naturally thrive in HE field environments, it is important to consider the ‘fish out of water’ analogy (Reay, et al., 2009), when they engage with the other students from deprived and low socio-economic backgrounds, as their great academic and life experiences meant that they cannot easily fit into the working class students’ social space or field. This phenomenon is referred to as ‘strangers in paradise’ with a note that they are perhaps ‘familiar strangers’ who cannot fit in socially because of their ‘superior’ class but will fit in academically (Puwar, 2004). Progressively, more contemplation is being given to the above in educational policy, as the learners’ passage and motive for depreciation are tracked and taken seriously. Significant rationales referred to include inability to belong and peer connections, despite academic ability (Thomas, 2012). Despite criticisms of Bourdieu’s theory, its actual value is that it permits researchers to consider the field as a set of interactions defined by various forms of capital without losing the individuals identity (James, 2011). Gale and Lingard (2015) noted one of the potencies of Bourdieu's argument is that he is habitually considered as an ethical Broadminded individual. Bourdieu advocates for scientific thoroughness instead of rigidity and how the instruments of habitus, field and forms of capital are constructed to assist scholars with thinking, in contrast to giving a restricted structure (Webb, et al., 2017). In effect, the actual value of Bourdieu’s theory enables scholars to think critically and more generally, to move further than the secluded experiences of individuals, to recognise how individuals and HE institutions operate in the field (Webb, et al., 2017). Even though Bourdieu focuses on the relative, he encourages spontaneity and a concern in connecting the scholar and what is being investigated (James, 2011). Whilst much of Bourdieu's work hinges on class issues, it is recommended that the instruments applied to studies consider other significant social and cultural issues (Reay, et al., 2005) in this circumstance, the mole concept experiences a diverse range of science students. Habitus does not exist in a vacuum; field congregates participants with similar habitus' dispositions in the same social environment. According to Bourdieu, it forms the foundation for any categorisation structure of society (Noyes, 2004). For Bourdieu, social class does not exist in the conventional sense, but exists only virtually and is viewed as a social space where individuals of varying habitus, practice their dispositions i.e. a space of difference (Bourdieu, 1985, p. 12). The universities and other establishments, including governments/political parties, are the fields where all these habitus' interact. Under university stratification (see 1.2.5) we discussed how the different tiers of universities do not only attract different types of students with similar habitus', but how they are also structured differently to either research-led or teaching-led, which informs their ethos' and hence influence science students mole concept experiences (Reay, et al., 2005).

A "field" is defined by Bourdieu as;

> *"a network, or a configuration, of objective relations between positions objectively defined...the limits of the field are situated at the point where the effects of the field cease. The principles of the dynamics of a field lie in the form of its structures and in particular, in the distance, the gaps, between the various specific forces that confront one another".* (Bourdieu & Wacquant, 1989, p. 39)

The fields of the undergraduate chemistry classroom, the academic establishment, and the field of education itself would be limited to the point that ‘the effects of the field cease’, but where this point is located, is difficult to say (Noyes, 2004).

The micro field level here would be the participants and the sub-field of the science/chemistry classroom (laboratory), while the macro-level remains the field of education itself. This research is based not only on the field of education (Noyes, 2004), but on the sub-field of the science/chemistry classroom/laboratory, which is closely related to the field of political power (see 5.3) discuses, the political decision that constructed the different types of students with different habitus’ found in the field of the science/chemistry classroom (see Robbins and Dearing reports 1963; 1979 respectively), and the fields of family and peer cultures, which intertwine to form the mole concept learning experience (Noyes, 2004).

An Interplay between 3 fields (Education, Family and Peer culture

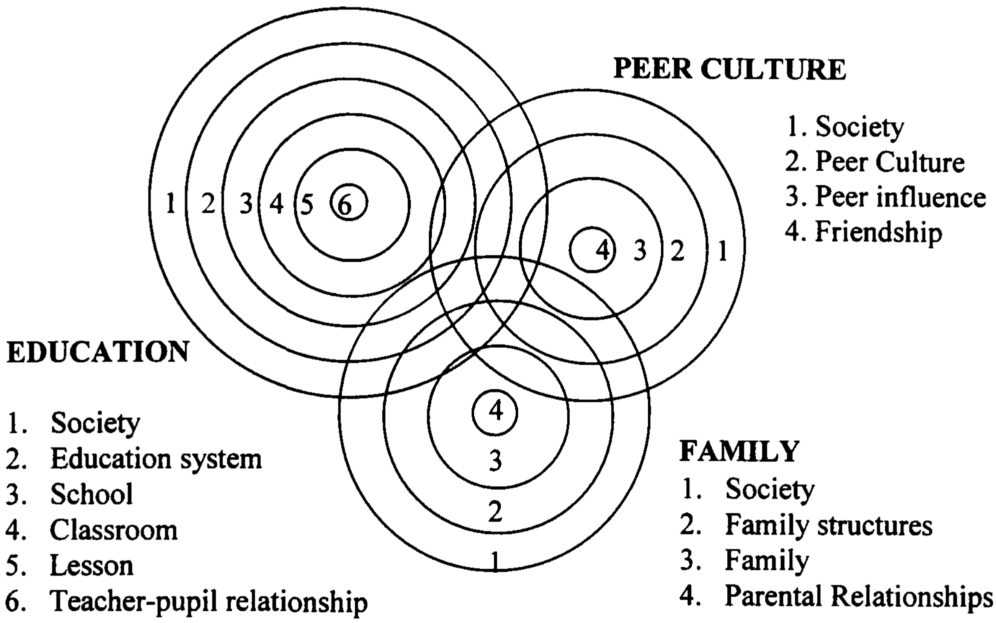

Figure 4; Fields for analysis of science/chemistry mole concept learning experience (adapted from Grenfell and James 1998; courtesy of Noyes (2004)

Figure 4; shows interplay between three proposed fields (Education, Family & Peer cultures).The field of education can interact with the family field through the influences of capital (economic, social and cultural), in that cultural capital determines the type of education system (university and peer interactions (DfES, 2003) that the student can experience (Reay, et al., 2005), the social status (class), which defines their habitus and hence social space position. Bourdieu stated that, "scholastic success is a function of the cultural capital inherent from the family" (Bourdieu & Saint-Martin, 1974, p. 357). The habitus influences the field; thus, the family structures guarantee the family inheritance of the students' educational experience, including their mole concept experience, forming the basis and aim of this research. The habitus of the students, which is derived from the family interactions as described in section 5.5.2 also influences the peer cultural field, because it determines the students' social position, in the social space or peer cultural field.

5.6.4 Capital; economic, social and cultural;

According to Bourdieu (1986), forms of capital are responsible for influencing the instruments of society to become more than instruments of chance, as capital creates social order and determines an individual's place in this social order. Although, in its materialised and personified manifestation, it collects over a period and is reproduced via the fabrics and operations of the social world, that most things are not equitable (Bourdieu, 1986). Nash (1990) noted that the outcome is the recognition of the person's position in society which is also the consequence of education, or what, according to Bourdieu (1984), is 'resignation to the inevitable'. Bourdieu's classification of capital as economic, social, and cultural is conceptual as he visualises capital as a resource engaged in shaping power and management of social resources and social reproduction (Webb, et al., 2017).

5.6.4.1 Economic Capital;

Material wealth is referred to as economic capital (English & Bolton, 2016). Economic capital is a valuable type of capital, particularly in the education field, as those who are materially capable can purchase access to different educational services, such as arranging for extra tuition and other types of educational services that can progress an individual's social position. An example of economic capital influence can be seen in the considerable debt related to university experience by some learners, which has produced a roadblock to HE access together with the difficulty of paying back the student loans once in employment, which results in constricted economic capital (English & Bolton, 2016). Although most of the participants in this research are mature science students who gained access to HE through access courses/foundation years, economic capital or lack of it played a significant role in this. Economic capital on its own is not sufficient to buy social position or social status, without depending on the other forms of capital (O'Brien & Ó Fathaigh, 2006). Nevertheless, the significance of economic capital is that it aids those who are viable and have attached a higher value to education to access good HE institutions, which eventually determines their experience, including mole concept experiences. As a result, they will acquire good employment, including research positions on finishing, thus ensuring social position, status, and economic capital (Bourdieu, 1986).There are three modes of cultural capital; 1) objectified, which is based on objects such as books, art, possession of cultural items (cultural goods); 2) institutionalised, which includes academic qualifications or 3) association to cultural valued educational institutions and embodied, which includes, activities that have their outcome from the mind like accents, clothing, learning culture (Tittenbrun, 2016). Cultural capital depends on habitus; therefore, an individual's cultural capital is associated with the status they acquired from birth (Burnell, 2015). Cultural capital comprises an ascribed mode of thinking and functioning in the context of cultures which are reproduced generation to generation within and between families (Patiniotis & Holdsworth, 2005). It is also thought of as being class specific, with the notion that capital which is accumulated by the middle classes is given superior social status (Bourdieu, 1990). Therefore, assisting middle class students to navigate access and smooth participation of the HE field, as their wealth is recognised (Patiniotis & Holdsworth, 2005). An important example is that middle-class students may be more accustomed to the academic language, contributing to their HE success (Burnell, 2015). Bernstein (1964) did extensive work on speech codes and concluded that the advancement of speeches and language is related to socialisation and social position, which starts early in life, as the outcome of primary socialisation and strengthens through secondary socialisation (Bernstein, 1964). Most scientific language is Greek/Latin, so students whose parents studied the classics will have an advantage, and these would be predominantly middle class. The word “mole” in the mole concept means “heap” in Latin (Kolb, 1978). Language and aptitude to use language are social initially and generate social consequences (Bernstein, 1964). Moore et al. (2016) offered another example to the Social Mobility Commission, where regional accents appear to hinder lucrative employment, as accents, other cultural features, social background, and attire, are thought to be implicated in the informal selection of employment applicants. Candidates from lower class heritage were disregarded, because of prejudice, as they were thought of as people who may not fit in or reflect the right corporate image (Moore, et al., 2016). Therefore, the accumulation of certain cultural capitals, such as language, starts early in life and is also present in the current academic discourse. The language form of cultural capital is vital in gaining university access and full university participation. Furthermore, there can never be equality of outcome as cultural capital is unevenly distributed and as different qualifications are associated with different degrees of prestige and HE institutions (English & Bolton, 2016). Economic capital and cultural capital are mutually linked because purchasing or generating economic capital in acquiring knowledge and other culturally treasured skills can enhance or magnify cultural capital and eventually social capital. Economic, social and cultural capitals are also related to the concept of power (financial power) because those who possess economic, social and cultural capital can reproduce these advantages through their offspring's, who can acquire privileged and prestigious places in the education field and exploit the social networks and increase the advantages of their acquired qualifications (Murphy & Costa, 2016). Sullivan (2002) noted that the above notion of cultural capital being reproduced through offerings as privilege, have attracted questions on the significance of Bourdieu's clarification of the role of cultural capital in education with the proposition that educational privilege is likelier than not to be the outcome of economics and support structures, than cultural capital. Nevertheless, it is more probably an intricate intersection of both forms of capital and at the same time, a means to an end, with education being a means of gaining capital and then being an end, it is not always socially neutral because it is intimately associated with the benefits of those who govern it (English & Bolton, 2016).

5.6.4.2 Social Capital;

Social capital, according to Bourdieu, functions as an instrument for social reproduction through contacts, networking and social associations to exploit collective and individual gains (O'Brien & Ó Fathaigh, 2006). Richardson (2002) states that it is the combination of potential and real resources, which permits membership, including managing social networks and groups, creating group capital and individual group members access to this capital. The level of social capital that individual agents possess is relative to the networks they have access to, together with their respective capital, they contribute to the network. Therefore, as habitus introduces high degrees of family-based social capital, the individual ought to work or contribute to its maintenance (Bourdieu, 1986). Three states govern the existence of social capital, these include; financial, practical and symbolic states (Bourdieu, 1986) which are associated with the functions of important people in the individual's life, who can be able to sustain, enable and sponsor, the person to acquire success (O'Brien & Ó Fathaigh, 2006).

5.6.4.3 Symbolic Capital;

Bourdieu employed symbolic capital to describe the how particular forms of capital are understood in society, such as the importance placed on items like educational qualifications, books, institutions, and activities. In effect, all modes of capital are symbolic (James, 2011). O'Brien and O Fathaigh (2006) believe that the above symbolic capital accounts for prestige, recognition and power; therefore, symbolic requisition of capitals is further significant than simply their possession (O'Brien & Ó Fathaigh, 2006). Forms of capitals are visualised as a trans-substantiated package of social energy; specially situated agents can transform the different types under particular situations and with diverse rates of exchange which relied on the interaction with various social fields (Bourdieu, 1984). Most students in the institution where this research is drawn, come from economically deprived backgrounds, and predominantly a lack capital, for instance, in education. The latest studies carried out by Donnelly and Gamsu (2018) and commissioned by The Sutton Trust referred to the various amalgamations of forms of capital that negatively influenced students from deprived backgrounds. These comprise less habitus, limiting students' encouragement support from their families, lack of role models, lack of social representation and economic drawbacks (Donnelly & Gamsu, 2018). A significant criticism of Bourdieu's theory centres on the fact that capital is too inhibiting; such that the sociological focal point nullifies the influence of other forms of capital, such as interactive or psychological. West et al., (2013) gave the example of the experience and impact of life-long-learning in modifying the capitals and habitus' of individual learners (West, et al., 2013). Cöté (1996;2001) also included identity capital in evaluating cultural capital, highlighting how people may deliberately or unknowingly use their own resources in helping themselves acquire social mobility. The person deploys significant efforts to obtain this type of capital while attaining it will use their transferable resources such as; ability, personal agency and skills, to exploit opportunities that will assist their acquisition of capital deemed valuable in their context. This will mean deploying effort and time in the HE field, to the maximum. So, in the university field this would mean investing time and effort in enhancing opportunities to achieve their goals, together with taking responsibility (Cöté, 2001). The outcome of this is that the person would experience an increase in cultural and identity capital. Reay (2004) highlights a parallel concept as 'work on the self', where there exists a connection between individual agency and structural elements and, as a result, differences in the capacity to acquire this mode of capital. Student from economically deprived background's change in habitus was as a result of their efforts on the self, including the values of such capital that they have accumulated (Reay, et al., 2009).

5.6.4.4 Cultural Capital;

According to Bourdieu (1984), capital is not limited to economics; it includes social and cultural elements, which combine to form one's position in a social space (class), another method of understanding his concepts of field and class. Haralambos and Holborn (2013) note that students' higher education institution choices, are influenced by the habitus of their families and schools, which creates different amounts of cultural capital. This research will dwell more on cultural capital because it can exist in multiple forms, including its institutionalisation, and because cultural capital forms Bourdieus' 'sociology of educational reproduction', through transmission and recognition (Bourdieu, 1986). These factors are relevant to this research because it helps to define the social positions (class) and how their habitus' influence the participants' field and mole concept experiences. Cultural capital refers to "the knowledge, skills and competencies an individual possesses and their confidence and ability to deploy them". Social class is the principal indicator of the amount of cultural capital an individual has. Haralambos and Holborn (2013) provided examples of cultural capital by stating how middle-class students, who have attended private schools, are often armed with vital information (from schools and families) about top tier higher institutions. This information, together with other acquired advantages such as; self-confidence, entitlement consciousness and certainty, give middle-class students a high level of cultural capital, helping eliminate adverse feelings of fear, shame and guilt. The above is in contrast to many working-class students, with less cultural capital, thus lacking the above knowledge about HE institutions, confidence and having instead, all the negative feelings listed above. It is concluded that, working-class students self-exclude from top tier universities (Haralambos & Holborn, 2013, p. 700). We can see from the above example that, cultural capital plays a direct role in students' university choices, which determines how they experienced the mole concept as previously explained.

5.7 Test of Bourdieus' theory;

Alice Sullivan (2001) conducted a study involving four English schools using the survey method. The participants were secondary school students (key stage 4) almost at the end of secondary school. The data received included questionnaires from 465 students, where their social class was determined by the careers of their parents in the highest-status occupations, while their cultural capital was determined by their parents' educational attainments. Other questions asked included;

- The TV programmes they often watched
- If they played a musical instrument
- Their favourite music
- The books they read
- Attendance at theatre, concerts, & art galleries
- Test on cultural icons knowledge
- Vocabulary test

The study then investigated the GCSE performances of the participants to determine which of the above factors influenced their grades. Sullivan (2001) uncovered that, students who watched more educational TV programmes such as; current affairs, documentaries, arts, science, sophisticated drama, and read complex fiction, had a great chance of being successful. On the other hand, students who watched TV game shows and soap operas had negative GCSE improvements, while music and cultural events attendance, had no major effect, indicating that events attendance and musical involvement are not considered significant cultural capital indicators. Students, who demonstrated more expansive vocabularies and a broader knowledge of cultural figures, were those who watched sophisticated TV programmes and read widely. Sullivan (2001) also found a strong correlation between students' cultural capital and that of their parents. The most successful students at GCSE had significant cultural capital, parents with high educational attainments, and in higher-value professional jobs. However, having primarily proven Bourdieu's theory Sullivan (2001) also concluded that the theory could not account for all class differences in achievement. According to Sullivan, (2001) there were significant differences in educational attainment between middle-class and working-class children even after considering the cultural capital effects. This research by Sullivan, (2001) is vital because it supports Bourdieus' theory, and it provides a blueprint for the practical part of this research. Cultural capital plays an essential role in indirectly determining how science/chemistry students experienced the mole concept. All the factors listed above determine the type of higher education institution the student attends and limits or improves their overall conceptual understanding. As the researcher, I have already established these elements, how the different types (tiers) of universities (research-led/teaching-led) or higher, lower and middle tiers, provides significantly different mole concept experiences, based on the habitus of the institution.

5.7.1 Bourdieu's critics;

Bourdieu's critics have pointed out his lack of gender and race-related issues and his interest in class over other areas of critical analysis (Reay, et al., 2005). However, most of his critics are sociologists who have taken mainly a broader look at his works, lacking important detail (Swartz, 1997; Jenkins, 2002). Giroux (1983) rebuts Bourdieu' concept of habitus as being too restrictive, as it "constitutes a conceptual straightjacket that provides no room for modifications or escape; hence, the idea of habitus, stifles the possibility of social change and collapses into a mode of management ideology (Giroux, 1983, p. 90). Bourdieu's aim was to unfold the logic of practices that disseminates power relations and inequalities in sections that appear to relate to actors in a largely homogeneous way (Noyes, 2004). Critics of Bourdieuran studies indicate that they were unsuccessful in considering how Bourdieu is useful in cutting across the duplexity of agency and composition (Webb, et al., 2017). Other forms of the criticism are directed at studies that underplay the effects of structuring and structured characteristics of Bourdieu's theory (Webb, et al., 2017). However, criticism of Bourdieu's work is usually not valid as it is often applied out of context (Reay, et al., 2005). For example, Bathmaker (2015) successfully demonstrated that, the benefits of university education is not only associated to the attendance of first tier or elite universities, but also how the field of HE largely includes diverse types of fields, which includes academic and professional fields (Reay, et al., 2009).

5.8 Summary;

Applying Bourdieu's theory of practice in this research, we acknowledged that there might be other theories that are dependable with the study aim. However, the importance of Bourdieu's work is that it deals effectively with the broader context in which science students' experience the mole concept in function with their habitus, field and forms of capital. Bourdieu's work allowed concerns of not merely the experience of Individual science students, but how people and HE institutions (fields) interrelates and operates in that specific field (Webb, et al., 2017). Also significant for work that seeks to highlight social justice in the context of inequalities within science education, Bourdieu's theories of practice can assist in exploring the supremacy of some groups and the subjugation of other groups (Reay, et al., 2005). Even though Reay, et al (2009) studies was only limited to habitus, while Bathmaker (2015) relied solely on Bourdieuran field this research will stick to Bourdieu's wishes and affirmation that, his theory should not be used individually, or in isolation (Bourdieu & Wacquant, 1992). This research seeks to demonstrate the usefulness and strength of Bourdieu's theory of practice as a whole by highlighting how his theoretical tools have aided to shape and inform this research, by applying them to the particular context of science student's mole concept experiences in university (Stahl, 2016). Bourdieu urges researchers to be impulsive about applying his theory by referring to the common belief "state of immediate adherence," which, according to him, "escapes questioning" (Bourdieu & Wacquant, 1992, p. 98; Bourdieu, 1990, p. 68). Good research practice requires a reflection on the researcher's habitus through understanding and acknowledgement of the situation of the researcher relative to what is being studied, as well as relative to the research field, which is often referred to as 'rejection of epistemological innocence' (Rawolle & Lingard, 2013). Personal habitus has informed this study, as I experienced the teaching and learning of the mole concept in multiple fields, including second and third-tier UK universities, together with industrial experience. Bourdieu's work can offer both the conceptual apparatus to link the theory versus method divide and language to express the theoretical stands of the researcher. It is further noted that several scholars of Bourdieu's work have great admiration for his varied scholarship, which gives much to so many. Capital (Economic, Social & Cultural) determines not only the habitus of the participants but also the field (Education, Family and Peer culture), which influences the social space occupied by the students in their field. All these field interactions work to influence how students experience the learning of the mole concept. As revealed by the Robbins and Dearing reports' of 1963 & 1979, respectively, political influences lead to the social construction of different categories of students in both the polytechnics that offered applied sciences, while the HE institutions were encouraged through funding mechanisms to concentrate on research (Walford, 1991). These created different types of students that would experience the learning of mole concepts differently.

CHAPTER 6: Methodology

6.1 Introduction;

This chapter will seek to outline an overview and rationale/basis for the methodology deployed in this study and how the methodology relates to the conceptual/theoretical framework discussed in chapter three. A detailed discussion in regard to the narrative inquiry style and methods employed to recruit participants, collect and analyse the narratives will be included. Important ethical considerations that were significant in selecting participants to guarantee their welfare during this study are be included. The narrator will also examine their role as a researcher within the study.

6.2 Interpretivism;

The ontological/epistemological stance of the study is centred on the idealist viewpoint, that reality/truth is multiple, and subject to individual interpretation (Slevitch, 2011). Therefore, the research is situated within the interpretive paradigm as it is appropriate to investigate individual mole concept experiences of science students (Patton, 2014). A Narrative Inquiry is a new qualitative methodology within the interpretive paradigm. It relates to the study and way of thinking about experience as understood narratively and relevant to this study as it can address uncertainty, ambiguity, and complexity (Mitchell & Egudo, 2003). It should also be noted that experience happens narratively (Clandinin & Connelly, 2000). Therefore, science students will be able to look back at their mole concept experiences, as well as examined their current circumstances and beyond (Cousin, 2009; Ricoeur, 1984). Thus a narrative inquiry methodology is appropriate, even though it has some drawbacks (Barrett, 2015). For example, Clandinin et al.,

(2007) noted that the popularity of the methodology has encouraged a dilution of research standards and quality. It is stated that all qualitative research is primarily interpretive (Silverman, 2017), which is in contrast with the positivist paradigm that sees the world objectively (Hammond, 2003) and seeks to comprehend the complicated world of lived experiences through the viewpoints of those who reside in it (Young & Collin, 2004). In this instance, meaning is constructed by the persons as they engage with the social world (Crotty, 1998). Interpretivists incorporate mostly a post positivist ideology, where knowledge is not fixed but is rather subjective and relative (Patton, 2014). The interpretive approach is suitable for investigating science students' mole concept experiences whilst setting and preserving the greater context (Patton, 2014), which is pivotal to the ethos of this research and relates to the theoretical framework. Therefore, whilst acknowledging that individual students have their personal viewpoints (Schwandt, 1994, cited in Denzin & Lincoln, 2013), this method provides the occasion for the researcher to judge how this personal reality can be influenced by micro and macro social factors (Thanh & Thanh, 2015). Denzin and Lincoln (2013) also highlighted that a close relationship between the researcher and the study data must be noted, as it makes it pertinent to the narrative method for data collection and analysis, which accepts co-construction (Mischler, 1986). Naturally, the sort of research questions used within the interpretive paradigm are those with less plainly defined boundaries because they are usually investigative in nature and are not intended to test hypotheses but rather to create them (Burck, 2005). The intention of this study is not to supply quantitative and objective outcomes, even though it is based on a scientific concept, but rather to investigate the distinctive and complete narratives of science students' mole concept experiences and to attempt an understanding and explanation of their habitus, field and forms of capital as applied to their mole concept experiences in the HE field. This is in agreement with the broader aims of qualitative researchers who investigate about people's experiences of circumstances and attempt to discover how these are discerned and experienced by persons and groups (Agee, 2009). The intent is not to create theoretical generalisation, but rather to supply an in-depth account of individuals' mole concept experiences in the context of the university field. This study hinges on the ontological/epistemological assumptions that truth/reality can be subjective or constructed, in this case socially constructed, therefore subject to multiple interpretations (Crotty, 1998). It is therefore related to theory construction (inductive) instead of theory testing (deductive). Denzin and Lincoln (2013) noted that because the character of knowledge is transient, evolving and dynamic in nature, it means that the findings of the research at a certain point may no longer be accurate. However, fundamentally this is natural within the interpretivist paradigm. Therefore, in this study, the interpretations of the findings will reflect the researchers' interpretation, which will be essentially subjective (Slevitch, 2011).

6.3 Narrative inquiry and Interpretivism;

The narrative approach examines the manners in which individuals experience the world. It relates the study of inspirations, habits, practices, metaphors and daily life experiences (Clandinin & Connelly, 2000). Narrative inquiry is a relatively new approach to qualitative research, which has emerged from post-positivists. Narratives have been applied in depicting the activities and experiences of humans from time immemorial and have a long history of deep connections to the human experience, including its exploration understanding (Webster & Mertova, 2007).

Narratives/stories telling are a universal method of human expression, including an oral form of expressing human experience (Labov & Waletsky, 1997). Moen (2006) thinks that our dialogue, interactions and life experiences constantly happen within ourselves and the world around us. Polkinghorne (1998), similarly to Moen (2006) noted as humans "immersed in narrative" and informing themselves stories in a "virtually uninterrupted monologue" (Polkinghorne, 1998, p. 160). It is suggested that this type of daily thinking is the narrative method (Bruner, 1990), even as the degree of life experiences and complexity, with the tendency to overwhelm most people, it can only be dealt with by ordering our experiences into significant units or stories. Humans find it tough to differentiate the life told from the life led, and usually, the process of generating and sharing stories results in them continuously being reshaped, told, and retold and reinterpreted (Webster & Mertova, 2007). Cousin (2009) noted that we could exist without storied types ourselves, which agrees that stories are vital operations in a state of continuous change. The narrative approach is fundamentally about studying human experience (Clandinin & Rosiek, 2007), focusing on the experience as a story, as individuals frame their lives through stories about who they are (Creswell, 2013). Narratives are a gateway through which individuals access the world and the mechanism by which their experiences are explained and given meaning (Riessman & Speedy, 2007). The terms narrative and story, though applied indistinguishably above, Polkinghorne (1998) differentiates them, by implying that the story is the product of experiences or occurrences being told, while the narrative goes further than including the individuals' influence thought processes that framed the story. As a result, the story becomes a meaningful construct that conforms to Clandinin and Connelly's (2000) application of the term narrative inquiry.

Usually, narrative approaches have clear demarcations along different lines, with one of such narrative lines being how the data is analysed, which in turn is linked to one of three approaches which involve: thematic approach, where the investigator picks out themes; dialogic/questioner, which is a performance analysis, as the focal point is on the way the story created and delivered; and structural, which includes scrutinising the way the story is delivered either tragically, romantically, comically, satirically or cast (Riessman, 2008). Researchers working in the area of narratives approach often refer to the event narrative framework, which sorts out stories into constructional units based on restoring events like orientation, abstract, coda and complication (Labov & Waletsky, 1967).

The above are considered to be associated and currently found in all narratives. Extreme importance is often placed on the storyteller's role, especially concerning how procedures replay and how they tell the stories, thus becoming part of the speaker's life history (Labov & Waletsky, 1967). Even though it is essential, but their approach invalidates the importance of stories delivered through other methods such as those narrated as components of conversations, those delivered collaboratively in a chaotic or disjointed way or as other forms of speech proceedings, or in the broad social context that creates narratives (Squire, 2008). The approach is narrow and inflexible for this research. Whilst it would have been great to adopt the past tense narratives, consistent with Labov and Waletsky's (1967) research, I also needed to incorporate the present and future with the greater social context of the narrator's experience (Clandinin & Connelly, 2000). That is why I had to interview a range of science (mole concept) lecturers, even though they were not the initial participants, the idea being to capture different elements of the past, present and future narratives.

The type of narrative is equally important; a classification of narrative types research described by Holloway and Freshwater (2007) is instrumental in clarifying some of the critical features of this approach. The type of narrative is equally important; a classification of narrative type research was offered by Holloway and Freshwater (2007), which is instrumental in clarifying some of the critical features of this approach. These features comprise the day-to-day stories that think about continuation and time. For example, the memoirs type stories which link past, present and future; the life history type stories which view the world from other peoples' perspectives; the cultural stories which are associated with cultural connotations and the combined stories link culture, biography and autobiography (Holloway & Freshwater, 2007, p. 16). In addition, this demonstrates how stories are frequently associated with other stories that belong to particular groups, especially mole concept stories developed from social constructs across the science community. Holloway and Freshwater's (2007) classification does not include all the different story types of oral history approaches centre on disordering the dominant dialogues or advocating for particular groups were not included (Chase, 2005 cited in Denzin and Lincoln, 2013). Connelly and Clandinin (Connelly & Clandinin, 1990) noted that narrative studies must not necessarily follow a set approach but should rather signify an unofficial collection of principles. Usually, some of the essential features of narratives include the fact that; they have a narrator and audience, finite time cycle, capable of captivating an audience, are associated with the individuals thus is based on their subjective experiences (Holloway & Freshwater, 2007). It is vitally important and clear that people narrate their individual stories, which cannot and should not be detached from the social context. Stories relating to similar experiences may divulge patterns but remain unique (Holloway & Freshwater, 2007). Equally important is that stories rely on the narrator's cultural and social knowledge and must be interpreted subjectively (Holloway & Freshwater, 2007).

6.4 Rational for the Narrative methodology;

The narrative approach is regarded as an expansion of the interpretivist research, which indicates its suitability for this research, as it demonstrates the possibilities of address ambivalence, complexity, and uncertainty (Mitchell & Egudo, 2003). The research aims to uncover individual science students' lived mole concept experiences, consistent with the narrative study approach (Creswell, 2013). It is suggested that narrative studies focus on units of analysis comprising one or more individuals; therefore, the number of participants is generally low. A fuller discussion of this will follow in section 6.5. Another reason for using the narrative approach is related to the idea that experience takes place narratively (Clandinin & Connelly, 2000). Therefore, the educational experience should follow the same trend Clandinin and Connelly (2000) pointed out how individuals naturally lead storied lives. Therefore, narrative studies illustrate such lives by collecting and telling their stories. They are often referred to as the first to employ the narrative research (Webster & Mertova, 2007) to illustrate a research methodology in teachers training focusing on telling stories concerning experience in the education field. In Clandinin and Connelly's (2000) work, the narrative is thought of as both the method and the phenomenon (Clandinin & Connelly, 2000), focusing on the individual, culture and society articulated through narration and analysis. The word inquiry indicates how the narratives or stories are employed, predominantly for research and other than just retelling of occurrences (Holloway & Freshwater, 2007). The growth of narrative studies in education research indicates it is an essential method of formulating human experience research while comprehending the cultural and social context that influences how students experience their learning. Therefore, narratives are a potent instrument, where complex problems in teaching and learning, like the mole concept, can be elucidated and examined (Webster & Mertova, 2007). The conceptual framework framed the social positions, highlighting the potent nature of habitus and forms of capital, which relates effectively with the narrative approach that centres on participants' life stories framed by social experience (Creswell, 2013). Narrative inquiry is also important when researching identity issues, where individual experiences are crucial in giving meaning to life (Roesler, 2006). It is important to note that all identity features are constructed by integrating our life experiences into a life story, in this case, a mole concept narrative/story.

6.5 Narrative inquiry overview;

The narrative approach examines the manners in which individuals experience the world. It relates to studying inspirations, habits, practices, metaphors, and daily life experiences (Barton, 2004). Narrative inquiry is a relatively new approach to qualitative research, which has emerged from post-positivists. Narratives have been applied in depicting the activities and experiences of humans from time immemorial and have a long history of deep connections to the human experience, including its exploration understanding (Webster & Mertova, 2007; Barthes & Duisit, 1975). Narratives/stories telling are a universal method of human expression, including an oral form of expressing human experience (Labov &

Waletsky, 1997). Moen (2006) thinks that our dialogue, interactions and life experiences constantly happen within ourselves and the world around us. Polkinghorne (1998), similarly to Moen (2006) noted as humans “immersed in narrative” and informing themselves stories in a “virtually uninterrupted monologue” (Polkinghorne, 1998, p. 160). It is suggested that this type of daily thinking is the narrative method (Bruner, 1990), even as the degree of life experiences and complexity, with the tendency to overwhelm most people, it can only be dealt with by ordering our experiences into significant units or stories. Humans find it tough to differentiate the life told from the life led, and usually, the process of generating and sharing stories results in them continuously being reshaped, told, retold, and reinterpreted (Webster & Mertova, 2007). Cousin (2009) noted that we could exist without storied types ourselves, which agrees that stories are vital operations in a state of continuous change (Wang & Geale, 2015) similar to their individuals’ narrators. The narrative approach is fundamentally about studying human experience (Clandinin & Rosiek, 2007), focusing on the experience as a story, as individuals frame their lives through stories about who they are (Creswell, 2013). Narratives are a gateway through which individuals access the world and the mechanism by which their experiences are explained and given meaning (Riessman & Speedy, 2007). The terms narrative and story, though applied indistinguishably above, Polkinghorne (1998) differentiates them, by implying that the story is the product of experiences or occurrences being told, while the narrative goes further than including the individuals' influence thought processes that framed the story. As a result, the story becomes a meaningful construct that conforms to Clandinin and Connelly’s (2000) application of the term narrative inquiry. Usually, narrative approaches have clear demarcations along different lines, with one of such narrative lines being how the data is analysed, which in turn is linked to one of three approaches which involve: thematic approach, where the investigator picks out themes; dialogic/questioner, which is a performance analysis, as the focal point is on the way the story created and delivered; and structural, which includes scrutinising the way the story is delivered either tragically, romantically, comically, satirically or cast (Riessman, 2008). Researchers working in the area of narratives approach often refer to the event narrative framework, which sorts out stories into constructional units based on restoring events like orientation, abstract, coda and complication (Labov & Waletsky, 1967). The above are considered to be associated and currently found in all narratives. Extreme importance is often placed on the storyteller's role, especially concerning how procedures replay and how they tell the stories, thus becoming part of the speaker's life history (Labov & Waletsky, 1967). Even though it is essential, but their approach invalidates the importance of stories delivered through other methods such as those narrated as components of conversations, those delivered collaboratively in a chaotic or disjointed way or as other forms of speech proceedings, or in the broad social context that creates narratives (Squire, 2008). The approach is narrow and inflexible for this research. Whilst it would have been great to adopt the past tense narratives, consistent with Labov and Waletsky's (1967) research, I also needed to incorporate the present and future with the greater social context of the narrator's experience (Clandinin & Connelly, 2000). That is why I had to interview a range of science (mole concept) lecturers, even though they were not the initial participants, the idea being to capture different elements of the past, present and future narratives. The type of narrative is equally important; a classification of narrative types of research described by Holloway and

Freshwater (2007) is instrumental in clarifying some of the critical features of this approach. The type of narrative is equally important; a classification of narrative type research was offered by Holloway and Freshwater (2007), which is instrumental in clarifying some of the critical features of this approach. These features comprise the day-to-day stories that think about continuation and time. For example, the memoirs type stories which link past, present and future; the life history type stories which view the world from other peoples' perspectives; the cultural stories which are associated with cultural connotations and the combined stories link culture, biography and autobiography (Holloway & Freshwater, 2007, p. 16). In addition, this demonstrates how stories are frequently associated with other stories that belong to groups, especially mole concept stories developed from social constructs across the science community. Holloway and Freshwater's (2007) classification does not include all the different story types oral history approaches centre on disordering the dominant dialogues or advocating for particular groups were not included (Chase, 2005 cited in Denzin and Lincoln, 2013). Clandinin and Connelly, (2000) noted that narrative studies must not necessarily follow a set approach but should rather signify an unofficial collection of principles. Usually, some of the essential features of narratives include the fact that; they have a narrator and audience, finite time cycle, capable of captivating an audience, are associated with the individuals thus is based on their subjective experiences (Holloway & Freshwater, 2007). It is vitally important and clear that people narrate their individual stories, which cannot and should not be detached from the social context. Stories relating to similar experiences may divulge patterns but remain unique (Holloway & Freshwater, 2007). Equally important is that stories rely on the narrator's cultural and social knowledge and must be interpreted subjectively (Holloway & Freshwater, 2007).

6.6 Narrative approach as applied to this study:

Although a narrative approach was selected as the most appropriate for this study, it has limitations and criticisms (Barrett, 2015). Its popularity in social research might have resulted in lower quality of research, exacerbated by studies that fail to recognise the rigour of narrative methodology (Clandinin, et al., 2007). Its frequent use has led to the obscuring of the margins of narrative study. The different interpretations and approaches to commissioned narrative research have resulted in certain uncertainties regarding the purpose and effects of narrative studies. Also, some studies claimed to be narrative but failed to follow the values associated with narrative inquiry (McMullen & Braithwaite, 2013). Clandinin and Connelly (2000) identified three main distinguishing features called “commonplaces”, which differentiates narrative inquiry from other methodological approaches. These include; sociality, place and temporality (Clandinin & Connelly, 2000, p. 20). These ‘commonplaces’ are associated with Dewey’s (1938) philosophy in education, which relates to the significance of examining the social, personal, situation and temporal. Therefore, to comprehend people, we need to study their individual experiences and day-to-day interactions. Additionally, Dewey (1938) suggested that experiences are developed out of other experiences and that this can be articulated through the continuation of the imagined present, the imagined past and the imagined future. Therefore, it is vital to acknowledge the immediate effects of experience and the medium and future effects on current understandings and experiences (Ricoeur, 1984). This is an important feature of narrative inquiry, where attention is given to how individuals reflect back and forth in self-reflection

(Cousin, 2009; Ricoeur, 1984). Considering this study; the above approach was applied to a large extent. Participants were asked to reflect on their mole concept experiences to determine whether or not they were taught the historical context and other aspects of the mole concept and reflect upon it in relation to their current experiences. Lecturer participants were asked to reflect on how they learned the mole concept and currently how they teach it. Wang and Geale (2015) believe the storyteller's present and past actions are vital, as they can offer an understanding of possible future actions. However, as indicated earlier, the narrator/storyteller can have many versions of their stories and choose which account they wish to tell (Cousin, 2009) and is related to the per-formative character of storytelling (Polkinghorne, 1998). The idea of impermanence distinguishes narrative study from other methodological approaches like phenomenology and highlights the importance of individual meanings and experiences (Ricoeur, 1984; Lindsay, 2006). Impermanence was significant for this study, as the researcher sought to understand the way science students' mole concept experiences shaped their overall science understanding. The other 'commonplace', termed sociality, relates to the environment and conditions governing how people's events and experiences unfold. Therefore, as applied to this study, it is the social context of habitus, field and forms of capital's influence on science students' mole concept teaching and learning. The last 'commonplace' relates to the precise place or variety of places for the events. Therefore, for this research, the place or setting is in the university, which is the secondary habitus of participants. However, some students learned about the mole concept, especially millimoles, from their primary habitus (home), through home socialisation. Therefore, it is claimed that this multidimensional way of working is responsible for the narrative inquiry's consideration as a methodology in its own right, instead of just a method to collect data (Clandinin, 2006). Clandinin and Connelly (2000) further noted that focusing on these 'commonplaces' where the narrative researcher examines complications of the conceptual composition of individuals lived experiences, together with the visualisation of their future possibilities, which is similar to what is also known as a sense of optimism (Ricoeur, 1984). The interpretive paradigm, in which the experienced centric narrative methodology belongs, is constructed on the belief that there are multiple realities, therefore an individuals' knowledge is not fixed, as well as the relativity of knowledge about the world (Squire, 2008). Thus, the core attribute of narrative inquiry rest on the fact that, although it may be possible to construct a valid view on reality, reality itself can be subjective and dynamic (Clandinin & Connelly, 2000), while the practice of reflection on experiences may modify the meaning and significance attached, bringing to focus details of past events (Ricoeur, 1984). The above also highlights a vital characteristic which distinguishes between experience centred narrative inquiry, in contrast to event centred narrative research, where there are constant individual representations (Squire, 2008). Considering this study, the classification of story types comes into focus (Holloway & Freshwater, 2007); their relevance to the study is that the temporal characteristics of habitus and experience are determined, together with the association of significant cultural and social influences and the shared mole concept experiences of science students. The intention was to focus on individual science students' experiences, which relates to a centred narratives approach. Experience centred narrative researchers believe in the sequential and important nature of stories and how they are applied to re-constitute past experiences and transformational displays and change (Squire, 2008). Elliott (2005) noted that, the manner in which narratives helps to divide and classify actions, events and experiences, are helpful both in assisting the narrator in expressing them and equally for the researcher to access and comprehend them. Similarly, there is significance in empowering research participants by giving them a voice in shaping the relevant themes in research, together with recognising their role and the role of the researcher (Elliott, 2005). Researchers, who are concerned with individual accounts of personal experiences, are usually interested in the part played by stories as a means of expressing and building individual identity and action (Squire, 2008). The above is central to this study in that; usually mole concept science students do not have a voice on how they are taught the mole concept, even though the literature revealed that there are more than one method of teaching and learning the mole concept (procedural and conceptual). However, somehow only the procedural method is in use both in teaching and learning (Surif, et al., 2012), even though conceptual learning is meaningful learning, which leads to deeper understanding (Ausubel, 2000; Niaz, 1985). Moreover, whilst stories can be altered and changed over time, scientific stories will probably go through very little or no change because the material under investigation is part of objective realism (Crotty, 1998). This study aims to accurately record what the participants wished to share about their mole concept experiences and aspects of their lives. In so doing, the practice of narration can assist the person in reflecting profoundly and to not only give relevance but to make meaning of emotions and experiences, together with considering praise, blame and accountability, for certain persons and circumstances (Elliott, 2005). Therefore, given the diversity and complex and abstract nature of the mole concept and its social construction within the scientific community, including science students, this study must contribute to understanding science students' difficulties through their narrative process.

6.7 Selection of participants;

The term sampling is an adaptation from quantitative studies, which gives the false notion that the selected participants constitute a representative sample of the general population, thus validating the findings as applicable to that population (Polkinghorne, 2005). In reality, lack of generalisability is one of the common criticisms of qualitative studies (Silverman, 2017). Grbich (2012) noted that by applying theory to support research or using research to understand the theory, researchers could make generalisations, with the aim that theory can be instituted to the same people in similar situations. For this study, the participants were selected using a questionnaire (see Appendix II) based on their ability to provide helpful insights about specific mole concepts and other experiences from their perception (Merriam, 2002). As a result, Polkinghorne (2005) favours the term selection instead of sampling. Gobo (2006) maintains that even as it is very different from quantitative approaches, giving details about participants' recruitments is vital for quality and transparency. Similarly, selecting the right participants is crucial since those selected must be able to assist in answering the research question (Silverman, 2017). Thus, it is relevant for qualitative studies to recruit individuals, settings, and groups where the issues under study are likely to occur (Denzin & Lincoln, 2013). Cousin (2009, p. 99) advocates "going deep rather than wide" this principle was significant for this research. There were no primary aims to select a particular number of participants, but basically to access as many participants as possible who meets the vital criteria consistent with the study aims (Silverman, 2017). For this study, the criteria were for participants to have experienced the teaching and learning of the mole concept at various levels and degrees. This approach is associated with the non-probability procedure (Grbich, 2012), which tend to be applied in qualitative studies. Other common approaches include; accidental, purposive, network/ snowballing, and convenience (Moule & Goodman, 2009; Grbich, 2012). In this research, recruitment was pragmatic and flexible to recruit as many participants as possible (Marshall, 1996). A questionnaire was used just for the initial purpose of identifying and recruiting those who can help answer the study questions in a significant rather than representative manner. The use of questionnaires as a recruitment tool was significant due to Covid-19 restrictions. Sampling was employed to select participants with mole concept experiences instead of focusing on concepts; therefore, theoretical sampling was not applicable (Gobo, 2006). There were no restrictions about the nature and degree of mole concept experiences of the participants' programme and their year of study. A recruitment questionnaire (see appendix II) was distributed to a wide range of science students (from Foundation years /access courses to PhD) at the London Metropolitan University for the sake of 'maximising variation' (Gobo, 2006). Initially, the plan was to recruit only chemistry students, but the researcher soon discovered that the mole concept was a social construct observed across the science community. It was vital to examine all range of thoughts deeply; therefore, we had to include all, including science lecturers. Access to this wide range of mole concept participants, was thanks to the work and influence of my supervisors, both of whom are science lecturers at the same university but did not take part in the interviews. I am familiar with Silverman's (2017) advice about the significance of selecting the setting and how diverse settings may provide different insights into aspects of social processes, which may replicate inequalities in education. However, the Covid-19 pandemic restrictions and time factor meant that this study could only take place online. The distribution of the recruitment questionnaire (appendix II) took place in March 2021. They covered a wide range of science students (Chemistry, Biomedical, Forensics, Pharmaceuticals, Sports Therapy, Biology, Human Nutrition and Cancer Immunotherapy), with varying levels of study (foundation/access, BSc and PhD's) and different degrees of mole concept understanding. Participants were consistent with the maximising variation theory (Gobo, 2006). The science lecturers were invited directly via email without completing a questionnaire. As indicated above, this was arranged by my supervisors, as they are science lecturers in the same university. Twenty-three students responded positively to the questionnaire by answering vital questions about their mole concept understanding, including two doctoral-level students. They selected between one to five, where one signified less confident and five more confident in their mole concept understanding and questions about highlighting their cultural capital and habitus. Additionally, three science lecturers with varying mole concept lecturing experiences agreed to participate in a one-to-one mole concept interview. One had 30 years of Open University Chemistry lecturing experience, and another had done post-doctoral chemistry lecturing at Oxford and Manchester Metropolitan universities, respectively. This type of sampling is consistent with network or snowballing, which relates to a third-party providing assistance or help in the recruitment of participants (Moule & Goodman, 2009; Grbich, 2012). Generally, the sampling was consistent with a purposive approach, but it was also essential for the selection to be flexible to recruit as many mole concept science students as possible (Sarantakos, 2013). The selection was in principle only, because in practice, the participants selected themselves, as everyone who responded to the questionnaire was invited and only those who showed up either in the focus group or a one-to-one, were interviewed. At this juncture, nine students took part in the interviews of which five were through a focus group and four in the one-to-one. All the twenty-three students who demonstrated an interest by completing the questionnaire were invited to attend the focus group, but only five participated. An additional four students attended one-to-one interviews. Three science lectures accepted interviews, two completed one-to-one interviews via WebLearn (London Metropolitan university's virtual learning environment - VLE), and the other responded by email. This number of participants (twelve in total) was felt to be sufficient to progress with the study. It is well-known that qualitative research often recruits a small number of participants who are often ‘context specific’ (Bold, 2012). Cousin, (2009) and Creswell (2013) observed that some narrative studies consist of only one participant. Other researchers indicate at least five participants as a minimum and suggested a figure of between 5 and 10 participants as an ideal number (Cousin, 2009; Bagnasco, et al., 2014). Even though for this study a small number were recruited using multiple participants, allowing for contributions from diverse perspectives, this may help to recognise both patterns and variations, and will also deepens the understanding of science students’ mole concept experiences (Polkinghorne, 2005). Mason (2010) recorded some suggestions that recommended that researchers continue to sample until the data reaches saturation point; nevertheless, Silverman (2017) highlighted that saturation is not easy to establish even though frequently mentioned. Nevertheless, the focus of this study was, as mentioned before, on “going deep rather than wide” (Cousin, 2009, p. 99) was the goal. It is further noted that qualitative studies frequently generate vast amounts of quality data, even if there are only a minimal number of participants (Holloway & Freshwater, 2007). In this study, all the participants came from London Metropolitan University and as describe previously, are science students and lecturers studying and lecturing in a range of science subjects, from foundation/access courses to doctorate. The lecturers taught chemistry, biochemistry and pharmacology. All four student and three lecturer participants who took part in the one-to-one interviews, were interviewed once, which lasted between 40-60 minutes each and five students participants took part in the focus group interview, generating all together, 13,479 transcribe words. In total, 12 narrative interviews were undertaken, including one lecturer interview done via email. Focus groups are a form of group interviews (Cohen, et al., 2011). However, they are contrived settings that bring together participants (science students) from different settings, who may not know each other, to answer and discuss mole concept related social questions (Hyden & Bulow, 2003). Focus groups are economical on time, even though they do not produce as much data as one-to-one interviews with the same number of participants (Hyden & Bulow, 2003). hence the one-to-one interviews, because the aim was to go deep rather than wide (Cousin, 2009). Participants' ages ranged from 25-50+ years, which is thought to help add variation even as most of the student participants originated from diverse regions, including the EU, Africa, and the UK (Gobo, 2006).There was also a wide variation in terms of social backgrounds, with some from privately funded compulsory education, most from deprived backgrounds and at least two lecturer participants describing their upbringing as working-class—essential details about the student participants in this study are represented in Table 1.

Table 1: Breakdown of the demographics for the participants in this study (names have been substituted to maintain anonymity)

Overview of students and lecturer participants								
Student	Programme of study	Gender	Region Ethnicity Country	Age group	Interview	Mole concept Understanding 1-5	Highest parent qualifications	Others
1 Gisela	BSc Biomedical science	F	EU White Germany	15-30	1-2-1 Via WebLearn 04/04/21	Initially 1, but upgraded to 4 After 1-2-1	Doctorate Pharmacology / engineer	Private boarding schooling
2 Isa	Level 3 foundation degree for biomedical science	M	Africa Black Somalia	26-35	1-2-1 Via WebLearn 01/04/21	4	GCSE Kitchen assistant	Degree level siblings
3 Emma	PhD Pharmaceutical science	F	UK White England	30-45	1-2-1 Via WebLearn 01/04/21	5	BSc Software engineer	BSc pharmacology Soap making hobby, No TV
4 Drita	Level 3 Foundation Biomedical science	F	EU White Albania	15-30	1-2-1 Via WebLearn 02/04/21	5	College Diploma Self-employed	
5 James	Level 3 Foundation Sports therapy	M	UK Mixed race English	26-35	Focus group	3		Gym / Photography hobby
6 Oprah	Level 4 BSc pharmaceutical science	F	African Black Zimbabwe	30-45	Focus group	3	Engineer and public health	Naturopathic medicine
7 Jacob	Foundation Human nutrition	M	UK		Focus group	3		
8 Mary	Level 3 foundation Sports therapy	F	UK White English	36-40	Focus group	3	High school diploma	Watches National geographic
9 John	1^{st} year BSc Chemistry	M	UK White English	36-40	Focus group	4	Civil servants	chemist
Lecturers								
1 Dr Kan	Organic chemistry and biochemicals	M	Asia Pakistan English					
2 Dr Paul	Chemistry lecturer	M	UK White English	60+	1-2-1 Via email			Postgraduate and open uni. Lecturing 30+ years
3 Dr Luke	Chemistry lecturer	M	UK White English		1-2-1 Via WebLearn		Working class background	Post doctoral lecturing at Oxford

6.8 The interviews: (The narrative space);

Generally, narrative researchers start their investigations by engaging with the participants via storytelling or observational monitoring and listening (Clandinin, 2006). However, in this study, stories were accessed via conversational interviews as the participants were not previously known to the researcher (Clandinin & Huber, 2010). After positive responses from a recruitment questionnaire, email invitations established the interviews (see appendix II), and were conducted online via WebLearn at the participants' convenience. Each interview lasted 40-60 minutes, except for the one participant who responded by email. Polkinghorne (2005) established that second interviews are important. They can add more depth to the narrative and enable both the researcher and storyteller enough time to reflect on the story and make changes where necessary. However, second interviews are important only in certain types of investigation (Polkinghorne, 2005). Some studies did not find any significant difference between interviews and did not experience any new themes generated (Shotton, 2018).There were no second interviews in this study, especially as the lockdowns due to the Covid-19 pandemic added another time constraint. However, participants could be contacted for further clarification if required. This was not necessary. There is however, no established pattern for getting storytellers to narrate their stories; nevertheless, it is vital to adopt a system that encourages the narrator to do most of the talking while allowing them the opportunity to speak first (Cousin, 2009; Connelly & Clandinin, 1990). The focus group and one-to-one's interviews commenced with explanatory talks from the principal researcher (me). It provided the rationale for the study, my role as a researcher, why consent forms should be signed and why I asked them personal questions about themselves and their family situations. This was to make the participants comfortable and cultivating a storytelling atmosphere (Riessman, 2008). Some researchers refer to this approach as a storytelling space for tales created or visited by narrative researchers (Barusche, 2012, p. 5). The created spaces can be achieved through conversations, correspondence, social media, and emails (Barusche, 2012), like in this study where at least one of the participants (Dr Paul) took part via email (Kvale, 2018; Elmir, et al., 2011). A good proportion of some narrative inquirers use rapid questioning tactics followed by asking participants to explain, consider, and justify alternatives. Nevertheless, my approach was to create the narrative space, so the participants could express themselves while I listened, which is in line with the minimalist approach (Wengraf, 2001). Wengraf (2001) works were significant in influencing part of the approach adopted in this research. Mainly Wengraf's (2001) contribution on the biographic narrative interpretive method (BNIM), where the first part was applied, as it is said to start with one elaborate question, then the narrator takes their time to answer, without interruption from the researcher. While at the same time, record or write down what is being said, as it will constitute the next part of the interview. Some aspects of this first section of Wengraf's (2001) approach was used during the focus group interviews, but it was not limited to only one question. Due to time constraints, all the questions were displayed in a single page format on the screen, so participants used it as a guide in telling their stories. However, the second and third stages of Wengraf's (2001) approach was a regular feature during the one-to-one interviews, as he recommended mostly questioning from the narrator and not going back over issues. Nevertheless, there were only a few instances where the researcher had to go back on an issue. For example, Gisela had rated her mole concept understanding as 1 out of 5 in the recruitment questionnaire. However, she demonstrated an above-average understanding during the interview, so the researcher had to go back to ask her why? Gisela explained that she was doubtful about the word 'concept' because she was a non-native speaker of English (native language - German), so she could not associate 'mole' with 'concept'. After clarification, she rerated herself to 4 out of 5. However, a semi-structured approach was applied throughout the one-to-one interviews (Bold, 2012). The questions were sequentially designed and asked when appropriate, rather than sticking to a set approach (Mischler, 1986). The questions were sequentially designed and asked when appropriate, rather than sticking to a set approach (Mischler, 1986). Broad and open-ended questions were used, designed to tell a complete mole concept experience that highlighted specific aspects of stories whilst encouraging open dialogue (Bold, 2012). Questions were asked about the historical context of the mole concept, as participants were asked to reflect on whether they had been taught the historical origin of the mole concept? This was to test the conceptual teaching of the mole, as it would have had the effect of helping learners to build concept maps of the mole. There are two main methods of teaching and learning the mole, procedural and conceptual methods. Research has already highlighted that most instructors prefer to teach only the procedural method and never bother teaching historical facts, which highlighting the non-interest in conceptual understanding (Surif, et al., 2012; Tullberg, et al., 1994). Further questions were designed to investigate student participants' mole concept knowledge including millimoles, habitus, field and forms of capital, especially cultural capital. Science lecturer participants were asked if they taught the historical context of the mole, to confirmed previous researchers' findings and test the field, amongst others. They were also asked how they learned the mole concept themselves (see Appendix III).

6.8.1 How the topic guides for the interviews and focus group were constructed;

The primary research aim was to uncover science students teaching and learning experiences, but the wider aim, which is expressed in the sub question, was to understand the degree to which the mole concept difficulties affect science students from low socioeconomic backgrounds (lower-class), as compared to those from the higher classes. So, the interview questions were designed to reflect this. We already knew from literature that the mole concept was predominantly taught by procedural method (Surif, et al., 2012; Chiu & Chang, 2005) (see sections 2.1.4 & 2.1.5), but we had to test this as well, to confirm if this was still the case. Therefore, some questions were designed to also reflect this. The questions relating to if the participants were taught both the historical context and mole related analogies, was to find out whether they were taught conceptually or not. Teaching the historical context of the mole would mean that, students would not only have learned about the origin and meaning of the word "mole" in Latin, which means "heap", but they would have been able to know or understand that Oswald (1900) was a chemist, while Avogadro was a physicist. These are crucial in conceptual teaching, as it would help students to start building relationships and connections and concept maps (Glaser, 1991). Analogies will help to accomplish the same, as it brings learning to the students lived experiences, or makes learning meaningful (Ausubel, 2000).

The questions relating to substituting values into equations, or using formulae to solve mole concept problems, was to establish whether the students were taught procedurally. Procedural knowledge is related to familiarisation with formulae in this context and relates to superficial and rote learning (Glaser, 1991). The question about how the students gained access into their current courses, was to establish if they were traditional or non-traditional students. Traditional students would have gained access through GCSE's and "A" levels, while non-traditional students would gain access through "access / foundation" courses. Questions relating to participants parents' occupations, highest academic qualifications, and if they sometimes go to galleries, theatres, and concerts, were aimed at establishing their social class and capital (economic, social & cultural), (Sullivan, 2001) (see section 5.5.6). Social class and student's mole concept understanding (ratings), are key indicators that are crucial in answering the research question and are vital in determining the outcome and proposal of this study (see Table 2).

6.8.2 Reflection on how the focus group was conducted;

The focus group interview was conducted in orderto triangulate with one-to-one interviews and questionnaire (Cohen, et al., 2011). The aim was to generate 'low-cost data quickly' (Hyden & Bulow, 2003), then confirm what the participants have already indicated in their questionnaires and if possible, identify potential candidates for the one-to-one interviews. It is said that focus group interviews are 'economical on time', as they usually produce a lot of data, in a short time, but not as much as one-to-one interviews, using the same number of participants (Hyden & Bulow, 2003). This study was short on time, so we had to generate more data as possible to help answer the research question, in a short space of time. We only carried out one focus group interview, even though we were aware of the fact that more than one is necessary in order to know if the 'outcome is unique to one group or not (Morgan, 1968). This was because of the reasons already given above, which was to evaluate the information already provided in the questionnaires, and to identify potential candidates for the one-to-one interviews. Focus group interviews provides many of the one-to-one interview advantages from a group perspective, with interactions amongst and between participants, to generate data (Descombe, 2014, cited in Cohen, et al., 2011). The method appeals to researchers who are interested in studying communications and interactions amongst participants, with major drawbacks in terms of managing group dynamics and data analysis (Savin-Baden & Howell Major , 2013, p. 374). This study would probably not have profited from high level participants interactions, even if we had the time. There was a big difference between participants mole concept experiences, such that those with above average mole understanding (mostly higher social class), would have dominated the discussions, and secondly, not all participants would have liked to discuss their family situations amongst their peers. We only had five participants, even though invitations were sent to more than fifteen, out of the twenty-five who responded to the questionnaire. The recommendation to plan for a no-show on the day was to 'over recruit by at least 20%' (Morgan, 1988, p. 44), as was the case. To have five participants was about right, since Morgan (1988) suggested between four to twelve participants per group, and Fowler (2009), recommended six to twelve per group. In order to save time and to be on point (Cohen, et al., 2011, p. 437) since the event was online, it was important to display the questions on screen, so that the participants reflect on them, as they took turns to respond. This was to prevent dominant participants taking more time, to the disadvantage of others (Smithson, 2000), and for participants to decide the type of personal information they were confident sharing. These justified the screen display of the questions. It is true that this method does not allow for a greater degree of interactions between the participants, but the emphasis was on data quality not quantity. The key data points, like validating their mole concept ratings, and determining their social class, were gleaned, as well as triangulating to enhance validity. Triangulation is the use of two or more methods to collect data (Cohen, et al., 2011, p. 195). There are several types of triangulations, but in this study, ‘combined levels of triangulation’, which depends on three levels of analysis of analysis, is used. The three levels include; the individual level (data from questionnaire, see Table 1), the interactive level (focus group, see Table. 2), and the level of collectivises (organisational & societal, see Table 2). Triangulation demonstrates ‘concurrent’ validity especially in qualitative research (Campbell and Fiske, 1959 cited in Cohen et al., 2011). We had to established participants mole concept experiences ratings twice, as well as their social class. Focus groups are designed for participants to ‘bounce’ an idea around (Morgan, 1988), but in this study, we needed to establish/investigate four main ideas, which includes: participants mole concept experiences (1 to 5 ratings), social class (via forms of capital), student type (traditional/non-traditional) and methods of mole instruction (procedural/conceptual). These cannot be discussed effectively, within the time frame which was about an hour. Some participants had very little mole concept experiences. For example, Mary who studied in Poland, rated her mole experience/understanding in the questionnaire as 3 out of 5, but admitted in the focus interview that she never had any mole related experiences (see Tables 1 & 2). This is one of the drawbacks of focus group method, because it is difficult to deal with group dynamics (Smithson, 2000). At least one participant (James) decided to write out his own response and gave it to his lecturer (my supervisor), who was the moderator, to read it on for him, while he was still in attendance. Some other drawbacks include the fact that focus group does not produce quantifiable/generalisable numeric data, which may lack reliability. As mentioned above, the triangulation used, was to eliminate these drawbacks and improve reliability.

6.8.3 The **relationship between the storyteller and the researcher;**

Narrative researchers agree that the stories told are influenced significantly by the person telling the story and by the reason for telling them, together with the input of the investigators' subjective analysis of them (Riessman, 2008). Thus, the outcomes are usually considered as co-constructed (Mischler, 1986). As a result, reflexivity is a vital part of the narrative study and important in this research's data collection and analysis. Therefore, highlighting the multifaceted nature of narrative methodology, where the researcher's role must be well defined (Clandinin & Connelly, 2000). Therefore, the researcher cannot be left out of the inquiry as they are complicit in their own study (Clandinin, 2006). The narrative methodology is often referred to as 'nested uses', as it starts with the narrative spur or motive, the longing to tell a story, which on its own is interpretive, leading to narrative data which the researcher then analyses. Another analytical stage happens when the outcome of the study is made public. Bruner (1990) highlighted that the whole procedure assists both the storyteller and researcher stop and reflect on the stories of their lives and others, suggesting that such a reflection can lead to individual and realistic changes due to the reflections (Clandinin, et al., 2007). Fundamentally, most narrative inquirers view themselves and the storytellers as co-constructing every section of the story, while others favour maintaining a safe distance (Clandinin & Huber, 2010). There were very few such issues in this study since everything happened online due to the Covid-19. Nevertheless, I am aware of the dual role of the student researcher, with full responsibility for the welfare of the student participants and the power imbalance (Elmir, et al., 2011). The participants completely controlled what they contributed in their stories (Clegg & Stevenson, 2013). The ‘halo’ effect, where storytellers tell the researcher what they think the researcher wants to hear (Kvale, 2018), was minimal or non-existent in this study because even though it is a qualitative narrative study, but the subject under investigation (the mole concept), is a scientific concept. Most of the questions were designed to conform with previous researchers had already established, so the answers are already known and expected, like in the examples given above conceptual and procedural teaching and learning of the mole concept (Surif, et al., 2012). As the researcher, I was conscious that having invited the participants to the interviews means the outcomes can be influenced somehow by my presence, contrary to normal stories that surface in daily life (Narayan & George, 2003). The whole research was motivated by my agency concerning the topic choice, theory, and methodology (Narayan & George, 2003).

6.8.4 Emotions and this study;

Qualitative researchers attempt to view the world through the lenses of others; therefore, as a consequence, research must be experienced emotionally and intellectually (Gilbert, 2001). The emotional effects on the participants and the researcher should be acknowledged since researchers do not live in a vacuum and cannot, therefore, be distant from their study (Dickson-Swift, et al., 2009). Hochschild's (1979) seminal work formed the concept of emotion work, primarily based on examining the significance of emotions in the workplace. It is noted that some social rules entail individuals to suppress or induce emotions concerning the context and situation (Darra, 2008). These social rules are mostly overlooked until there is a disparity between what they perceive and feel they should perceive. Once this happens, the person is obliged to deploy emotional labour, which depends on constructed behaviour to portray a socially accepted behaviour (Darra, 2008). The studies relating to emotion work and labour have been limited only to a small range of professions such as healthcare and flight services professionals (Hochschild, 1979; Darra, 2008), but not many have investigated the effects on qualitative inquirers. The emotional impact of engaging in qualitative studies involving victims of rape was vital because it specifically investigated the effects on the researcher (Campbell, 2002). The sensitivity of the issue and the personal exchanges with the research participant was highlighted as needing emotional labour to enable the researcher to handle their emotions. Emotional labour with reference to this study was minimal and non-existent on the part of the participants because there were no visible signs of any participant being upset at any stage of the interviews. However, realising the shortfalls of the science education system in enabling equal access to scientific knowledge was emotionally draining during the interviews. For example, Isa (from Somalia) showed an above-average understanding of the mole concept even though he is a non-traditional science student pursuing a non-traditional route. The system appears to tag learners as either capable or incapable of understanding certain instructional materials, including the mole concept, even though not all the tools available in the teaching and learning of such materials is being deployed. Procedural teaching and learning of the mole concept depend on mathematical ability, whereas conceptual engagement does not and leads to deeper understanding/meaningful learning (Ausubel, 2000).

6.8.5 Transcribing the narratives;

All the narrative was transcribed word for word by the investigator a couple of days after the interview (Birt, et al., 2016). Even though this took time, it was a valuable exercise to familiarise myself with the data and highlight important contributions that addressed the research question. It is recommended that enough time is spent studying the interview notes to help the transcribing process (Wengraf, 2001).

6.9 Data analysis:

Hunter (2010) describes the complicated and challenging process of data analysis as ‘the long and winding road’. It is made clear that there is no one particular procedure for analysing narratives because it can start at any juncture within an iterative procedure, involving "analysing, collecting data, synthesising, reanalysing and so on" (Bold, 2012, p. 121). Meaning analysis starts before and during the narrative and transcribing processes (Bold, 2012). Data analysis within the interpretive paradigm is always subjective and based on the researcher's interpretation (Clandinin & Connelly, 2000; Riessman, 2008). In this study, the analysis started early, as I had to include questions that tested previous research results related to the mole concept. For example, as previously stated, I had to inquire about non-teaching of the mole concept using the conceptual method and the predominance of the procedural method, based on previous research outcomes like in Surif et al. (2012) and Tullberg et al. (1994). I also had an idea on what to expect from affluent participants and those from economically deprived backgrounds, as a result of feedback data from the recruitment questionnaire (see appendix II), so I had an idea about their relative primary and secondary habitus’ and cultural capitals (Burnell, 2015). Another inclusive definition of narrative analysis highlights the fact that it is an approach that examines how individuals make sense of their lives via the stories they tell and construct (Earthy & Cronin, 2008). Therefore, it is critical to understand the meaning and purpose of stories being told (Earthy & Cronin, 2008). There are four main approaches of analysing narrative data, includes; thematic approach, which focuses mainly on content; dialogic/performance, which links more to the social significance of the narrative by examining the; who, when, where and why questions; and the visual approach, which amalgamates images and words. For this study, which aimed at examining the mole concept experiences of science students/participants, the focus was on experience and meaning (Holloway & Freshwater, 2007) through capturing themes, relationships amongst and between individuals and the context of the narratives. Aligns with thematic experience-oriented analysis, interest in what is being told rather than telling (Riessman, 2008; Bold, 2012). The participants in this study were not fragmented into thematic categories as recommended by Riessman (2008, p. 12) Instead, they represented them as individuals because of the significance of their stories in answering the research question. Therefore, the subsequent chapter (7) will be an account of each participant's story and my interpretation and reinterpretation of their narratives, applying thematic analysis, with the data presented in a format that highlights its interpretive and biographical focal point.

Tabulating data is one of the methods of organising and presenting data in qualitative research (Cohen, et al., 2011, p. 547). Tables 1, 2 & 3 provide a summary of all the data collected in this study.

Table 2 Data analysis / Student participants Interviews										
Student	**Student type**	**Interview type**	**Mole Concept Ratings; 1-5 Before (B) & After (A)**			**Social class & First Mole Contact (FMC)**			**Evidence**
			(B)	**(A)**	**evidence Appdix. No**	**FMC**	**Class**	**Parents occupation**	
1 Gisela	Traditional (BSc)	1-2-1	1	4+	I, Gisela Lines 17-20	KS3 Sec. School	Higher-class.	Doctor PhD/ Engineer	Appendix I Gisela - Lines 43-46 FMC-, Line 8
2 Isa	Non-Traditional (Foundation/access)	1-2-1	4	4+	I, Isa Lines 56-59	FE / HE Access Course	Lower-class	Working/ Kitchen staff	Appendix I Isa - Line 25 FMC- Line 3
3 Emma	Traditional (PhD)	1-2-1	5	5+	I, Emma Lines 17-18	KS5 A-level	Higher-class	Software Engineer	Appendix I Emma - Lines-38-41 FMC- lines 9-11
4 Drita	Traditional BioMed Foundation	1-2-1	5	5+	I, Drita Lines 18-24	KS3 Sec Sch Yr8 Grade 7	Higher-class	Self-employed College diploma	Appendix I Drita - Lines- 85-88 FMC –Lines 6-12
5 James	Non-Traditional (Foundation yr)	Focus Group	3	3	I, James Line 2-3&9	FE / College	Lower-class	Care/cleaning & Construction	Appendix I James - Lines 11-12 FMC- Lines 2-5
6 Oprah	Non-Traditional (foundation/access)	Focus Group	3	3	I, Oprah Line 5	FE / HE	Lower-class	Untrained businessmen	Appendix I Oprah - Lines 31-32 FMC –Lines 2-3
7 Jacob	Non-Traditional (foundation/access)	Focus Group	3	3	I, Jacob lines 7-9	FE / College	Lower-class	Unskilled Engineer/care	Appendix I Jacob-Lines 19-20 FMC – Line 2
8 Mary	Non-Traditional foundation	Focus Group	3	1	I, Mary lines 17-30	FE / High Sch.	Lower-class	Sailor /Captain (Poland)	Appendix I Mary- line 30 FMC* – Line 2*
9 John	Traditional (transition)	Focus Group	4	5+	I, John Lines 1-9	KS3 Yr 8 7^{th} Grade	Higher-class	Civil servants/ Teachers	Appendix I John - Lines -11-12 FMC – Line 2

Table 2, shows a summary of the data from the questionnaire, focus group and one-to-one interviews; It shows student type (traditional / non-traditional); Interview type (one-to-one / focus group); mole ratings before interview (B) & after interview (A), and where to find the evidence; students first encounter with the mole (FMC); students' social class; parents' occupation; & where to find the evidence in the appendix I.

Table 2 indicates that the first participant Gisela is a traditional student, who had a one-to-one interview, and she rated her mole concept understanding in the questionnaire, before the interview, as 1, and after the interview as 4, but we rated her as 4+ (see Appendix I, under Gisela, lines 17-20). Her first-mole contact (FMC) was in secondary school (year 8), her social class is higher-class, backed by her parents' occupation (Table 1 shows her parents' highest educational qualifications, see Appendix I, lines 43-46, while the evidence for her FMC is in line 8).

Isa is participant number 2, a non-traditional student, who did a one-to-one interview, rated himself 4 in the questionnaire and was rated as 4+ by the researcher after the interview (see Appendix I, lines 56-59). Isa's first-mole contact was in his FE access course, and his from a lower social class, as his parents' kitchen staff (see Appendix I, line 25, and the evidence for his FMC is line 3).

Participant number 3 is Emma, who is a traditional student in a PhD course; she did a one-to-one interview and rated her mole understanding as 5. She was rated 5+ after the interview (see Appendix I, lines 17-18. Emma's first-mole contact (FMC) was in her "A" levels (I would have guessed far earlier than this), while she is from a higher social class, with a parent occupation as a software engineer (see Appendix I, lines 38-41, and the evidence for her FMC is in lines 9-11).

Drita is participant number 4, who is a traditional student in a biomedical foundation course; she did a one-to-one interview and rated herself as 5 in terms of mole understanding. She was rated as 5+ after the interview (see Appendix I, lines 18-24). Dritas' first-mole contact was in secondary school grade 7 (year 8 / KS3), and she is from a higher social class, with self-employed business parents (see Appendix I lines 85-88 and lines 6-12 for her FMC).

James is a non-traditional student doing a foundation year sports therapy course. He is participant number 5; he participated in the focus group interview and rated his mole understanding as 3 in the questionnaire, which remained extant after the interview (see Appendix I, lines 2-3 and 9). James first encountered the mole in FE, and he is from a lower social class, with parents whose occupations are care/cleaning and construction workers (see Appendix I lines 11-12 and lines 2-3 for FMC).

Participant number 6 is Oprah; she is a non-traditional student who gained access to BSc in pharmaceutical science through a foundation course. She took part in the focus group interview and rated her mole understanding in the questionnaire as 3, which remained extant after the interview (evidence in line 5). Her first-mole contact was in FE/HE, and she is from the lower social class, with her parents' occupations as a businessman and public health worker, respectively (see Appendix I, lines 31-32, and for FMC lines 2-3).

Jacob is participant number 7, who is a non-traditional student. He took part in the focus group interview and rated his mole understanding as 3, which remained extant after the interview (see Appendix I, lines 7-9). His first-mole contact was in FE, and he is from a lower social class, as his parents' occupations are an unskilled engineer and a care worker (see Appendix I lines 19-20 and line 2 for FMC).

Mary is a student participant from Poland. She is a non-traditional (foundation year) sports therapy student, who took part in the focus group interview and rated her mole understanding as 3 from the questionnaire; this was re-graded to 1, after the interview (see Appendix I, lines 17-30). Mary first encountered the mole in FE, and she is from the lower social class; her parent occupation is sailor/captain in Poland (see Appendix I, line 30, and line 2 for her FMC). Her description of events was somehow cloudy, due to language limitations. For example, she rated mole understanding as 3, but her experience of the mole was not very clear during the interview.

John is participant number 9, a traditional student in a BSc chemistry course (see Table 1). He took part in the focus group interview and rated his mole understanding in the questionnaire as 4; this was upgraded post-interview to 5+ (see Appendix I, lines 1-9). His first-mole contact was in secondary school (Year 8/grade 7/KS3), and he is higher-class, as both of his parents are civil servants (teachers) (see Appendix I lines 11-12, and for FMC line 2).

Table 3 Data Analysis / Lecturers Interviews								
Instructor	**Teaching Method**			**Evidence**	**Assessment Method**			**Evidence**
	Procedural	**Conceptual**	**Both**		**Summative**	**Formative**	**Both**	
1 Dr Luke	Procedural			Appendix I Dr Luke, Lines - 34-37	summative			Appendix I Dr Luke Lines- 54 – 59 “Mini summative tests”.
2 Dr Kan	Procedural			Appendix I Dr Kan Lines – 23-25	summative	Formative Coursework/ E-assessor	Both	Appendix I Dr Kan Lines – 45-47
3 Dr Paul	procedural	Conceptual	Both	Appendix I Dr Paul Line – 28-33 & 34-38	Summative	Formative (coursework)	Both	Appendix I Dr Paul Lines – 51-55

Table 3 shows a summary of data from science lecturer participants’ interviews, one-to-one interviews. It summarises their teaching and assessment methods and where to find the evidence in appendix I

Dr Luke is lecturer participant number 1, who lectures mainly procedurally, the evidence can be seen I appendix I, lines 34-37. He assesses the mole mostly by summative tests, and the evidence for this can be found in lines 54-59 (mini summative tests).

Dr Kan is lecturer participant number 2, who lectures mostly procedurally. The evidence can be found in lines 23-25. He uses all three forms of assessment (summative / formative / e-assessor). The evidence can be found in lines 45-47.

Dr Paul is the 3rd lecturer participant, who uses both procedural and conceptual methods of mole instruction; the evidence can be seen in appendix I, lines 28-33 & 34-38. He also uses both assessment (summative & formative) methods, the evidence for this can be found in lines 51-55.

6.9.1 Validity and Reliability of data analysis;

As indicated earlier under focus group, the use of a variety of methods in sampling, together with using a wide range of participants, provided a high degree of data validity. To be more accurate, this is 'data triangulation' in contrast to, methodological, observation, or theory (Denzin (1988) cited in Robson, 2002, p. 174). Winter (2000) is of the opinion that qualitative data validity can be addressed through richness, depth and honesty of the data achieved. The use of multiple methods (questionnaire, focus group, and one-to-one interviews) ensures the richness and depth of the data, while data honesty is guaranteed by safe storage of all the WebLearn audios in the university computer system, since it was conducted through there. Data honesty is part of descriptive validity, as it reflects the accurate and verifiable account of what is recorded, without distortion in any shape or form (Winter, 2000). Maxwell (1992) prefers the word ‘understanding’ as opposed to ‘validity’, since researchers are part of the world they study. However, it is not always possible to achieve 100% validity with qualitative data, because of the subjectivity of the participants, as their perspectives, opinions and attitudes can add some degree of bias. Triangulation helped to eliminate some of the subjective bias in this study. For example, some participants ascribed themselves wrong mole concept experience values in the questionnaire. Gisela rated herself 1 out of 5 in the questionnaire, but a 4 out of 5, during the one-to-one interview. Mary gave herself 3 out of 5 in the questionnaire, but she was assessed as a 1 out of 5 (see Table 2). Therefore, validity in qualitative research should be regarded only in terms of degree (Gronlund, 1981). Triangulation in this study therefore maximised the data validity and minimised its invalidity. This study was born out of the researchers’ own habitus, (primary and secondary), and sampling was a social phenomenon, therefore the researcher was an important instrument in the data collection analysis, and interpretation. This is part of theoretical validity, which is the theoretical construction introduced in the research by the researcher (Maxwell, 1992). We adjusted the participants’ mole experiences ratings where appropriate, as described above, based on the questionnaire and interviews. We also ascribed participants’ social class, based on information about their habitus and capital. The explanations of the outcome of this study can be sustained by the data obtained, and this is internal validity (Cohen, et al., 2011). The emphasis in qualitative research is geared towards internal validity (Winter, 2000, p. 8) because it must not seek to generalised, even though it can, like in this study, but represent the phenomenon under study. The researchers' interpretation of the data is therefore valid and reliable, because it is based on honest sampling, the researchers' habitus, and the advantages of triangulation.

6.9.2 E-mail participant;

Dr Paul responded to the research through email, even though we spoke over the telephone initially. Email interviews have similar drawbacks as telephone interviews in that; both may not have the feel of a personal interview as the participant and researcher are deprived of many communication channels (Cohen, et al., 2011). Never-the-less, Arksey and Knight (1999) identified some advantages, which included the fact that it is sometimes cheaper and faster than face-to-face interviews, and more importantly protects the anonymity of the participant, more than other methods. Dr Paul's demographics was not too important in this context, as the main trust of the study is on the mole experiences of the different types (traditional/non-traditional) and class (Higher/Lower) of students, and the degree to which the mole concept difficulties affect them. Yes, the lecturers' input was important in enabling us to understand the prevailing teaching methods (procedural/conceptual & summative/formative assessment), and to confirm previous studies findings on these. It was also important for triangulation, but on its own, does not affect the outcome of the study. However, Dr Paul's input was important, as he was one of the three science lecturers who taught the mole using both methods. He taught conceptually by using analogies and exploring the historical context (see Table 3).

6.9.3 The Use of NVivo™

CAQDAS (Computer-Assisted Qualitative Data Analysis Software), of which NVivo™ is one of many and was chosen because it is available free of charge from the London Metropolitan University IT department. NVivo is designed to manage the data, but not code it as commonly believed (Stuckley, 2015; Silver & Lewins, 2014). I uploaded all the interviews transcribed data into NVivo™, which enabled all the data to be in a single place for easy retrieval (Silver & Lewins, 2014). CAQDAS and NVivo have their criticisms, including the fact that it can easily detach the researcher from the data and possibly control the analysis process (Tummons, 2014), presumably because several researchers are hesitant to amend initial coding categories after their identification (Bergin, 2011). These criticisms are often countered, as Information Technology (IT) is gaining ground in research and highlighting whether or not one uses the traditional approach of highlighting and manipulating sections of transcribed interviews or the CAQDAS, the basic process does not change (Stuckley, 2015). Tummons (2014) noted that it is still debatable if the traditional approach ushers the researcher closer to the data. However, CAQDAS, by making the data easier to arrange, retrieve and navigate, can assist this process (Silver & Lewins, 2014) and eliminating the necessity for vast volumes of paper cuttings (Stuckley, 2015). It was common practice for me to regularly revisit the transcribed interview data throughout the analysis, which enabled me to constantly familiarise myself with the stories and the participants who told them. Initially, a significant amount of time was spent examining the transcribed data to familiarise myself with who said what and re-reading at times. The preliminary coding process generated a couple of codes (Appendix IV), by applying the wild approach (Cousin, 2009) where anything I considered significant is coded, at times applying more than one code for a specific data, which highlights NVivo's advantage (Silver & Lewins, 2014). Subsequently, coming back to the initial aim of my research was significant in refocusing the analysis, together with applying Bourdieu's theory of practice, resulting in my awareness of new items that emerged and discovered meaningful codes that contributed to answering the research question (Riessman, 2008; Gale, et al., 2013). The overall process transitioned from an inductive to almost a deductive data analysis approach (Gale, et al., 2013). My general approach relied on searching for units of the stories that revealed vital statements or experiences, which are usually bodies of text or just a line of text (Riessman, 2008). Searching for themes or categories was important for identifying shared experiences as repeated content was identified in the narratives (Earthy & Cronin, 2008). Another significant way of locating important themes in the narratives is to search for recurrent content (Squire, 2008; Andrews, et al., 2013). In this research, the main themes were arranged into major categories that focussed on mole concept experiences. These major categories were employed in the organisation of transcribed data and the codes created; nevertheless, I had to revisit the transcribed interviews during the analysis frequently.

6.9.4 The Ethics of narrative Inquiry;

Negotiating access into the grounds of narrative research is usually considered an ethical practice and is vital to clearly state the inquirers and the participants (Connelly & Clandinin, 1990). Some critical responsibilities include; privacy, participants well-being and protection of dignity (Connelly & Clandinin, 1990). The above was given enough attention during the whole process of dealing with data collection and analysis. Ethical approval was sort and granted by London

Metropolitan University's ethical committee (Appendix V). Formal approval is necessary and confirms that significant ethical concerns have been reflected upon. However, it is established that the inquirers' responsibilities go further than just granting institutional ethical approval (Clandinin, 2006). The researcher, therefore, retain the privilege in this research of working ethically with the participants and the duty of making sure that they were not adversely affected in any way by participating. BERA (2018) guidance was essential in informing the researcher's conduct throughout this study.

6.9.5 Informed Consent;

One of the vital ethical responsibilities is informed consent and is associated with the principle of autonomy (Hammersley & Traianou, 2012). All the participants were provided with a summary of what the study was about before the interviews; this was to aid informed consent (Hammersley & Traianou, 2012). Informed consent was achieved through the recruitment questionnaire and consent letter (Appendix II and III). The questionnaire already gave them a good idea of what the study was all about and had a question at the end for them to insert their email addresses if they would like to participate in the study. The consent letter also included details about the nature of the study and how their information would be used and protected, based on BERA (2018) guidelines. The participants were all mature students, and lecturers which meant they could make informed decisions either to participate or not; for example, not all the 26 students who responded to the questionnaire attended interviews. Five students received £5 Amazon vouchers for participating in the focus group - they had to sacrifice their online learning break to attend. All participants were promised a copy of a puzzle game I invented. 'Periodic puzzle' is a tile puzzle game of the periodic table's first thirty elements, which will be distributed post-Covid-19 lockdown and face-to-face attendance at university resumes. The other one-to-one interview participants chose an interview time that was convenient for them. The above reflects the important principles of voluntariness and disclosure (Franklin, et al., 2012). Student participants may benefit indirectly as the study's outcome may be used to inform educational practice and were also aware that it will constitute the central part of a doctoral thesis that could be published. This simple and common approach does allow participants to think about some of the vital ethical concerns, though not a hundred percent (Hammersley & Traianou, 2012). Additionally, the consent letter was included in the London Metropolitan university's ethical approval processes for examination by their ethics committee. Student participants were made aware that they could withdraw their consent at any point in the process (Hammersley & Traianou, 2012). Further explanations and a summary of the study were offered again at the beginning of each one-to-one interview, enabling participants to seek clarification or ask questions. Written consent was obtained when they completed the questionnaires (Appendix II). Nevertheless, consent is considered an ongoing process rather than a single event (Hammersley & Traianou, 2012).

6.9.6 The welfare and protection of those taking part;

Another primary principle of research ethics is that participants should not experience physical or emotional harm above what is considered routine in their life experiences (Breakwell, et al., 2012). This study took place online; therefore, most of the welfare and protection issues were already eliminated and therefore, student participants retained their student identities throughout the process (Clegg

& Stevenson, 2013).

6.9.7 Confidentiality;

The concept of confidentiality is equally related to data storage (see 6.9.7), requiring the researcher to safeguard the narrators' personal data and acquire their consent concerning the use of their information (Moule & Goodman, 2009). However, complete confidentiality cannot be guaranteed because potions of narratives will be included in the thesis and possibly published; much effort was devoted to protecting participants' identities (Traher & Wai Ming, 2017). Each participant was assigned a pseudonym to protect their identity. It was also noted that researchers must decide if the narratives should include data that could lead to confidentiality being compromised (Traher & Wai Ming, 2017).

6.9.8 Narratives data storage;

The Data Protection Act of 1988, revised in 2018, requires that data gleaned from participants must be stored securely according to the Act. The University "Box" system stores all research data, which is a heavily secured system. The University computer network is password secured and compliant with data protection procedures and thus adequate for the storing of electronic data in various forms, including voice recordings, transcripts and for using NVivo data analysis software documents. Unnecessary data was deleted as soon as possible, and participants were informed if some of their data might be reserved beyond the study for more academic work. This is considered adequate provided it is stored safely (Legislation.gov.uk, 2018).

6.10 Summary;

The Data Protection Act of 1988, revised in 2018, requires that data gleaned from participants must be stored securely according to the Act. The University "Box" system stores all research data, which is a heavily secured system. The University computer network is password secured and compliant with data protection procedures and thus adequate for the storing of electronic data in various forms, including voice recordings, transcripts and for using NVivo data analysis software documents. Unnecessary data was deleted as soon as possible, and participants were informed if some of their data might be reserved beyond the study for more academic work. This is considered adequate providing it is stored safely (Legislation.gov.uk, 2018).

CHAPTER 7: FINDINGS

7.1 Introduction;

This chapter examines in practical terms the mole concept experiences of a range of science student, together with the sociological factors that governs such experiences, by applying narrative methodology (Clandinin & Connelly, 2000). The chapter adds to what is already known about science students' mole concept experiences, for example the fact that there are two main methods of teaching and learning the mole concept (procedural and conceptual), but only one method is predominantly used (Surif, et al., 2012; Tullberg, et al., 1994) and the idea of millimoles, which is taught only to certain sector of the science community, notably science research students (see responses for Emma a PhD student below). The literature review and theoretical framework helped in understanding the narratives through the generation of NVivo codes (see section 6.9.2), four main themes emerge to answer the research question, which are; first degree socialisation (habitus-1); second degree socialisation (habitus-2), field operators / actors input and mole conceptual & procedural experiences.

7.2 Key themes in the data;

Other themes from the data includes; participants social class (Higher-class or Lower-class), participants Mole Rarings (MR), and participants first mole encounter [First Mole Contact (FMC)] These themes will seek to answer the research questions, with the last three (Social Class, FMC & MR) revealing that class is significant in determining how science students experience the mole, especially the degree to which mole concept difficulties affects lower-class students. The data is presented in three bar charts (Figures 5a & 5b, 6, & 7), afterwards we shall be depicting each of the twelve participants who took part in the narrative part of the study. Fourteen others took part by responding to the questionnaire, making a total of twenty- six participants.

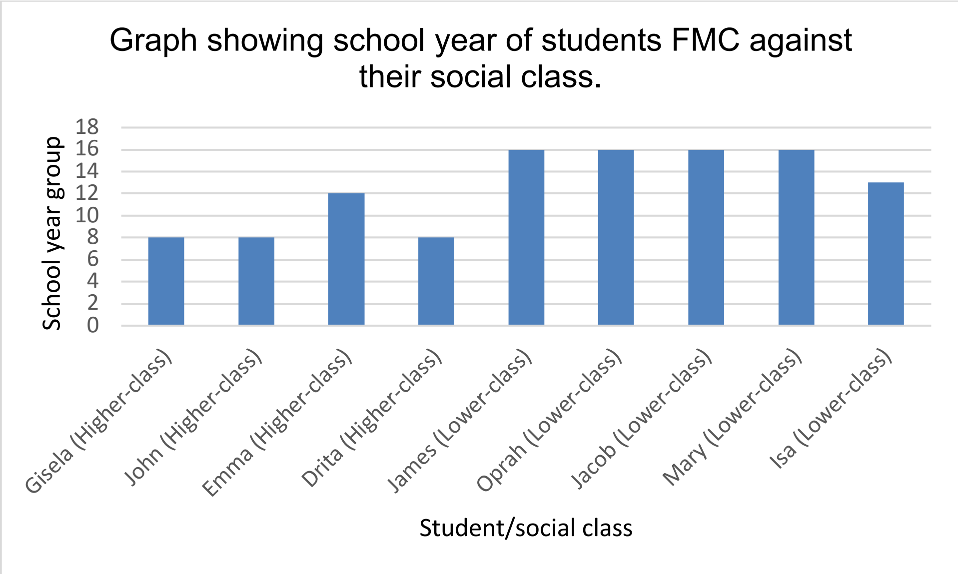

Figure 5a: Student participants and the year group they first encountered the Mole (FMC) Showing that almost all participants from lower-class & non-traditional, had their first mole lesson (FMC) far late in their academic careers, while those from higher-class & traditional, had their FMC far earlier. From year groups 8 to 12 are the normal year groups. From 14 to 16 are considered FE / HE.

Some of the key themes in the data include; social class allocation, mole ratings, and First Mole contact (FMC). The bar chart above (Fig. 5a) shows student participants and their first-mole contact. The year group is on the “y” axis and represents their exact year groups from year 8 to 12. Years 14-16 represent FE/HE. The bar chart shows that almost all the students who experienced the mole in FE/HE for the first time are non-traditional students from lower socio-economic classes, except Emma. Emma’s case is unique because even though she is a traditional student, she still did an access course due to the big gap between her qualifications and her current course. Over the expended period she may not accurately recall when she first heard of the mole. So, Isa, James, Oprah, Jacob and Mary, all lower-class participants, had their FMC in FE, while Gisela, Drita, John & Emma, all Higher-class participants, had their FMC far earlier in their academic careers. Higher social class correlates with early FMC experience, and lower social class correlates with late FMC experience.

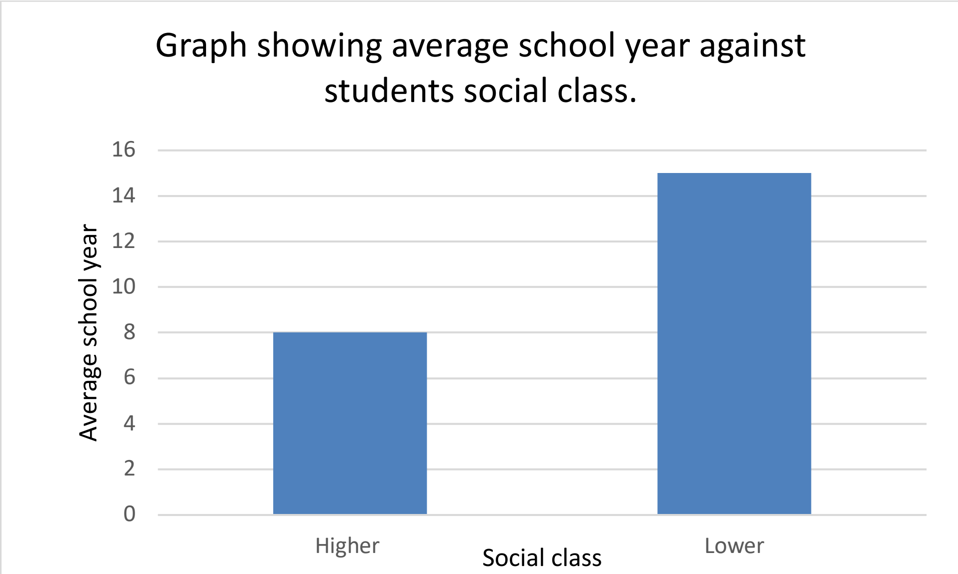

Figure 5b showing the average of school year that student participants first encountered the mole (FMC), indicating that higher-class students encountered the mole far earlier in their academic careers than lower-class students, who first encountered the mole for the first time in FE / HE.

Fig.'s 5a and 5b indicates why this study is proposing the teaching and learning of the mole conceptually far early in the academic cycle, even at key stage two (Key stage 2 (KS2)/upper primary) is influential. This should be done in tandem and in relation to the other SI units of measurements, so as to maximize both prior and conceptual knowledge.

7.2.1 Student type & social class versus mole ratings

Figure 6 shows student participants' social class & student type in relation to their mole concept ratings (experiences) after the interviews. Fig. 6 shows that almost all students with higher-than-average mole ratings are from the higher-class category, which correlates with their early mole encounter "First Mole Contact" (FMC) experiences (see Fig. 6), except for Isa. So, Gisela, Emma, Drita and John, all higher-class and early FMC, have higher than average mole ratings. Isa's case is also as unique as Emmas' FMC in that Isa has both intrinsic and extrinsic motivation. He had a considerable gap from compulsory education to FE/HE. He had not done well in his GCSEs and now had siblings who were doing well in HE, especially in the sciences. He interacted with the science books left around by his siblings, which increased his cultural capital. He also liked working in a science laboratory after having an experience during his FE access course (see appendix I, Isa). On the other hand, James, Oprah, Jacob and Mary, all lower-class and non-traditional students with late FMC, have lower mole ratings than higher-class students. Therefore, we observed that science students from lower socioeconomic backgrounds disproportionately experience the mole concept difficulties already identified by other studies compared to higher-class students.

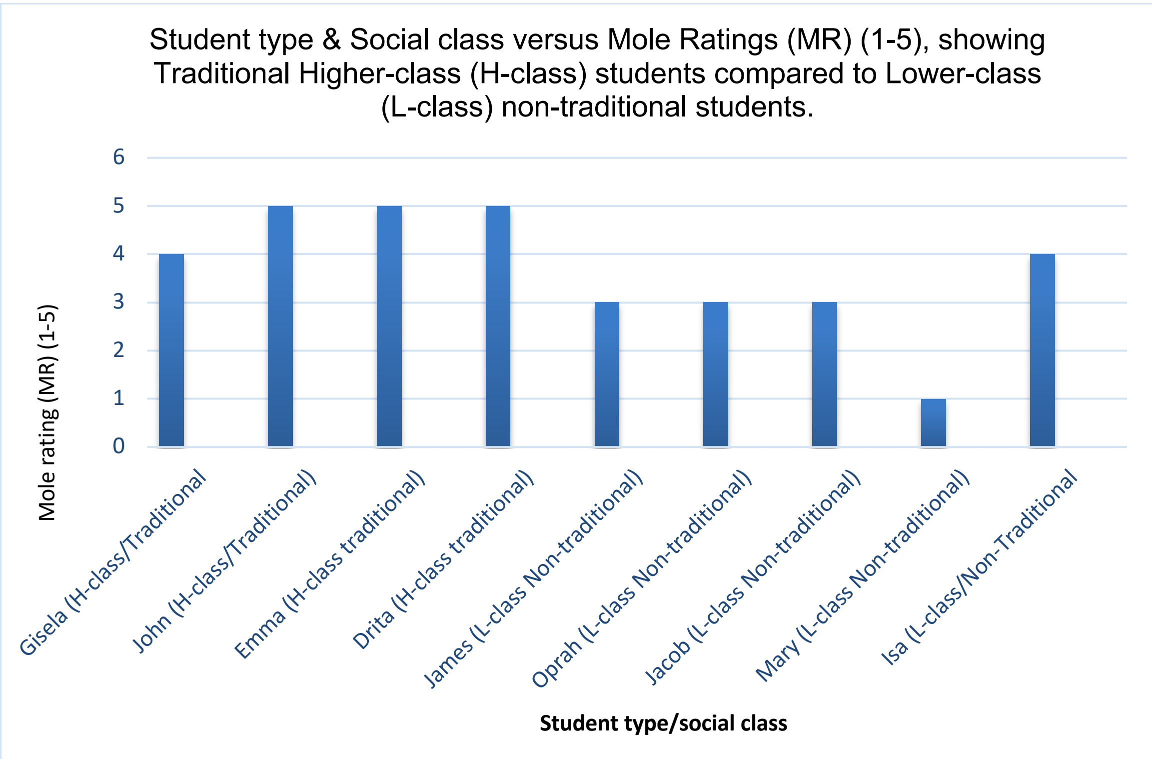

Figure 6: Student participants' mole ratings versus type of student / social class, indicating that almost all student participants form lower-class and non-traditional, had the lowest mole ratings, compared to those from higher-class and traditional, with higher mole ratings (except Isa MR=4)

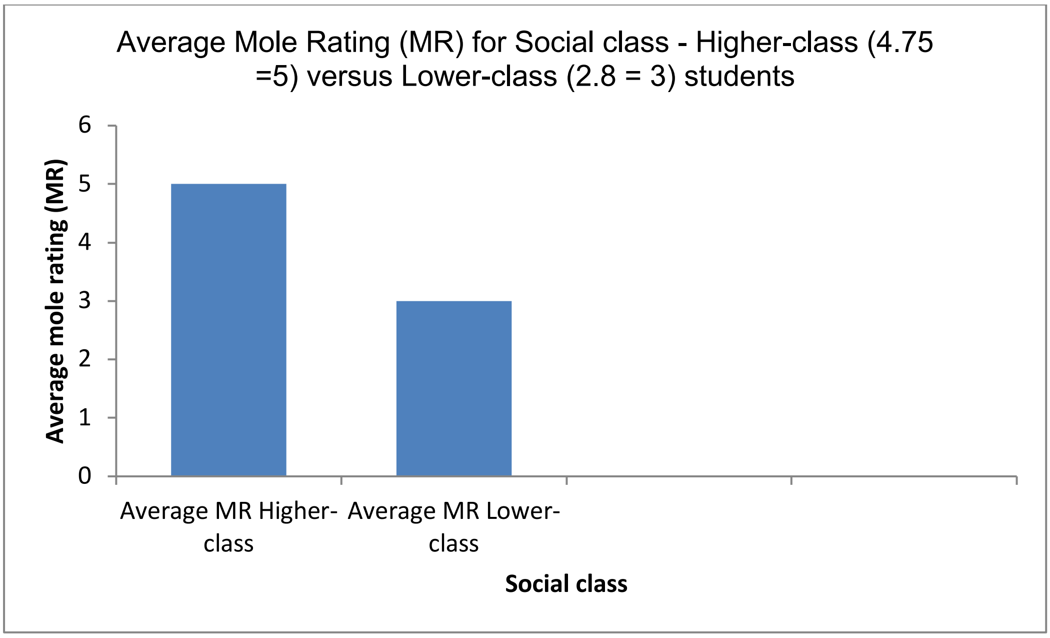

Figure 7: Average mole rating (MR) for Higher-class compared to Lower-class students participants indicating that social class is a factor in mole related experiences

Figure 7, is a summary of figure 6, indicating that, Lower-class student participants have lower mole ratings compared to Higher-class participants. The average for the Higher-class participants would have been far higher if we had increased the upper limits of the ratings from “5” to “10”. Some participants would have indicated the upper limit of “10”, or we would have ascribed higher than “5” mole ratings to some of them. For example, Emma the PhD student would have rated herself as “10”, and John the BSc chemistry student would have rated himself more than “5”, if not “10”. On the other hand, if some of the lower-class participants had increased their ratings to say “5”, if the upper limits were raised to “10”, we would have downgraded them after the interviews, because some of them had limited understanding or encounter with the mole.

7.3 Introducing the individual narratives;

7.3.1 Gisela; (GA)

Gisela is a BSc foundation year biomedical science student age group 26-30 years, originally from Germany where she attended a private boarding school. She first encountered the mole concept formerly around 2003 during chemistry lessons in that institution but previous to that, her mother had told her something about it as she indicated initially in the recruitment questionnaire, which she also confirmed during the one-to-one interview. Her parents are economically well-off, with the mother having a doctorate degree in pharmacology. She is a perfect example of how habitus (both first- and second-degree socialisation), field and forms of capital especially economic and cultural capital work to influence students' mole concept experience. She acknowledges that her current science orientation, was as a result of the science books in her home and her mother's influence, despite the fact that there was a strong counter influence by the private boarding school (field), to orientate her towards the arts;

> *CA*
> *When did you first encounter anything concerning the mole concept?*
> *GA*
> *I think that was in chemistry, in my boarding school in Germany. It must have been around two thousand and thirteen."*
> *CA*
> *"Have you ever used it in practical terms?*
> *GA*
> *That depends if you mean in conversations with my mother in practical terms, yeah, then actually to put it in practice in a laboratory, No."*

Further evidence of her first-degree socialisation can be seen from these exchanges below;

> *"Would you say that your current course now was inspired by your parents, or ~~was it~~ friends and teachers?*
> GA
> ***I think my parents definitely influenced the choice of my current course, from their occupation and from what they have laid around because that's the kind of environment that I have been exposed to."***
> *"So, from this I can deduce that you are not from an economic disadvantaged home at all?*
> *GA*
> *"No, not really but, it's only the materials, only the books, if I didn't pick the books,*

I would never learn about this, I would never have chosen biomedical science."

She was one of the few students who understood what millimoles was, because her mother told her about it, even though she could not remember the exact factor in which a mole is divided by to get a millimole, she stated 100 instead of 1000.

CA
"Have you heard of millimoles before?
GA
"Yes, millimoles, Yes, I think it's a hundred
CA
Okay, so what do you think it was?
GA

It would be moles divided by ten to the power of four, or to the power of three, I am not quite sure anymore, but milli means a hundred, so that would be a hundredth of one mole."

So Gisela's habitus' both first and second degrees had a direct impact on her mole concept experience. Her private school (field) tried to orientate her towards the arts, but because of her home or first-degree socialisation and her own personal agency, she chose the sciences. She was taught the mole concept procedurally and prefers using equations to solve mole related problems due to her mathematics ability. Gisela initially rated her mole concept understanding in the recruitment questionnaire as 1 out of 5. During the interview I inquired why she rated herself that low, considering that she had demonstrated an above average understanding of the concept. Her response was that she did not understand the word 'concept', even though she knew what 'mole' was, so she gave herself that score to be on the safe side. She then re-rated herself 4 out of 5, which I think was her right level of comprehension.

7.3.2 Isa (IA);

Isa is a foundation year in biomedical science student, who previously did an access to science course just to qualify for the foundation year in biomedical science. He had to follow this path, because according to him, he had a long gap in his education especially as his GCSE results were not great. He is aged between 26-35 years old and he is black African from Somalia.

Unlike Gisela, he has very low cultural and economic capital as his parents are not highly educated since they are currently still studying for their GCSE's and both work as kitchen assistants. However, his first-degree habitus is indirectly rich as he has siblings who are in higher education and had left science books at home that the interacted with and together with the influence of the local library, built this interest in pursuing his biomedical science course. He first heard about the mole concept when he was doing his access to science course. He nevertheless has an above average understanding of the mole concept, as he rated himself in the recruitment questionnaire, 4 out of 5. Isa had a long gap year from education where he did local jobs. Despite his parents' economic situation, they still managed to hire a private Somali tutor who taught him at home in Somali language, especially in subjects like maths where he was struggling: He had a one-week opportunity working in a science laboratory (field), while on his access to science course which increased his interest in science.

Isa had a good procedural understanding of the mole concept considering his limited habitus and capital; he learned the mole procedurally and never had any idea of conceptual teaching and learning;

> *CA*
> *"Did they teach you how to solve mole concept problems at all?"*
> *IA*
> *"Yes, in the access course, yes, well in general, mole is just a unit, we use it to measure chemical values, or chemical amounts and we know that one mole of any chemical is actually equivalent to this value of 6.02 X 10^{23}, and that is Avogadro's constant number.*
> *And there is a triangle where if you write it, it's easier to read, where you divide by the grams with EMR RMM) the molar mass to get the moles or do the opposite or the reverse.*

But not the history, I am still unsure about the history since most of the teaching goes in-depth into calculations rather than explaining where it came from.
Well, I understand that it came from the person with that name, but not the in-depth history about it."

This confirms previous studies which found that instructors prefer the procedural method of teaching the mole concept because it is less time consuming and easy for accountability. Learners can solve mole concept problems procedurally without even an above average understanding of the concept (Surif, et al., 2012; Chiu, 2004; Chiu & Chang, 2005). Isa, like Gisela, did not know about the two main definitions of the mole, which are Ostwald's (1900) definition which coined the word mole meaning "heap" and Avogadro's, which relates to a mathematical constant (Kolb, 1978). In contrast to Gisela, Isa is a non-traditional student from a low socio-economic background.

7.3.3 Emma (EA);

Emma is a PhD pharmaceutical science student, who has gained her BSc last year in pharmacology. She is English and white, age range about 34 years, with soap making as a hobby. Emma's parents are middle class, with her father working as software engineer and had a BSc in software engineering; her mother had GCSE's. Emma applied for her BSc as a mature student, using her "A" level qualifications, so she is a traditional student with an academic gap of 15 years.

Emma first heard about the mole concept during her "A" levels, 15 to 16 years ago. She had a huge gap in her education and only encountered the mole concept again during her BSc degree and had been doing mole calculations since, she uses millimoles on a daily basis in her current studies.

Emma had a rich habitus as she went to a private primary school but attended a comprehensive secondary school. She describes her parents as generally supportive but not specifically to mole concept or the sciences, as there was no national curriculum when her parents were growing up. They therefore did not study any chemistry or science. She attributed the motivation for her interest in doing her current course to Dr Kan who is currently her PhD supervisor. Her parental interactions at home were minimal, as both of them worked long hours, so she does her own homework through personal agency. She also had very little peer influence in choosing her current course, since most of her friends went into computing. She was liked by her teachers at school because of her personal educational agency. Even though Emma seems to have been taught the historical context of the mole at BSc level, but the teaching was mostly procedural (using formular method), in Emma's own words she said;

> *CA*
> *"So, how was the mole concept taught? Did you just have a series of formulas to substitute values into?"*
> *EA*
> *"Emm, well "A" levels, I would say they didn't really go into what Avogadro's number was, but they just said, it's this number, it's to do with carbon^{12}, just forget about it. We just focussed on balancing equations and that kind of thing and during the BSc, it was probably more involved with balancing equations, working out concentrations and combustion analysis, that kind of thing."*

Like Gisela and Isa, Emma was not taught the distinction between Ostwald's (1900) and Avogadro's definitions of the mole which both represents the chemists and physicists' views respectively. Neither were they taught using analogies, other than Emma's experience with a stuffed mule or flush mule.

7.3.4 Drita (DA);

Drita is a foundation year in biomedical science student she is white and originally from Albania with an age range between 20 to 30 years. She started in the foundation year because of late entry and difficulties in equating her Albanian qualifications to GCSE and “A” levels, even though she already had admission into a medical school in her native Albania. She was advised to do the foundation year in biomedical science, as a route to studying medicine; Drita stated that;

> *“Ehh, I haven’t done GCSE’s, basically I finished my secondary education in Albania and with the formal qualifications that I had, I started the foundation year so that I could complete the equivalent to “A” levels through the foundation year.”*

She is an academically good student with an above average understanding of the mole concept as she rated herself 5 out of 5, in the recruitment questionnaire. She was first introduced to the mole concept at seventh grade, which is equivalent to year eight in the UK school system, and she started doing stoichiometric exercises since, like working out number of moles, concentrations, and balancing equations. She is also confident with using the mole in practical terms in the laboratory especially using procedural method;

> *“So did you use moles in the practical sense and theoretical sense as well?”*
> *DA*
> *“Yeah, we use mole in the lab as well during some practical’s when we performed some reactions, I can’t remember exactly because this happened about two years ago, and in the end we had to calculate the mass, since we knew how many moles were used and we had in the end to calculate the mass in grams of a specific product.”*
> *“Did you use mostly the formula method to do this or another method?”*
> *DA*
> *“Yeah, the formula M is equal to grams over molar mass.”*

She was of the opinion that there was only one method of dealing with mole concept problems (procedural) and was never taught any mole concept analogies. This confirms the outcome of previous studies mentioned above. No one had pointed out the difference between Ostwald and Avogadro’s views on the mole mentioned above;

> *“To be honest I have never heard before that in physics and in chemistry there was*

a difference between the definitions of the mole. I know that there were the same. I heard about Avogadro because basically we have used them since I was like eighth or ninth grade and also now in foundation year, but not that I knew there was a difference between physics and chemistry of the mole."

Drita's parents are local businesspeople, their highest qualifications are diplomas, because they never did HE. Nevertheless, she had a very rich habitus, both first- and second-degree socialisation because she always had private tuition for a range of subjects and a home library to support the fact that it is a requirement for every student in Albania to read at least ten books a year, as confirmed by these exchanges;

CA
"Did your parents assist you at home with your work; hire private tuition or anything like that?"
DA
"Yes, I had private tuition since I was like in my first grade for maths, for language and for English and when I went into secondary, I had private tuition for Biology, chemistry, maths and like for all those other subjects, I always had private tuition."
CA
"Do you have a mini library at home or a bookshelf where you can read extra books?"
DA
"Yes, especially for sciences such as physics, biology I have always had books, and also for literature because in Albania, I don't know how literature is done here in England because we had to read like ten books every academic year, so I have always had a library full of books and science books when I went to secondary school."

She described her economic situation as stable, because they never lacked anything;

CA
"Can you describe yourself as being economically disadvantaged?"
DA
"Well, we have like stable economic, yes we have been economically stable, family, because my parents have been providing money and food being enough for us and also have holidays like normal family."

So, I will class them as middle class, with her own personal academic agency, as her parents had little direct input, other than providing economically, but she had very high cultural capital and field. A test for cultural capital includes ones' attendance at cultural institutions like galleries, museums and theatres, which she did in Albania, but could not do here because of the lockdown;

> CA
> *"Do you sometimes go to galleries, cinemas, theatres, concerts etc?"*
> *DA*
> *"When I was in Albania, yes, but not in England I have never been yet to galleries or theatres, because they are closed due to covid-19."*

7.3.5 Dr Luke (DrL);

Dr Luke is a chemistry lecturer from the institution where this study is taking place; he is white English and describes his background as working class. He did postdoctoral work both at University of Manchester and Oxford University respectively, so he has had teaching experiences at all three tiers of universities within the university's classifications (see university stratification section 1.2.5). So, he has got meaningful experience in the way mole concept is taught and learned across the board. His narrative will be strong evidence together with others, regarding the mole at different settings and types of learners in the Bourdieuran field. At the time of this research Dr Luke ran the BSc Chemistry programme at the institution where this study is taking place. Even though currently he is not lecturing the mole concept, but it is a topic that he has taught through the different tiers of universities. He taught mole concept at level four, which corresponds to BSc first year, but also taught different types of students, including Biology, chemistry, pharmaceutical sciences etc;

> *CA*
> *"When teaching the mole concept, what types of students did you teach? Were they non- traditional students / mature students?"*
> Dr L
> *"It was a very diverse and different types of students that we have in*

the first year, so the first Years module that I taught it on, included all of the biology students as well as the chemistry students and also pharmaceutical science, forensics science and pharmacology etc, so every single first year between the bio sciences and the CPS cluster, would have been in the lecture. So that gives you a range of different groups that are in the class, so there were mature students, males, females, different ethnicity, races, different disabilities as well, so it was a very broad range of people in the class."

The above confirms that the mole concept is socially constructed within the science community and reveals its importance. He also confirmed that the lecturers had the freedom to structure and deliver the concept anyway they see fit;

> CA
> "*Thanks, so what does the curriculum or course material prescribes for teaching the mole concept or do you have the flexibility to do what you wish, or do you have a prescribed course to follow?"*
> DrL
> *"No, we have the flexibility to do whatever we wished."*

Dr Luke confirmed that he does not see the value of teaching the historical context of the mole because he thinks it does not add to the overall concept;

> CA
> *"Thanks, do you often teach the historical context of the mole concept?"*
> DrL
> *"What do you mean by that, or going back who decided it or what?"*
> *CA*
> *"Yes, starting from the Greek [sic] word mole, did your students know where it came from, and what it means?"*
> DrL
> *"No, No, I never taught them that."*
> *CA*
> *"Is it because the system did not require that?"*
> DrL
> *"Yes, it's not a requirement, and also I don't think it adds more to the gravitas of the concept, because something that happened so long-ago students now are certainly not interested in facts like that, they are more interested in the applications of it."*

The above exchanges confirm that Dr Luke is interested only in the procedural method of teaching the mole. We will examine the field activities latter. So, it is mostly procedural teaching and learning as confirmed by previous studies cited above and the students did not know about millimoles, which is alright considering that it is procedural method. This would be the same trend in both University of Manchester and Oxford University confirming previous research;

> *CA*
> *"What type of institution did you attend yourself; you just mentioned London Met during your BSc. Was that the only one you attended?"*
> DrL
> *"No, no, I attended the University of Manchester for my degree and my PhD, I did some post doctoral work there as well, and then I moved to Oxford and did some post doctoral work there as well and became a teaching fellow."*

He used both summative and formative assessment methods to assess the mole concept, but with more summative inclination.

> CA
> *How did you assess the module, was coursework or tests or did you use both etc?*
> *DrL*
> *"It would be in a mini test, in a small percentage test" CA*
> *"And the test would be mostly like a summative assessment where you ticked the right answers, that sort of thing"?*
> *DrL*
> *"Yes, mostly yes it would be the opportunity to do summative tests as well, so sample papers and tutorial questions to allow them to work out problems before they have an assessment on it."*

He had used pictures to illustrate the mole, but not to the extent of calling it conceptual teaching.

7.3.6 Dr Paul (DrP);

Dr Paul could not attend the one-to-one interview via WebLearn, so he sent his responses to the questions via email. Paul is chemistry lecturer with more than 30 years of lecturing experience with the Open University, he also taught foundation level maths, physics, biosciences, earth sciences, communication skills. He is white, English and about sixty years old and had taught the mole concept to university foundation courses, PGCE chemistry teachers and all post 18 years.

He confirmed what Dr Luke had said, that lecturers have the freedom to teach the mole concept with much flexibility as you wish, "*provided the concept is learnt, understood, appreciated, and can be applied correctly*."

Dr Paul agreed in part, for teaching the historical context of the mole, which was in contrast to Dr Luke's position. This points to the fact that Dr Paul instructs using both methods of teaching the mole concept (procedural and conceptual);

> CA
> *"Do you teach the historical context and origin of the mole"?*
> *DrP*
> *In part, yes, but depends on the group of students. I went into a little of science history generally with my PGCE students. Otherwise, the mole was introduced as the chemical unit of quantity; the coefficients in a correctly balanced chemical equation showing the mole ratio, and from there, reacting masses and products can be deduced.* See Q14.

He also uses analogies to bring the mole concept alive and to relate it to the students' experiences, which are all elements of conceptual teaching, see evidence for procedural teaching below; in the following exchanges;

> CA
> *"In teaching how to solve mole concept problems, do you rely mostly on the use of mole concept formulas, or do you use other methods?"*
> *DrP*
> *"After defining the mole as a unit of quantity, it was best just to go straight into worked examples which generally simplified the ideas. This requires a certain maths ability to understand powers of 10, fractions, ratios, proportions, and decimals.*
> *This is all key material; you don't want a medic or similar giving you an incorrect dose. Does happen."*

Apart from teaching the historical context of the mole, another evidence for Dr

Paul’s conceptual teaching is his use of analogies, one example is when he wrote that one mole of water weighs 18 grams, which I will add that, 1 mole of water is18ml since 1ml weighs 1g;

> Dr P
> *“One analogy I have used, not so much in calculations, but to illustrate the magnitude of one mole and the smallness of atoms and molecules. One mole of anything contains 6 x 10*23 identical anything’s. Mini motor cars if you want a mole of minis!!!*
> *To illustrate the smallness of matter, one mole of water is 18gms, about a teaspoon. This contains 6.02 x 10*23 water molecules. This is 100,000 greater than all the grains of sand on the Earth. So, you would need every grain of sand on hundred thousand Earths just to have same number of water molecules in one teaspoon of water. (By the way, atoms/molecules are huge compared to the particles that make them up. If an atom was scaled up to size of the Earth, the central nucleus, where the atom's mass is, would be size of a football).”*

Dr Paul’s vast lecturing experiences meant that he can use his own conceptual method which includes valuable analogies, see below for some of his areas of lecturing;

> DrP
> *“Do you mean where have I taught or where was I educated?”*
> *“Virtually all my academic career has been in the University sector, Post Grad at Uni of Sussex, Uni of Herts, Open Uni, and after retirement, p/t at London Met, Uni of East London and Uni of London, Queen Mary College.”*

He used mainly formative assessment in assessing the mole concept and confirmed that he learnt the mole concept in a totally different way from the how he is teaching it today;

> CA
> *“How did you learn the mole concept yourself and is it different from the way you are teaching it now?”*
> *DrP*
> *“Very different now. At school it was then called the gram-molecule, and from my poor memory was introduced via Boyle's Gas Laws. However, it was not really a big thing, and only when I worked in an analytical lab, pre-University, one of my peer group colleagues showed and explained ideas and calculations in words of one syllable. i.e. do this, do that, divide by this., etc. (I was taught how to solve algebraic*

equations at school similarly, not from the teacher but the boy who sat next to me. He explained method in schoolboy language). We did run some London Met tuts [tutorials] that way with good, more advanced students helping in tutorials.). Seemed to work ok but wasn't continued."

From the above, we can also see how peer influences can construct mole concept learners' experiences in the Bourdieurian field, especially where students explain to others, what they know.

7.3.7 Dr Kan (DrK);

Dr Kan is chemistry/organic chemistry and biochemistry lecturer in the institution where this study is taking place, he is English, with Pakistani heritage. Dr Kan stated that he does not directly teach the mole concept, but he does cross teaching of the same students with Dr Paul and helps the students in tutorials with their mole concept problems but not in lectures, helping majority non-traditional science students (foundation year, access to science, BTEC, etc) with most from deprived backgrounds. He uses mostly procedural methods to help the students. His own educational background shows he attended mostly second tier universities.

CA
"What type of institution did you attend yourself?"
DrK
"My background is, I did an undergraduate MSc at Kings College and then I did my PhD at Birmingham University."

They assess learners work mostly summatively through mini test, but also some formative assessment through coursework. He describes himself as middle class, with working class parents.

7.3.8 Focus group participants;

We had five participants in the focus group and due to time factors, they were asked to follow the guide of a series of questions displayed on the screen to tell their narratives.

7.3.9 John (JN);

John was one of the focus group participants, he is a first year BSc chemistry mature student, age range 36-40 years and gained access through a foundation year general science course. He is white and from England. His participation is significant, because he is the only chemistry student in the study, but however contributed a significant inside on how physicist think, because he first heard about the mole concept in a physics lesson as he described it below;

> JN
> *"So, basically, I came across mole, I believe in 7th grade, it wasn't actually chemistry, it was physics and as much as I remember from that period, it was you know, how many particles in 12 grams of carbon^{12} isotope I mean, that was like in high school level,*
> *And basically, I mean, when I think about mole, the first thing that comes to my mind is mass over molar mass, so and then we know about the number of particles in such amount of substance,"*

The physics class dwelled on the Avogadro's definition by highlighting the number of particles 12 grams of carbon^{12}, which is exactly 1 mole. This is given by applying Avogadro's constant (6.02×10^{23}).

He also indicated a preference to procedural teaching and learning of the mole, when he talked of concentration being moles over volume;

> JN
> *"And I mean the other thing that came across when we talk of the mole, was when we talk about concentration, so we can actually calculate molarity based on the number of moles over the volume, eh pretty much that's what I know about the mole so far, from my earlier studies and foundation year,"*

John has a strong habitus, because his parents are teachers, so he had great cultural capital, with his parental influence orienting him towards higher education;

> *"Basically, my parents yes, they are all teachers and they never really pushed me towards science, but they always pushed me towards higher education,"*

He had a first degree in hospitality management and worked for 15 years before coming back to change course towards science (chemistry). He is a good student with personal agency and likes going to concerts, museums, and Galleries.

7.3.10 Mary (MY);

Mary is a 36-year-old mature student, doing foundation year in sports therapy, she is white and from Poland. She rated her mole concept understanding as 3 out of 5. Her hobby is watching the National Geographic television channel. She first heard about the mole concept in high school while in her native Poland. Sports therapy appealed to her because of her love of sports, so she was inspired after sustaining an injury during a sporting activity. She had never solved any mole concept problems and enjoy going to concerts, theatre, and museums.

7.3.11 Jacob (JB);

Jacob is a foundation year human nutrition student, who rated his mole concept understanding as 3 out of 5, who came across mole concept in high school. He cannot remember if he was taught the historical context of the mole, because it was quite a long time ago. He was taught procedurally and cannot remember being taught other methods of dealing with mole concept problems. He cannot equally remember being taught any mole concept analogies.

He had peer influences in deciding to do human nutrition, because his elder brother is doing the same course, at the same university, which greatly impacted on his decision to enrol;

> JB
> *"In terms my current course of study, ehm, I suppose the foundation year counts as an access course of some means because I couldn't go straight to the dietetics 'course that I would have liked to go on to because of course London Met uni is the only university in the country to offer such a pathway, so I am quite pleased,*
> *And also, the fact that my older brother is also on the same course, so that did influence my decision."*

His father is an unskilled engineer, while the mother is a carer, and he was influenced by someone in an insurance company where he used to work and by his own personal agency.

7.3.12 Oprah (OH);

Oprah is a level 4 BSc pharmaceutical science student, age range 30-45 years. She is a black African student originally from Zimbabwe. Her father is an engineer, while her mother is a public health civil servant. She gained access into her course through a foundation year, where she first learnt about the mole, after having a huge gap of about 10 to 15 years from education. She was taught the procedural method of solving mole concept problems. Her work in clinical trials research is crucial in her science interest. It was her own personal agency that leads her into doing the course.

7.3.13 James (JS)

James is a level 3 foundation year Sports Therapy non-traditional student. He is mixed race English, from the lower social class group, as his parents' occupations are Carer/Cleaning and construction workers.

His hobbies are gym workouts and photography. He first encountered the mole in FE and rated his mole understanding as 3 out of 5.

7.4 Analysis of Habitus;

7.4.1 First Degree Socialisation (Primary Habitus);

Gisela's narrative is one of the rear examples where home socialisation (primary habitus) has direct impact on her science and mole concept experiences. Her mother has a doctorate in pharmacology and works for the German government and did not only influence her university course, but actually instructed her on the mole concept, including millimoles, as she made the following statement when asked if she had ever used the mole in practical terms;

> GA
> *"That depends if you mean in conversations with my mother in practical terms, yeah, then actually to put it in practice in a laboratory, No."*
> *"I think my parents definitely influenced the choice of my current course, from their occupation and from what they have laid around because that's the kind of environment that I have been exposed to."*

This home socialisation specific to the mole concept, is unique to Gisela and points to the social osmosis taking place within the family especially in an affluent family like hers with huge cultural capital indicated in this stamen when asked if she was not from an economically disadvantaged family, she responded as follows;

> GA
> *"No, not really but, it's only the materials, only the books, if I didn't pick the books, I would never learn about this, I would never have chosen biomedical science."*

This is in sharp contrast to Isa, who had very little economic capital as he originated from Somalia and had only heard about the mole when he started an access to science course. Nevertheless, one can still draw parallels between Isa and Gisela as both have similar cultural capital influences through science books lying around as revealed in this statement;

> GA
> *"The books I am using at the moment are from my brothers and sisters, who have finished university, they also did science course, specialising in biology, and I have a close library in my community where I can just pop in and get a book."*

These family influences are crucial in determining affinity for science in general and mole concept experiences, Isa is one of the participants with an above average mole concept understanding, rating himself 4 out of 5 which I agreed with, as he gave the clearest definition and explanation of what the mole is all about, in this statement.

> GA
> *"…well in general, mole is just a unite, we use it to measure chemical values, or chemical amounts and we know that one mole of any chemical is actually equivalent to this value of 6.02 times ten to the power of 23, and that is Avogadro's constant number."*

Both Emma [PhD pharmacology student] and Drita [biomedical science foundation year student from Albania] have similar rich habitus' as Gisela, as all had attended private schools or had private tuition at some point. Emma with a software engineer parent went to a private primary school, but Drita had private tuition in many subjects as she stated here;

> DA
> *"Yes, especially for sciences such as physics, biology I have always had books, and also for literature because in Albania, I don't know how literature is done here in England because we had to read like ten books every academic year, so I have always had a library full of books and science books when I went to secondary school."*

We can see the influence of books here in the above four narratives, especially science books in influencing the participants' interest in science and thus mole concept understanding, even Isa with limited economic capital, had science books influences and some form of private tuition. So, the provision of home mini libraries is crucial in shaping habits, educational and science related habits and habitus. The existence of books lying around is considered symbolic capital as it is clear that all forms of capital are symbolic capital (James, 2011).

Drita's parents are local businesspeople, considered middle class; she already qualified to enter medical school in Albania, but had to travel to the UK.

John [1st year BSc chemistry student] had **a higher habitus and capital as** parental influences **are visible, even though** not directly related to mole concept as such, but rather towards HE as a whole because both of his parents are teachers (higher capital) as he indicated here in answering a question on who influenced his decision to study his current course;

> *"Basically, my parents yes, they are all teachers and they never really pushed me towards science, but they always pushed me towards higher education,"*

Forms of capital depends on habitus (Burnell, 2015), and John had superior habitus because of his parents higher cultural and economic capital. So, it is natural to see their involment in encouraging and influencing his HE choices. Boudieu (1986) pointed out how forms of capital are responsible for determining the instruments of society that creates social order. John's cultural capital is having a positive impact on his life choices, as his parents are taking an active role in his HE and would influence the way he experiences learning in general, and the mole in particular.

Jacob [foundation year human nutrition student] was influenced by his elder brother who is doing the same course at the same institution as he confirmed in this statement in answering the same question above about influences towards their current course;

> *"…and also, the fact that my older brother is also on the same course, so that did influence my decision."*

Oprah [level 4 BSc pharmaceutical science student], even though she was influenced by her work in clinical research in the UK, but her initial and wider influence was from her grandmother who is a traditional healer. Her goal now is to study pharmaceutical science with the aim of developing those traditional remedies from her grandmother, that intention was clear in this statement;

> *"…she knew all the plants, how to mix things, she did pass some of the information and it will be interesting to see whether when I do my drugs discovery modules, whether I will be able to kind of link what I know from my most practiced tradition to actually ehm, ehm"*

Even though she was clear that her parents did not influence her course selection and that it was her own personal agency, nevertheless one can see the grandmothers' indirect influence.

From all the above student participants, we can see how family osmosis or interactions shaped and influence participants' interest in science and their mole concept experiences. For example, Gisela first learned about the mole from her mother who is a Doctor of Pharmacology, she also learned about millimoles from her. This is direct cultural capital and habitus influence. John had an indirect influence through his rich habitus and superior capital that had an impact on his HE choice. Primary habitus is second nature (Bourdieu, 1990). Educational achievement is a vital cultural symbol of middle-class identity and a symbol that allows access to other forms of symbolic capitals, including economic status and occupation (Manstead, 2018). The difference in parental educational attainment (cultural capital), and social roles (social capital) which are the outcome of a rich habitus

(Burnell, 2015), between higher-class and lower-class science students, has an influence in their experiences. Symbolic capitals such as books in mini libraries or 'lying around', has a great impact on students' educational experiences in general and the mole concept in particular. Some students from low socio-economic background, with low social and economic capital like Isa, access formal and HE from a disadvantage. According to Bourdieu (1990), HE (field) characteristics or norms are more familiar to higher-class science students, than the lower-class, because like "fish in water" they are more in tune with the HE culture from their habitus. It is thanks to the porous nature of the field (Stahl, 2015), which enabled changes in the educational field to allow access to HE through different routes, otherwise students like Isa, would never have had the opportunity to access HE. Isa's mole concept experience is as a result of HE changes to address equality of access. He had the opportunity to study biomedical sciences due to access/foundation course. The same changes can be made to introduce mole in schools (at UK KS2 level).

7.4.2 Second degree socialisation (secondary habitus);

According to Papapolydorou (2016), the advantages of primary socialisation in terms students' encouragements and support from parents are crucial in the field of education. What was also important for Gisela, Emma and Drita was that their families had both economic and cultural capital which enables them to provide private education or tuition including mini libraries at home which enriches not only their learning experiences, but their Higher Education (HE) aspirations as well.

> ***Gisela:*** *"I think that was in chemistry, in my boarding school in Germany. It must have been around two thousand and thirteen."*
> *"I was part of a boarding school, so I lived at the school and only saw my parents during weekends, so we didn't really talk too much about*

school or the concept or maths or those kinds of topics."
***Emma:** "Ehh! Well, for primary school, I went to a private school and then I moved into a comprehensive secondary, ehm, and my parents and family were very supportive generally and ehm,"*
***Drita:** "Yes, I had private tuition since I was like in my first grade for maths, for language and for English and when I went into secondary, I had private tuition for Biology, chemistry, maths and like for all those other subjects, I always had private tuition."*

Middle-class advantages offer easy HE accesses, smooth participation and certainly better outcomes, even as it is stated that, field characteristics are more familiar to middle-class students (Bourdieu, 1990). The above three middle-class students would also demonstrate more social capital which will enable them to interact more with both lecturers and peers to improve on their mole concept experiences (Warin, 2016). For example, Emma was influenced by her lecturer (Dr Kan) who also took part in this study, to do a PhD and he is currently her supervisor. She now uses the millimoles often.

***Emma**: "Ahh, well, having done pharmacology for already for the previous 3 years, I worked with DrK during my 3rd year project, and he is now my PhD supervisor, so it was mostly his influence, I would say, that's why I am doing the course now."*
CA
"Have you heard of millimoles before?"
"Yes, that's the unit I am using most of the time when I am testing compounds."

Millimole is a mole divided a thousand times, similar to the millimetre, which is a meter divided a thousand times.

Drita also had close field interactions with teachers and peers as she stated here;

***Drita**: "Yeah, for all the class, especially during our last year that we have to work more with our desk, the teacher will always give us extra materials especially in literature which was one of the hardest subjects was literature, where we had to work with lots of pass papers, analysing poetry, or fragments from different books and also in maths, because maths was the hardest, so basically in maths and literature we had a lot of extra papers."*

This type of teacher-student interactions will always help to ground the students' understanding of the material under investigation. Gisela equally had huge field influences as revealed by the following statements;

> ***Gisela*** *"…I had a lot of mentors and tutors in the boarding school that I was at, who were with us twenty-four-seven, so there was a lot of help there that was basically substituted our parents, I am not sure how you can put that into your questionnaire, I am very sorry."*
> *"Yes, they did help, very well, their science department is actually well developed, they had a lot of equipment, they had a lot of good teachers, a lot of good courses, I think that definitely influenced me in a way, just by the things that they were offering, not so much by the way that motivation was happening, but more the equipment that were there and the teachers, the way that they were teaching."*

Gisela's private boarding school experience is as a result of her rich habitus and capital. Her parents could afford the cost of her boarding school, and the school is her secondary habitus. The relationship between habitus, field, and capital, produce social practice (Bourdieu, 1984, p. 101). There is therefore a direct link between primary and secondary habitus or field.

These are all field influences that determine how students including mole concept students experience teaching and learning, which confirms the assertion that 'school /university structuring experiences, is governed by the habitus acquired in the family' which includes; educational standards and HE awareness, social confidence and entitlement consciousness (Bourdieu, 1973). However, Isa from an economically deprived background had a totally different field experience of the mole, which came far later in his life as he had a long gap in his education. He first learned about the mole during an access to science course at a local college;

> ***Isa:*** *"I heard about the mole concept when I joined the access to science, a year before, so say, two years before, in a study back, because I had a gap year, because my knowledge at secondary school wasn't that great. I think I have that memory in my hand and think I learnt a lot in the mole concept in access to science, so this is to say I have quite an understanding, during those pass two years."*

Isa will have to operate or compete in the same institution with the others, as different habitus's does exists in the same field (Reay, 1998). It is also stated that, the capacity to invest in and profit from education are not always equal (Bourdieu, 1986), but by the look of things, Isa is coping well, and even rated his own mole concept understanding of 4 out of 5, which I totally agree with. It is stated that, 'the field is porous and thus subject to modification (Stahl, 2015), therefore any changes towards addressing inequalities should be done in the education field. Isa's experience is replicated by most of the other students from economically deprived backgrounds with the usual characteristics of gaining access to HE through access courses. The type and quality of the educational establishment (field), determines how science students experience the mole concept i.e., different tiers of universities (see university stratifications above). But the porous concept of the field may permit progressive change in education (Bathmaker, 2015), which may mean the reintroduction of the conceptual teaching and learning of the mole concept. The mole can be taught conceptually even in schools, same as the other units (metric) of measurements. This is what this study will be proposing.

7.4.3 Field Operators/Actors Input;

Second degree habitus (secondary habitus) takes place in the field, it is field socialisation involving different habitus's and will thus influence the way students think (Reay, 1998). The field is also where educational changes may take place because it is thought to be porous (Bathmaker, 2015). It is therefore important to examine some field actors in order to confirm or dismiss previous studies and to gauge students' mole concept experiences form the standpoint of those who deliver it. The main idea was to increase variation by recruiting a wide range of participant with the tendency of going deep rather than wide (Cousin, 2009; Gobo, 2006).

The questions asked to the science lecturers were therefore different from those of the student participants, for example; questions concerning if they taught the historical context and any of mole concept analogies, were designed to investigate if they teach conceptual methods, otherwise according to research they teach the mole concept procedurally as it less time consuming and easy for teachers' accountability (Chiu & Chang, 2005).

This response from Dr Luke about the types of students he lectures the mole concept to, indicates the importance of the concept and the fact that it is socially constructed within the science community;

> ***Dr Luke**: "It was a very diverse and different types of students in the first year's group that we have in the first year, so the first-year module that I taught it on, included all of the biology students as well as the chemistry students and also pharmaceutical science, forensics science and pharmacology etc, so every single first year between the bio sciences and the CPS cluster, would have been in the lecture."*
> *"So that gives you a range of different groups that are in the class, so there were mature students, males, females, different ethnicity, races, different disabilities as well, so it was a very broad range of people in the class."*

Dr Luke had post-doctoral experiences in both Oxford and Manchester universities, which are all first and second tiers institutions, so his narrative gives us an idea of what is taking place in those institutions as well.

> *Dr Luke: "…I attended the University of Manchester for my degree and my PhD, I did some post- doctoral work there as well, and then I moved to Oxford and did some post-doctoral work there as well and became a teaching fellow."*

He does not see the importance of teaching the historical context of the mole and indicated that in these responses;

> *Dr Luke: "No, No, I never taught them that."*
> *"… It is not a requirement, and also I don't think it adds more to the gravitas of the concept, because something that happened so long-ago students now are certainly not interested in facts like that, they are more interested in the applications of it."*
> *CA: "Do you think that, if the students know that the mole means a heap, like a heap of sand or that sort of thing, if they knew that information, would that have benefited their conceptual understanding?"*
> *Dr Luke: "No, I don't think so."*

The importance of teaching the historical context of the mole is to help the learners create their own mental picture of the mole, for example most students don't know that the word "mole" in Latin means "heap", like a heap of sand which may start to relate the subject to the students' experience leading to conceptual learning which is also termed meaningful learning (Ausubel, 2000). The historical context of the mole may also seem irrelevant to most science lecturers who teach procedurally because formula methods are less time consuming and easy for accountability (Chiu & Chang, 2005). The evidence for teaching procedurally is confirmed by this statement;

> *Dr Luke: "… I use to relate it into yields of reactions; we went through moles as part of that then working out percentage yields, so it's like related to one of the lab classes they get on their Thursday afternoon module, so it's like linking two modules together to show how the theory would help them with the actual practical aspects of working in the lab."*

Mole concept historical teaching would have also help to separate the two views that governs the definition of the mole i.e. the chemists view depicted by Ostwald's (1900) definition and Avogadro's which focuses on the number of particles within the mole (Kolb, 1978), including the historical linking of the Ostwald's definition and Avogadro's number / constant (Hawthorne, 1973).

The lack of mole concept teaching analogies is also a strong indication that, it is mainly procedural teaching, with no conceptual input. When asked if he sometimes uses analogies to illustrate the mole, he answered thus;

> *Dr Luke: "I use pictures of the moles in my lecture's slides, to show them how to work out a limiting reagent in a reaction, so I relate it to the size of the mole and said you can't obviously produce any more product than the amount of moles that you start with, so that related to the size of the mole that was on the picture. So then we looked at which mole was bigger and then we decided that, that was the limiting reagent."*

The assessment methods used in assessing the students' mole concept progress in the field was also examined, especially as some studies have indicated that summative assessment is the main method used by instructors to assess the mole concept (Cervellati, et al., 1982). It was clear from the narratives of the field operators (lecturers), that summative assessment was the predominant method, with some amount of formative assessment from laboratory coursework to online assessment work which includes instant feedbacks. This is Dr Luke's response to the assessment question;

> CA: "How did you assess the module, was it coursework or tests or did you use both etc?" Dr Luke: "It would be in a mini test, in a small percentage test."
> CA: "And the test would be mostly like a summative assessment where you ticked the right answers, that sort of thing?"
> Dr Luke: "Yes, mostly yes it would be the opportunity to do summative tests as well, so sample papers and tutorial questions to allow them to work out problems before they have an assessment on it."

Dr Paul presents a slightly different picture in the field, from Dr Luke's experience, because he appears to teach the mole both procedurally and conceptually, as he admitted to teaching the historical context of the mole and using analogies to bring the mole to the students' experiences;

> *CA - "Do you teach the historical context and origin of the mole?"*
> *Dr Paul: "In part, yes, but depends on the group of students. I went into a little of science history generally with my PGCE students. Otherwise,*

the mole was introduced as the chemical unit of quantity; the coefficients in a correctly balanced chemical equation showing the mole ratio, and from there, reacting masses and products can be deduced…"

Even though he did not highlight the origin of the Greek word mole, meaning "heap", but he made a good attempt. He also uses analogies to illustrate the mole, which indicates that he teaches conceptually. One of the analogies he uses refers to one mole of water weighing eighteen grams, which can be improved to 18ml since 1ml of water weighs 1g. This is what he has to say about using analogies;

Dr Paul: "One analogy I have used, not so much in calculations, but to illustrate the magnitude of one mole and the smallness of atoms and molecules.
*One mole of anything contains 6 x 10*23 identical anything. Mini motor cars if you want a mole of minis!!!*
*To illustrate the smallness of matter, one mole of water is 18gms, about a teaspoon. This contains 6 x 10*23 water molecules. This is 100,000 greater than all the grains of sand on the Earth. So, you would need every grain of sand on hundred thousand Earths just to have same number of water molecules in one teaspoon of water. (By the way, atoms/molecules are huge compared to the particles that make them up. If an atom was scaled up to size of the Earth, the central nucleus, where the atom's mass is, would be size of a football)".*

Dr Pauls' long teaching career of 30 years and different types of learners he has engaged with, must have contributed to his conceptual reasoning development, which is reflected in this statement;

Dr Paul: "Do you mean where have I taught or where was I educated?"
"Virtually all my academic career has been in the University sector, Post Grad at University of Sussex, University of Herts, Open University, and after retirement, p/t at London Met, University of East London and University of London, Queen Mary College."

On mole concept assessment, he indicated summative assessment if it takes place, confirming other studies (Cervellati, et al., 1982), but declared that the mole is not often assessed; Assessments not generally done at universities and courses requiring A level or equivalent entry, but might require reinforcement in practical classes, i.e., as in answer to Q9. At OU, no direct Q on moles, but calculations involving moles/ gas volumes etc could be part of longer questions. Work based around the concept.

For instance, burning natural gas: CH4 + 2O2 = CO2 + 2H2O. Energy is given out to cook, or heat, or power motor vehicles. The Chemist uses the unit of Joules per mole of methane, whereas a physicist uses Joules per kg of methane. This is a lot more methane. Resulting in quite different answer, one mole methane is only 0.016 kg.

From the above response, we can still see his inclination towards conceptual reasoning, which will add to science students' mole concept experiences.

Dr Luke could not remember how he was taught the mole concept, but I would guess he was taught procedurally as indicated by previous (Surif, et al., 2012; Tullberg, et al., 1994). This is in contrast to Dr Paul who remembered how he was taught and declared that it was very different from;

> *Dr Paul: "Very different now. At school it was then called the gram-molecule, and from my poor memory was introduced via Boyle's Gas Laws. However, it was not really a big thing, and only when I worked in an analytical lab, pre-University, one of my peer group colleagues showed and explained ideas and calculations in words of one syllable. i.e., do this, do that, divide by this., etc."*
> *"(I was taught how to solve algebraic equations at school similarly, not from the teacher but the boy who sat next to me. He explained method in schoolboy language). We did run some London Met tuts that way with good, more advanced students helping in tutorials.). Seemed to work ok but wasn't continued."*

His explanation how he learnt the mole concept also includes peer interactions and shows how vital it is for students to learn from each other. He also confirmed how he learned the mole procedurally by applying his mathematic ability (algebraic skills). This also highlights the fact that learners who not proficient in mathematics, or have a mathematics phobia, will be put-off if teaching is done only procedurally. He further added to his response by stating this;

> *Dr Paul: "I had been thinking, "how was I taught it", and realised I hadn't been, it was picked up in bits and pieces along the way.*
> *When I was at school the mole was not a topic as such. We worked in equivalent weights and Normality. In this way all reactions became 1 to 1 so reaction (mole) coefficients became unnecessary in calculations. The reacting weight, (we now called mass), of material was divided prior to process according to how it reacted, so that no factors were involved in subsequent calculations."*
> *Nowadays by direct use of the mole any reacting factor enters the calculation, solutions are made up using the mole, (molar mass) and are called molar, thus a 1M solution of sulphuric acid contains 98gm of sulphuric acid per litre. If we wanted to make an allowance for having 2 replaceable H atoms, we could still weigh out 49 gm per litre, but now solution would be labelled 0.5M The factor of 2 has to be taken into account in any subsequent calculation. Similarly, with potassium permanganate, a 1M solution would contain 158 gm per litre. Again, in practise, we could take the factor of 5 into account, and weigh out 31.6gm per litre, the solution would be labelled 0.2M, and reaction factor of 5 taken into account later, in any calculation.*
> *You can see that the mole concept when I was at school was unimportant because it wasn't used directly as it is now. All analytical processes were 1 to 1 and factor taken into account in original weighing. Now factors appear in the calculation, but at least you know how much material is in the reagents irrespective of subsequent reaction. In the days of Normality and equivalent weights you needed to know in advance what the reaction stoichiometry (ratio) was in order to produce the 'Normal' solutions.*

The above responses from Dr Paul shows how time has changed the field of science education in the context of the mole, with mostly procedural teaching and learning, it also reveals how confusing it has become to both teachers and students and even if student may figure out the mole, but some may still find the calculations difficult;

Dr Paul: "Students may find it challenging to start, but once you start giving plenty of examples in tutorials, and lab classes, confidence grow, and most achieving students find it less demanding than some areas. They still may find calculations difficult, however, even if the mole part is ok."

Dr Kan had similar field experiences like Dr Luke but only differs in the area of mole concept assessment where he uses both summative and formative assessment methods, leaning more to formative assessment through the use of institutional software;

Dr Kan*: "To add one more thing, when M-J does teach the mole concept, we do have the partnership called learning science where we go through a step by step way of how to work out the number of moles and then we got worksheets that they provide, that actually randomise the numbers, then they can work through at their own time and then get instant feedback from doing these, so if they going wrong, they wouldn't get it wrong at the end because the worksheets wouldn't let them continue, so they would carry on doing it and they get feedback."*

"So for example if it say what's the number of moles of X, if they don't get it right, then they'll get instant feedback from the worksheet and then they can do it again until they get the right answer. So we are giving them lots of examples as well, I think that are key to the students.
So when we teach the mole concept, that's taught not only to chemistry students but to anyone who is doing one of the wet science, any of biology subjects, any of the chemistry and pharmacology related subjects."

The above indicates the importance of combining methods, in this case summative and formative assessment methods to achieve a desired goal; the same should be done for conceptual and procedural methods of teaching and learning the mole concept. On the issue of teaching the millimole, Dr Kan responded that, not at the lower levels, see below;

Dr Kan: "We don't tell them directly, but in term of what you just said, we do use Avogadro's number to work out the number of particles or number of molecules using the mole concept, so we do, do that at level four with the students.

At level four like you said with the chemists, we go over the mole as a mole as well and then at level 6 where I do a practical, where the students are put into a situation with a pharmaceutical company where they have to do a synthesis, two different ways to make the same compound, they are told they had to consider the idea of working on small scale and then consider when you are making your own large scale industrial applications, so they understand the concept of going from millimolar scale to kilogram ton scale at level six, that's where I introduce that bit there."

Instructors who teach procedurally will not want to introduce millimoles at an earlier stage, but to teach it conceptually, is not only possible, but advantageous. The equivalent argument for not teaching it early is similar to refusing to teach students about the "millimetre" or "gram" until later in an advance stage of their studies, simply because they will only have to deal with a "meter" or "kilogramme" at their current levels. This is because instructors find it less time consuming and easy accountability, to teach procedurally (Chiu & Chang, 2005).

This study will be proposing the teaching of the mole conceptually in schools, together with the other SI units of measurements like; Length – meter (m), Mass – kilogram (kg), Time – seconds (s), Amount of substance – mole (mole) etc.

7.5 Mole Conceptual and Procedural Experiences;

Most of the student participants if not all, declared that they were not taught the historical context of the mole and none had a clear experience of mole analogies. This indicates and confirms their other responses that they were only taught procedurally.

On millimoles, only Gisela [mother with PhD pharmacology] and Emma [PhD pharmaceutical science student], knew about it. Gisela learned about it from her mother through family socialisation (primary habitus) and Emma through her advance studies. Her supervisor Dr Kan declared above that he only teaches milimoles to higher level students. Both Emma and Gisela had strong habitus', higher capital (economic, cultural and social), which gave them a good field advantage. The students from low socio- economic backgrounds did not know about millimoles, hence the inequality. But if the mole is taught in schools like the other SI units, this inequality will not exist. Below are some of the responses from Isa and Drita, when asked about millimoles;

> *CA: "So, have you ever heard of millimoles before?" Isa: "No." Drita: "Yeah". "Can you tell me the difference between moles and millimoles?" "Is it the volume over number of moles right?"*

Teaching the historical context of the mole, would have meant the instructor separating the two views of the mole i.e. the chemist, epitomised by Ostwald's (1900) definition of amount of substance and the physicist, by Avogadro's constant (Kolb, 1978), even as it is reported that Hawthone identified a link between Ostwald's definition and Avogadro's number (Hawthorne, 1973). To put it into context, if a glass full of rice is a mole (because rice is uncountable noun), then chemist (Ostwald) is interested in the rice in the glass as a whole, but the physicist (Avogadro) is interested in the number of grains of rice in the class, hence he developed a mathematics constant (6.02×10^{23}) to count them. This is why the first time John heard about the mole, was in a physics class and emphasis on the particles in a mole;

> ***John**: "So, basically, I came across mole, I believe in 7th grade, it wasn't actually chemistry, it was physics and as much as I remember from that period, it was you know, how many **particles in 12 grams of carbon^{12}** isotope I mean, that was like in high school level."*
> *"And basically, I mean, when I think about mole, the first thing that comes to my mind is mass over molar mass, so and then we know about the **number of particles in such amount of substance.**"*

Lumping the two views together is not only confusing to the learners, but to the instructors as well (Tullberg, et al., 1994). For example, Dr Luke did not see the need for teaching the historical context of the mole.

Emma [PhD student] was introduced to the Avogadro's number, but then told to forget about it;

> ***Emma**: "Emm, well "A" levels, I would say they didn't really go into what Avogadro's number was, but they just said, it's this number, it's to do with carbon^{12}, just forget about it."*

They were right to tell her to forget about the Avogadro's number, because no one actually uses it in practical terms, for example people are more interested in a glass of rice as a whole and not the number of grains in the glass, or the number of bricks that would build a house (if we consider a brick as a mole) and not the number of sand particles.

The field is porous therefore susceptible to educational change (Bathmaker, 2015), habitus may be difficult to change, but institutional change to accommodate conceptual method of teaching the mole will greatly improve second degree (secondary) habitus and thus the science students' mole concept experience.

7.6 Cultural reproduction in this study;

This study highlights the role of social class in shaping the mole concept experiences of science students, because the mole concept difficulties already highlighted by several studies, does not affect all science students equally. Evidence from Table 1 (see section 6.7) which shows the breakdown of the student participants demographics, shows that most lower-class students rate their mole understanding as 3 out of 5, except Isa (not his real name), with most actually below 3, while higher-class students rate their understanding as 4 & 5, except Gisela who rated herself as 1 out of 5, because she did not fully understood the word ‘concept’, but actually she was between 4 and 5. The tendency for class status to pass down the generations, is cultural reproduction, because class status is acquired through cultural capital (tastes, habits & expectations), which helps individual to have an advantage in society (Sullivan, 2002). An example of this cultural reproduction is the case of Gisela who learned about the mole and millimoles from her mother who has a doctorate in pharmacology. She also attended a private boarding school in her native Germany, where they tried to orientate her towards the arts, but because of her mother’s influence (habitus), and the science books she interacted with both in her home school (field), she opted for Biomedical science. This is an example of cultural capital being reproduced. Cultural reproduction is said to be the reproduction of educational advantages, as the theory is concerned with the connection between ‘original class membership’ and the ‘ultimate class membership’, and how this connection is negotiated by the education system. This is true for all the higher-class students, whose parents had higher academic qualifications, ranging from college diplomas to doctorate digress (Gisela, Emma, Drita, & John) (see Table 1). Sullivan (2002) stated that, Bourdieu’s work should be viewed in the context of inequalities in educational attainment based on class, as we saw above, with the higher-class science students indicating a higher-than-average mole concept understanding. While lower-class students indicated lower than average mole understanding, except in the case of Oprah, and the wider questions of class reproduction. It is said that class inequalities is legitimised by the education system (Sullivan, 2002), this is so because in the case of teaching the mole, it is said that instructors prefer the procedural method to the conceptual. Therefore, students who lack mathematical ability, are easily classed as “unable”, while those with mathematics ability can easily solve mole concept problems and arrive at the right answers, without even an average understanding of the concept involved (Chiu & Chang, 2005) but they will feel that they merit their progress. Educational success is therefore facilitated by the ownership of cultural capital and the habitus of the dominant class (Sullivan, 2002), as in the case of the higher-class participants of this study. (See Table 1). Lower-class science students like Isa, Jacob & James, in general, do not possess the same degree of habitus and cultural capital as the higher-class students, hence their limited mole concept understanding and experience, as they indicated themselves. The UK governments policy of widening participation (Boeren & James, 2017) increased the number of non-traditional students, who can now gain access into HE through non traditional routes (access courses). The science sector was attractive to them because of the job opportunities in the healthcare, food, chemical and sports industries. But the HE field is more challenging to most these students from low socioeconomic backgrounds, as compared to higher-class students, because of sociological factors (habitus, field & forms of capital). Some students enter the HE field already equipped with higher than average mole concept understanding due to what they have already acquired from both their primary and secondary habitus’. Thus, the HE field remains unequal, especially as instructors themselves can be agents of inequalities (Bourdieu, 1990). For example, instructors will prefer the procedural method of mole concept instruction which disadvantaged many students, especially non-traditional students, as the curriculum is narrowed. The capacity to invest and profit from education, is not equal (Bourdieu, 1986), because students have different social context. Stahl (2015) is of the opinion that, non-traditional students have contrasting primary habitus' of limited ideas and commonness, while higher-class students are more accustomed to not only the academic language, but the general HE culture (Burnell, 2015). Gisela was already familiar to the mole and millimoles, before HE, while most of the non-traditional students, did not. This is a perfect example of inequality in HE participation, brought about by differences in habitus & forms of capital, and perfectly reproduced. Higher-class students with superior habitus', and capital, will turn to be successful, as most already had an advantage, and their success will be seen as the result of their individual gifts, whereas for lower-class students, their failure will be attributed to the lack of ability. Therefore Bourdieu, (1990), sees educational qualifications as instruments to aid the legitimisation and reproduction of inequalities, as higher-class individuals will appear to merit their place in the social structure (Sullivan, 2002).

7.7 Summary;

In general, there is a clear divide in the mole concept experiences of the student participants from affluent and middle-class habitus' and those from less affluent and working-class. The middle-class student participants first came across the mole earlier in their academic careers (secondary/7th grades and "A" levels) as they turn out to be traditional students, while the less affluent and mostly non-traditional working-class student participants would have their first mole contact in either access or foundation courses. Few of the participants from affluent backgrounds like Gisela and Emma, knew about millimoles which was not the case with the rest. This revealed the inequalities in the field, which confirms why middle-class students are more familiar to field characteristics or norms (Bourdieu, 1990), than their working-class counterparts. It is also clear that, the capability to invest in education and benefit from it, is not all way equal (Bourdieu, 1986).

Almost all the student participants were not taught conceptually, which increases the disadvantage on the mole concept learners from less affluent backgrounds. All the participants were taught procedurally. All the science lectures participants taught the mole procedurally, at least one of them (Dr Paul), uses conceptual method of teaching the mole, including the use of analogies. All of them employed both summative and formative methods of mole assessment, with summative assessment dominance. Dr Kan uses a university software program to facilitate formative assessment of the mole.

CHAPTER 8: CONCLUSION

8.1 Introduction;

The aim of this chapter is to examine the findings and the implications of this study, which will include the contribution this research makes, towards the teaching and learning of the mole from schools (primary/KS2/2nd grade) to HE fields. Some of the limitations of the study will be addressed together with recommendations for future research. Narrative inquiry was used to examine the mole concept experiences of nine science students ranging from foundation years, BSc's to PhD, together with three chemistry lecturers with varying teaching experiences, to help answer the research question. We should equally bear in mind the fact that qualitative research differs from scientific studies in that, the principal goal is not aimed at testing theory like in scientific research, but rather to construct theory while questioning emerging ideas that shapes our principal aim (Pearson & Li, 2005). Therefore, theory is employed as a means to understand data and not limited to data mining (Webb, et al., 2017).

This study is based on the fact that the mole as a unit of measurement and exchange, is not rigid as often thought, even though it is a scientific concept. That it is not only objectively/scientifically real, but that its reality is constructed socially and therefore subject to sociological factors which are Bourdieuran (Habitus, field, and forms of capital). We agree with other researchers that, the abstract nature of the mole poses problems to all learners, including instructors, but that these problems affects lower-class learners with limited habitus' (Burnell, 2015), more than higher-class science learners who are more adapted procedurally to deal with the difficulties. That conceptual teaching and learning of the mole at an earlier stage in the academic cycle will benefit all learners.

Research Questions;

How can we understand the socio-cultural influences that shape science students' mole concept experiences?

How does the teaching methods influence the way science students' experience the mole concept?

A sub-question to the above is;

Does the mole pose the same degree of difficulty to all students from the different social classes?

Even though this study examined science students' and lecturers' mole concept experiences, but the wider aim was to deconstruct the mole, in order to uncover the inequalities embedded within its teaching and learning. The English education system harbours structural inequalities (Leathwood & Hayton, 2002; Lahiff & Gould, 2001), the science sector is not excluded. Several studies have highlighted major difficulties in the teaching and learning of the mole (Surif, et al., 2012; Tullberg, et al., 1994; Phillips, 1989; Cervellati, et al., 1982; Niaz, 1985; Larson, 1997; Chiu, 2004; Chiu & Chang, 2005) and made recommendations, some of which includes; the teaching of both methods of resolving mole concept problems which are the conceptual and procedural methods (Surif, et al., 2012). But till date, very little have been done about it, with teaching and learning still centered on the procedural method, even as revealed by this study. This mole difficulty is not experienced in equal magnitiude by science students from all social classes, such that it has resulted in huge inequalities within the science sector, leading to the exclusion of many (mostly from deprived backgrounds) from the scientific field. Those learners with personal grit who manage to scrape through with a science degree, are socially constructed to serve as local industries workers, while those with better degrees and from higher tiers universities (mostly middle-class students), serve as researchers (Walford, 1991). To address these inequalities which have resulted due to the social injustices is the wider aim of this study. Therefore, this study is proposing the conceptual teaching of the mole as a unit of measurement, in primary schools. We are proposing that it should be taught at the same time and in relation to the other (S.I) units of measurements, as a means of levelling up the science education field.

Sub-question;

Does the mole pose the same degree of difficulty to all students from the different social classes?

The bar chart (Figure 8) below summarises the answer to this sub second research question.

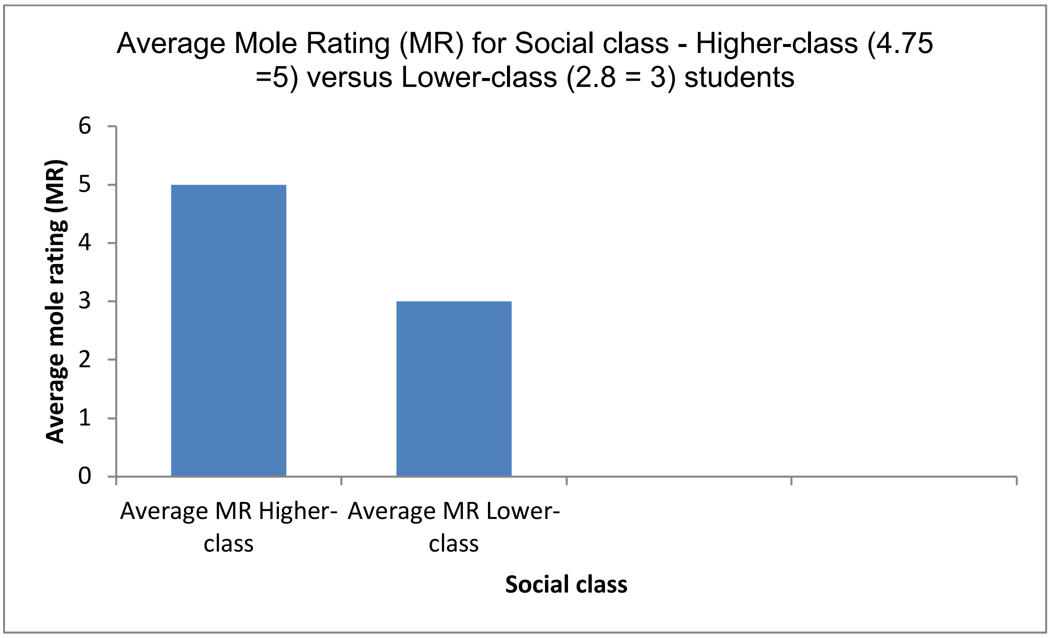

Figure 8: Average mole rating (MR) for Higher-class compared to Lower-class students participants indicating that social class is a factor in mole related experiences.

The Fig. 8 indicates that science students from the different social classes do not experience the mole difficulties in the same magnitude. Learners from the lower-class rated their mole understanding lower, as compared to higher-class learners. The chart would have shown even wider difference in their mole understanding if we had used the upper mole rating of “10”, instead of “5”.

Second research question;

The second research question was also answered from the data;

> *How does the teaching methods influence the way science students’ experience the mole concept?*

The teaching methods had a significant impact on all science students’ mole experiences. The data showed that teaching and learning was predominantly through the procedural (mathematical / formular) methods. However, there were glimpses of conceptual teaching by Dr Paul, but it was limited as to date, there no clear guidelines on how to teach the mole procedurally. The lack of conceptual teaching would mean that would mean that, several students would not have the possibility of experiencing it. Conceptual learning is meaningful learning (Ausubel, 2000)(Ausubel, 2000), therefore learners who would have had the opportuinity of experiencing the mole taught in their context, would be disadvantaged. Assessment method was predominantly summative, with all its limitations highlighted in chapter 3. Summative assessment measures only the limits of a learners’ ability, and not the power of their effort (Oates, et al., 2011), but “ability” itself is problematic, as discussed in section 4.4 Meritocracy. Dr Kan uses both summative and formative assessment and e-assessor in assessing his students. Yes, the teaching methods can significantly influence how science students experience the mole.

Socio-culture space for mole concept interaction

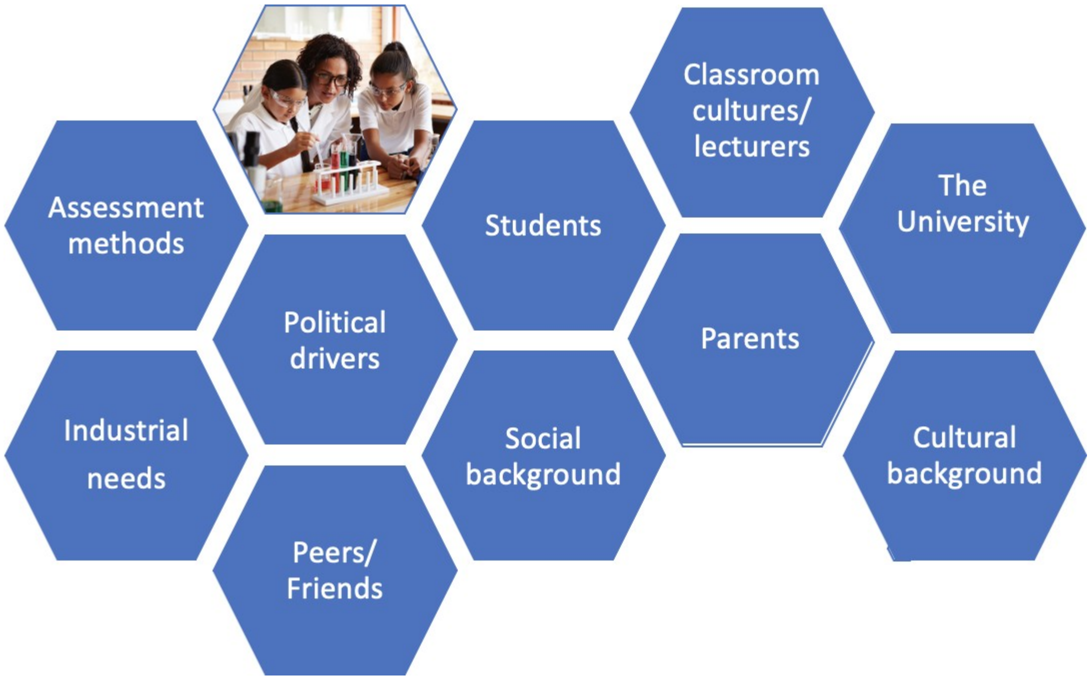

Figure 9. Socio-cultural Influences of Teaching and Learning the mole (Adapted from Heugh, 2014). It is an extension of fig. 3 but highlighting the inclusion of primary education in the Mole Concept field.

8.2 Summary of main findings;

8.2.1 The teaching and learning of the mole and social justice in this this study;

The teaching and learning of the mole can be visualised as a metaphor reflecting science wide teaching and learning. Perhaps not so much in the biological sciences, but much so in the physical sciences especially physics, where mathematics or the use of formulae predominates. The way science students experience the mole, is through its teaching and learning, which reflects inequalities within the different types of science learners (traditional and non-traditional), and correlates with their social classes (Higher-class & Lower-class). We have already highlighted the fact that, the mole challenges both instructor and learner from the literature review (Tullberg, et al., 1994)(see section 2.1.4). It is further pointed out in the literature that, the difficulties that science students encounter in dealing with the mole, is related to certain features governing the instructions, such as; curriculum content; instruction methods; and assessment (Cervellati, et al., 1982) (see section 2.1.3). I will examine these in turn, in order to highlight how the teaching and learning of the mole is situated in the context of social justice in this study. Considering the instruction methods, it was clear from the literature review that, there are two principal methods of teaching and learning the mole, which are procedural (mathematics / formula) method, and the conceptual (concrete) method (Surif, et al., 2012) (see section 2.1.5). Surif et al., (2012) also indicated that, the procedural method predominates the teaching and learning of the mole, with other studies confirming that, the procedural method is preferred, because according to some instructors, it is less time consuming, and easy for accountability (assessment) (Chiu, 2004; Chiu & Chang, 2005). So, why does the procedural (mathematical/formula) method of teaching and learning the mole, pose such a challenge to learners? This is because it poses at least, two degrees of complexity, with mathematics itself being govern by numbers which are abstract (Angello, 2017). The mole like mathematics, consist of both abstract and concrete elements as well, because atoms, molecules, ions, electrons, protons & neutrons, are all abstract quantities. The concrete element of the mole would be when scientists deal with chemical measurement on the laboratory bench.

However, before we go into the aspect of the teaching and learning of the mole that promotes inequalities, I will like to first of all highlight the abstract and concrete nature of teaching and learning mathematics, as suggested by Angello (2017). We can draw parallels with the procedural teaching and learning of the mole with mathematics, as it based on formulae manipulation. It is said that most students find it difficult to comprehend abstract mathematical content, as compared to concrete, as Angello (2017) successfully identified both aspects, and further suggested that, there is a gap between the abstract and the concrete aspects of mathematics, that must be bridged, in order to increase learners understanding through critical skills development (Angello, 2017). This is exactly the case with the mole concept, but the crucial question is, how to bridge this gap? This is where it becomes crucial, because it involves the use of sociological tools. Angello (2017) suggested that, to bridge the gap between abstract and concrete aspects of mathematics, instructors must be conscious of learners' *prior knowledge* experiences, in relation to the new mathematics content. So, what is involved in the bridging? It is recommended that bridging the gap between abstract and concrete aspects of mathematics, *scaffolding* mechanism is required. Scaffolding involves the provision of the prior knowledge that the learner can apply to the new knowledge or concept, and prior knowledge is gained through a balanced and broad curriculum. Teaching and learning the mole concept procedurally, attracts the same challenges of bridging the gap between abstract and concrete aspects of the mole, and to bridge the gap, will require a balanced and broad-based curriculum as well. So, where the sociological factors come into the teaching and learning of the mole, is in the provision of, or lack of a balanced and broad curriculum (Moore, 2017). What does a balanced and broad curriculum entails, and how is it provided? A balanced and broad curriculum involves the provision of *prior knowledge*, which is gained through a rich mixture of learning experiences (Moore, 2017).

Moore (2017) stated that, it is a well established view that, a balanced and broad curriculum is best, because it meets the needs of all learners. She added that there has been the narrowing of the curriculum because of *pressure on testing and* *assessment* in some schools, due to league tables. Teaching and learning the mole by only procedural (mathematical)l means, is a reflection of a narrowed curriculum, which is supported by the literature review, as some instructors prefer the procedural method because it is 'less time consuming, and easy for accountability' (Chiu & Chang, 2005). Teachers' accountability here is testing, mainly summative assessment. Conceptual teaching and learning of the mole, would involve broadening of the curriculum, because to form analogies or build concept maps, the learner or instructor, needs broad base prior knowledge, provided by a mixture of learning and teaching experiences. Using a formula/procedural method, is the opposite, as learners would not need much knowledge. By simply manipulating the formulae, the learner can arrive at the right conclusion, without even an average understanding of the underlying science concept (Chiu & Chang, 2005) (see section 2.1.5).

There are however, social justice implications due to the inequalities in the way some students' experience the teaching and learning of the mole. The narrowing of the curriculum by the use of mainly procedural method in the teaching and learning of the mole, introduces at least two degrees of complexity. The complexity from the abstract nature of mathematics itself introduce through the use of formulae, and the abstract nature of the mole itself, as particles such as atoms, molecules, ions, protons, electrons and neutrons are abstract. These complexities can be more challenging to certain types of students', especially those from low socioeconomic backgrounds, than students from middle-class households. Students from middle-class families, are well equipped to deal with these complexities and challenges, far more than science students from low socioeconomic backgrounds, because of their social advantages gained from their habitus's (Bourdieu, 1985), provides and promotes a balanced and broad curriculum. Bourdieu (1985) highlighted the fact that habitus is significant in bridging the divide between subjective and objective realities, or between the social and the scientific. He also indicated that, the school/university (field) structuring experiences, is influenced by the habitus acquired in the family, which include University tiers awareness, entitlement consciousness, and social confidence (Bourdieu, 1973), all of which will influence their HE and thus mole concept experiences. Students from households with mini-libraries and educated parents (higher forms of capital), will build a bigger library of prior knowledge and hence can make better connections between the abstract and the concrete aspects of the mole. This is an element of the broad and balanced curriculum. A broad and balanced curriculum is beneficial to all students and particularly for learners from low socioeconomic background. A narrow curriculum, such as using only the procedural method in mole concept teaching and learning, can restrict learners choices and opportunities (Moore, 2017).

Narrowing of the curriculum has even led to an intervention from the chief inspector of OFSTED (Office for Standards in Education, Children's Services and Skills) Amanda Spielman, confirming that, curriculum content will be ascribed higher priority as compared to performance tables (Moore, 2017). This is because league tables encourage instructors to 'teach to the test', which means the narrowing of the curriculum, as in the procedural method of teaching the mole, where some instructors rely on it for accountability (Chiu, 2005). Narrowing the mole concept curriculum by teaching only the procedural method, introduces inequalities. It is said that the inequalities in the education system, are both educational as in the mole concept teaching and learning method, and social because achievements and educational opportunities reflects ethnicity, gender and class (Leathwood & Hayton, 2002). Inequalities would exist in the way science students experience the mole, because of social differences, even if the field is the same. Reay (1998) stated that, different habitus's might exist for different science students in the same field (HE), due to prejudice and bias. In this case, he was referring to secondary habitus. Science students in the upper tier universities, would experience the mole differently, because the curriculum is broaden, with cross curriculum initiatives like providing mathematics busters across the general science modules. The researcher experienced this when he started the chemistry course in a higher tier Central London University. Initiatives like the buster maths sessions were not available in the lower tier South East London University he subsequently attended. Students can easily disengage, especially if they lack an initial understanding of the mole (Omwirhire, 2015; citing Musa, 2009), due to its abstract nature. This leaves a lot of students at a disadvantage, to such a crucial topic that links theoretical to practical science. It is therefore a social justice issue, as the outcome of narrowing the science curriculum, first through teaching of only the procedural method of dealing with the mole concept, and secondly through the introduction of applied courses (Walford, 1991) to predominantly third tier Universities, located mostly in less affluent or working-class areas. It is clear that, University stratifications correlated with students social classes and reflects their household income and other forms of capital (Reay, et al., 2005). This is expected, as third tier Universities recruit predominantly working-class students. This social justice issue is also as a result of the social construction of students and workers identities. Students from third tier universities (mostly working-class), are socially constructed through the narrowing of the science curriculum and mechanisms associated with

HE funding, to serve as local industry workers. While students from higher tier Universities also known as research-led Universities, are constructed to serve as research scientists (Walford, 1991). It is equally clear that both primary and secondary habitus (family & HE/school), created different values of capital, including cultural capital, which plays a huge role in science students' HE choices, and determines their mole concept and overall student experiences. This study relies on Bourdieu's theory of practice which introduces concepts like Habitus, Field & Forms of Capital, to analyse and interpret our data. We have already established that the mole is socially constructed, similar to any currency. Currencies are a social construct, because society accepted to give it value ((Pettifor, 2014), see section 1.2.4). The mole is therefore a chemist/scientist's currency, because the science community has accepted to give it value, with the chemist seeing it as "amount of substance", the physicists see it as a mathematical constant (Avogadro constant), the pharmaceutical scientist will see it mostly in terms of millimoles, and yet the nano-scientist working with nano-particles will see it in terms of nano-moles. These are all social constructs of the mole, in the science community, as it is regarded as part of social wealth, with a social value according to Reid (1996), (see section 1.2.8). So, because the mole was socially constructed, to uncover the inequalities within its structures, it was important to deconstruct all aspects of the mole, beginning from its definition, methods of instruction, assessment methods, right down to millimoles and nano-moles. We have highlighted the inequalities associated with its teaching and learning, as instructors prefer the procedural method which narrows the curriculum and therefore adversely impacts learners from low socio-economic backgrounds.

The mole is socially constructed within the science community, the chemists will like to view the mole as ‘amount of substance’ (Ostwald, 1900), which is actually its definition coined by a German chemist Ostwald in 1900; the physicists would focus on the number of particles within the mole and will use a mathematic constant (6.02×10^{23}) the Avogadro number (Kolb, 1978) to count it. It should be noted that Avogadro was an Italian physicist who developed the (Avogadro) constant (6.02×10^{23}). Yet the healthcare industry will be interested more on millimoles, which is 1/1000th of a mole, since they deal with very minute quantities. It should also be noted that the millimole is a subdivision of the mole which is exactly similar and in the same context as the millimetre, the gram or the milligram which are a thousand subdivisions of the meter, kilogram and gram respectively. The participants who took part in this study were characterised by diversity and complexity, both in relation to their mole concept experiences, heritages, demographics, as well as lecturers teaching experiences of the mole. We had participants who originated from Albania, Germany, Somalia, UK and Zimbabwe. The participants academic and mole concept experiences range from foundation year, BSc to PhD students, with courses that includes; chemistry, biology, biomedical, forensics, pharmaceuticals, sports therapy, human nutrition and cancer immunotherapy sciences. The three lecturers had vast and diverse lecturing experiences with Dr Paul having 30 years teaching experiences with more than three universities and Dr Luke had post-doctoral experiences with all three tiers of universities in the UK including Manchester and Oxford Universities. All the lecturer participants were chemists, with Dr Kan specialising in organic chemistry. The main idea was to increase variation by recruiting a wide range of participant with the propensity of going deep rather than wide (Cousin, 2009; Gobo, 2006). The answers to the questions which shaped the participants narratives were valid because they were consistent with outcomes of previous research and the questions were not directly asked. For example, previous studies indicated that mole concept teaching is done predominantly by procedural method, with little or no conceptual method. To test this, lecturer participants were asked if they taught the historical context of the mole and if they sometimes used analogies to illustrate the concept. Those who taught only procedurally like Dr Luke will say things like, “the historical context does not add to the gravitas of the concept” and how “students are not interested in those types of facts”, that “students are more interested in the application of the mole”. Historical context would have taught the students that the name ‘mole’ in Latin, means ‘heap’, like a heap of sand. This alone can start to build a conceptual frame in the minds of the learners, where they can begin to create concept maps. The use of analogies to illustrate the mole will bring the concept to the learners’ everyday experiences, leading to meaningful learning (Ausubel, 2000). The lecturer participant, who taught the mole conceptually like Dr Paul, will teach the historical context of the mole and would also use analogies like, “one mole of water weighs 18 grams”, which I totally agree and will add that one mole of water is 18ml, since 1ml of water weighs approximately 18g. On the other hand, to verify if student participants were taught the mole concept by procedural method only, they were asked whether or not in solving mole concept related problems, they relied on formulas that they substituted values into (See Appendix V). Most of the student participants will talk about a formula triangle that they often used, which confirmed that it was mainly procedural method of teaching the mole, as indicated by previous researchers (Chiu, 2004; Chiu & Chang, 2005; Surif, et al., 2012). Procedural method of mole concept teaching is advantageous to instructors in that, it is less time consuming and good for teachers' accountability (Chiu, 2004; Chiu & Chang, 2005). To test for forms of capital, participants were asked about their parents' occupations and highest academic qualifications. They were also asked if they had mini-libraries at home and their hobbies, including going to theatre, concerts and visiting galleries. This was to test for cultural capital (Sullivan, 2001).

8.2.2 How can we understand the socio-cultural factors that shaped science students' understanding of the mole?

Different habitus's does subsists for different student participants in the same field (Reay, 1998) due to all the sociological factors already described. In this study, those student participants from more affluent (middle-class) backgrounds like Gisela, Emma, John and Drita, encountered the mole far earlier in their academic careers, mostly secondary school (year 8 or grade 7) and "A" levels as most of them turn out to be traditional students at the HE field. At least two of the middle-class student participants (Emma and Gisela) already knew about millimoles from their habitus's and advance science studies, especially as both of them have had privately funded education. This is in sharp contrast to the other student participants who are mostly from low socio- economic backgrounds (working-class). They are also non-traditional students, as they gained access to HE through access courses where most of them encountered the mole for the first time if not only during the actual degree course. This was the case for Isa, James, Oprah, Jacob and Mary. We can see here clearly, that habitus and forms of capital (economic, social and cultural), influence the way science students in this study, experience the mole in the HE field and may even determine their academic outcomes, such that the social value of the qualifications gained by such underprivileged students', will be less, compared to the middle-class students (Reid, 1996; Walford, 1991). Habitus is described as the outcome of family socialisation, which in most cases can be modified through peer group engagement (Swartz, 1997). It is clear from the study that, students from low socio-economic backgrounds which include non-traditional students participants in this study, have contrasting primary habitus' and limited mole concept ideas (Swartz, 1997; Stahl, 2015). Primary habitus is second nature (Bourdieu, 1990). Forms of capital (social, economic and cultural) determines not only the habitus of the participants, but also their field (HE and peer culture).

8.3 The conceptual contribution of the thesis;

The mole concept is socially constructed within the science community as indicated earlier, but the problems associated with the teaching and learning of the mole have been highlighted by other researchers mentioned above and who concentrated their studies mainly on chemistry students, while using quantitative methodology. This study departs from that, by not only applying a qualitative methodology through narrative inquiry but examines science students across the spectrum and lecturers in the context of social justice. The unique contribution of this study is not limited only to the above, but also includes the highlighting of the inequalities embedded within the teaching and learning of the mole (see section 8.4, recommendations below). This study also proposes the conceptual teaching of the mole in schools (from Key stage 2 upwards), at the same time and in association with the other SI units of measurements [Length (m), Mass (kg), Time (s) and so on] (Harris, 1995).

Bourdieu's theory of practice, which comprise habitus, field and forms of capital (economic, social and cultural) was used to investigate the mole concept experiences of a wide range of science students and lecturers, therefore remaining true to Bourdieu's affirmation that the concepts should not be applied separately (Bourdieu & Wacquant, 1992). Nevertheless, it was not used as a fixed framework but instead to apply habitus, field and forms of capital as a prism or sieve to deconstruct the mole, by examining every strand of the participants' mole concept experiences, through thought processes (Webb, et al., 2017; Stahl, 2016). Therefore, my perspective has deployed the theory in a fluid manner as I have also drawn on the works of other investigators like Shotton (2018) and Noyes (2004), to stretch the theory so as to examine the experiences of the nine science student participants and three lecturers who took part in this study. Bourdieu (1990) indicated that fitting into HE is subject to the university field being associated with the individual's habitus', but in this research, the theory of habitus was extended to examine how the habitus of the institution influenced individual student experiences, by relating lecturers (field actors) teaching experiences to those of the students (Reay, et al., 2009). Most of the lecturers in this study taught the mole procedurally, except Dr Paul who uses analogies and often teaches the historical context of the mole (conceptual method indicators). It is stated that, the boundaries of the university field are porous (Ignatow & Robinson, 2017), therefore most of the changes to address the inequalities can only come through the education field and teaching reform. It should also be noted that 'the capacity to invest in and profit from education is not equal' (Bourdieu, 1986). Therefore, the wider and continuous aim of this study is to make sure that this contribution, does not only remain as an academic exercise, but aid in levelling up the science (mole concept) education field.

8.3.1 Originality;

Almost all mole concept research is based on investigating mole related difficulties and mainly depends on the positivist paradigm and quantitative methodology. This study takes a different approach by relying on the interpretive paradigm and qualitative methodology (narrative inquiry). Instead, we have investigated the disproportionate nature of the mole difficulties experienced by science students from lower-class compared to higher-class learners. Sociological theory and methods were deployed to investigate the unique paradigm of this study.

Furthermore, this study has highlighted conceptual teaching and learning as a remedy in addressing some of the inequalities associated with experiencing the mole and has developed analogies to assist this (see sections 1.2.3 & 1.2.4). We have also highlighted the social context of the mole by identifying its social construction, especially in the science community, by separating its two definitions constructed by Oswald (1900), the German chemist, and Avogadro, the Italian physicist. The 26^{th} General Conference on Weights and Measurements in 2018 CGPM (2018) has since voted to change the definition of the mole, from "amount of substance equivalent to 12g of $Carbon^{12}$" (Oswald the chemist definition), to: "the amount of atoms/molecules given by the Avogadro constant" (Avogadro the physicist definition). This definition is more of a physicists' view of the mole. It would be interesting to determine whether most of the delegates were physicists, which confirms the social context of the mole.

Lastly and more importantly, this study has proposed the **conceptual** teaching and learning of the mole in schools (UK schools levels upper primary and KS2) in tandem with the other S.I units of measurements. These are all unique to this study and are original contributions to knowledge.

8.4 Professional practice recommendations;

This study is recommending the teaching of the mole conceptually in schools (Key stage 2/upper primary or 2nd grade), together with and in relation to the other SI unites of measurements as a matter of urgency. The mole concept teaching and learning difficulties identified by other studies exists because of the over dependency on the procedural method and its associated drawbacks. The lack of conceptual teaching and sociological influences including forms of capital which determines habitus and class differences (Bourdieu, 1990), has created huge inequalities and social injustices. Reay et al., (2005) found that university stratification corresponded with students social classes and reflected on their forms of capital including household incomes. Also, important to note, is a quantitative study on chemistry students' difficulties in solving mole concept problems concluded that, this was as a result of certain instructional features, which includes; content of curriculum; teacher training; assessment; and instruction method (Cervellati, et al., 1982). this study revealed that, students from more affluent backgrounds [middle-class] (Gisela, Emma, Drita and John), had an earlier mole concept starting experience (grade 7, or year 8) compared to students from low income households [working-class] like; Isa, James, Mary, Oprah and Jacob who only first heard about the mole when they joined an access to science course, which is more later in their academic careers. On the other hand, Gisela even knew about millimoles far earlier because of her habitus, as her mother had a doctorate in pharmacology and had told her about it. This, together with other science books in her household (mini library), had influenced her choice of pursuing biomedical science, instead of the arts that her private funded boarding school was trying to orientate her towards. It is therefore clear from this research that, an early introduction of the mole, has a beneficial effect on how students' experience the mole, and their HE choices. The porous nature of the field means that it is open to change (Bourdieu, 1990), therefore the primary education field is ripe for change. Any mole concept change in the KS2 field will serve as first contact to all social groups similar to the metric units of measurement, such that when the learners come across it subsequently in secondary and HE, it will become 'second or multiple nature', because according to Bourdieu, field characteristics or norms are familiar to middle-class learners, it is their second nature (Bourdieu, 1990). Therefore, it is vitally important to make the conceptual teaching of the mole in primary schools, everyone's second or multiple nature, in order to address the inequality. If someone like Isa, have had early (primary school) mole concept experience or first contact, he may not have taken 15 years out of education, before coming back to pursue biomedical science studies via an access course. Isa has a good understanding of the mole concept, as he rated himself 4 out of 5 mole concept understanding in the recruitment questionnaire, which I confirmed as accurate during the one-to-one interview. His understanding was however mainly procedural, a conceptual mole knowledge from primary school, would have perhaps constructed a research scientist out of Isa, due to his interest in laboratory work.

The second recommendation is for the teaching and learning of the mole concept in HE using both procedural and conceptual methods as previously highlighted by other researchers (Surif, et al., 2012; Cervellati, et al., 1982; Chiu, 2004). The conceptual method of teaching and learning the mole should include the use of analogies of which this study has introduced three analogies (see section 1.2.3). The teaching of the historical origin of the mole, should also serve as part of conceptual teaching and learning, because if a learner knows that the word ‘mole’ means ‘heap’, they may easily relate it to their own experiences and build concept maps, hence conceptual learning.

8.4.1 How to teach the mole conceptually in schools;

The mole should be taught conceptually in schools in tandem with and in relation to the other SI units; For example, the SI unit for Length is the Meter (m) and the meter divided 1000 times gives us the millimetre (mm); the SI unit for Mass is the Kilogram (kg) and the kg divided 1000 times gives the gram (g), which further divides 1000 times to give a milligram (mg); So is the SI unit for ‘amount of substance’ Mole (mol) which divides 1000 times to give millimoles. It may be important to put things into context, by using moles of common substances like water (H_2O), which one of the lecturer participants in this study (Dr Paul) mentioned as an analogy, when he said, “1 mole of water weighs 18g. Which I agreed and highlighted the fact that, 1 mole of water is eighteen millilitres (18ml), since 1ml of water weighs approximately 1g. We can also say that 1 millimole of water is 0.018, as 18 / 1000 = 0.018 millimoles. This can be incorporated into numeracy lessons, where to divide by thousands, hundreds, or tens, you simply move the decimal point to the left based on the number of zeros. In this case, the decimal point is moved 3 places to the left because a thousand has three zeros. On the other hand, a mole of Sodium chloride (common salt) is approximately 58g and 0.058 millimoles. At a higher level (secondary/KS3/4), students will begin to appreciate why the molecular mass of a mole of water is 18g / 18ml. They will be able to establish that, it is because a molecule of water (H_2O) contains one atom of oxygen and two hydrogen atoms, with the oxygen atom having a nucleus that is made up of 8 protons and 8 neutrons, giving it a combine mass of 16g and hydrogen atoms only weighs 1g since it has only 1 proton in its nucleus and no neutron. Thus, 2 lots of hydrogen atoms will give 2g plus the 16g of the Oxygen atom, to give a total mass of 18g for each water molecule. The same can be said for common salt NaCl, where 1 mole weighs 58g, and a millimole will be 0.058. Students can be encouraged to work out the moles and millimoles of some common substances. Conceptual teaching and learning is meaningful learning, which leads to deeper understanding as the teaching material is brought to the learners' experience (Ausubel, 2000). Dominant social groups such as the middle-classes, often deploy their cultural capital to acquire educational advantages and social status, which can be replicated down the generations (Bourdieu, 1990). Harman (2017) noted that Bourdieu highlighted education as the field that does not only facilitate social change, but also serves as an instrument by which the middle-classes socially reproduced their advantages (Harman, 2017). Some middle-class students in this study are already involve in research because they had good BSc degrees, whereas most of the working-class students at best will only scrape through and as such, will be socially constructed to serve as local industry workers (Walford, 1991). Even though other studies had highlighted the problems associated with teaching and learning of the mole, their remedy of using both methods (procedural and conceptual) was never heeded to. The recommendation of teaching the mole in primary schools conceptually, as a remedy for addressing the inequalities and hence social injustice, is unique to this study and is an original contribution to knowledge. These recommendations if implemented will not only increase equal access to the sciences but will also guarantee equal participation and equal outcomes (Reid, 1996). Academic qualifications are part of social wealth; which is defined as anything that has value in society and they are the outcome of educational processes which must be equal according to the principle of equality of opportunity (Winch, 1996), but educational outcomes cannot be equal if science and mole concept students enter the HE field with unequal basic information. Equality of outcome is based on the principle of equality which recognises that ‘the end point of a process ought to be the same for everyone who goes through it’ (Winch, 1996). But if some students access the HE field with less than average basic information, this would mean that their participation will be unequal, therefore unequal outcomes. Such students at best will have qualifications that are worth less than average and this would be the experiences of working-class students. For example, Isa who took part in this study is from a working- class background. He developed interest in biomedical sciences after working in a laboratory for two weeks during his access to science course; he therefore may like to be a research scientist. Currently he is starting off at a disadvantage, because even though his mole concept procedural knowledge was good, he did not know what millimole was, until I explained it to him (see Figures 6 & 7). His lack of millimoles understanding is similar to someone knowing about the meter (m), but not about the millimetre (mm). However, some of his peers already knew about millimoles. So, the quality his degree may not lead him to become the research scientist that he is aspiring to, because the system socially constructs research scientists and local industry workers.

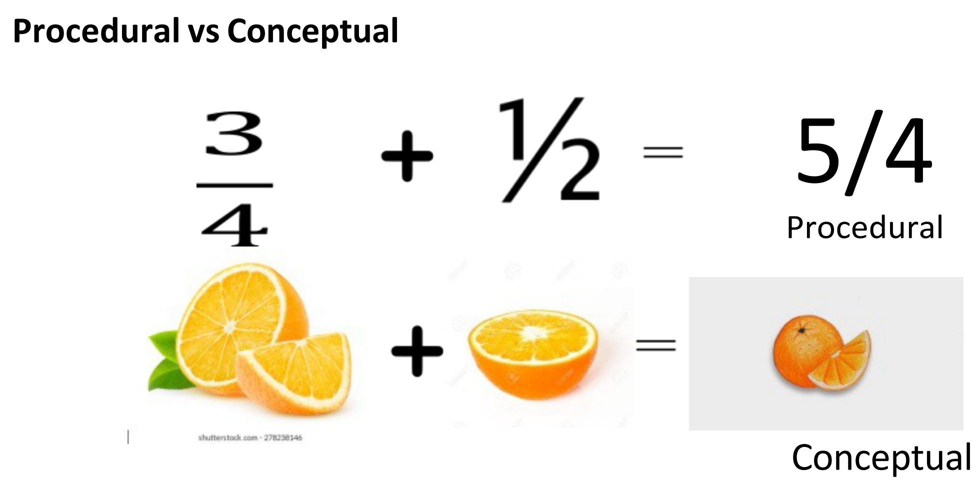

Figure. 6. Visualisation of Procedural versus Conceptual teaching and learning (created by Agbor, 2021 for presentation see Appendix V).

Analogies for conceptual teaching and learning

Figure 7: An analogical illustration of the mole in a West African food market. The measuring cups represents the mole, while the rice and garri (tapioca grains represents atoms, molecules, electrons or ions. The number of grains in the cup would be the Avogadro's number. (Created by Agbor, 2021 with images Courtesy of Alamy photos for presentation see Appendix V).

8.5 Recommendations for future research;

The mole is already a highly researched area, even though most of the research is based on quantitative methodology. If all the recommendations highlighted above are implemented, then further qualitative studies will be needed to determine how effective these field changes are working to reduce the inequalities. There will be need for a joint research that will cover the whole educational field (KS2 to HE).

Even though one of the participants have had post-doctoral lecturing experiences at all the three tiers of universities in the UK, he only taught procedurally, so further research will be needed to throw more light on teaching practices taking place in all three types of UK universities. It will also be interesting to know how the student participants in this study end up with their science careers.

8.6 Limitations of this study;

The vigour of this qualitative research is that the methodological approach based on narratives, allowed for in-depth understanding into the individual experiences of a wide range of science students' and lecturers' mole concept engagements. It was nevertheless, not possible to make statistical generalisations (Polit & Beck, 2010).

The prevalent pandemic (Covid-19) lead to the lockdowns of the whole UK society for very long periods, therefore it was not possible to do face-to-face interviews. Consequently, there was no input of the research data from observing the narrators, as everything was done online. Participants' recruitments had to take place via questionnaire, which is not usually a qualitative method of sampling. There were also time limitations especially during the focus group interviews as most of the participants only had their break time, with some having to leave early for other appointments. Only one interview was conducted per participant, and I am not sure if a second interview would have added more value. The narrative data depended on the honesty of the narrators (Shenton, 2004), but they were consistent with what is expected, especially as other researchers have highlighted similar mole concept problems, couple with the fact that some of the stories are in part, a reflection of the authors' own habitus and mole concept experiences. Bourdieu wondered if social research is mostly the reflection of the inquirers partial and bias viewpoints (Bourdieu, 1995). This does not apply in this study because, we already knew what to expect before the questions were answered and usually the questions were not direct. For example, to find out if a science lecturer participant teaches the mole procedurally or conceptually, they were asked if they sometimes teach the historical context of the mole and if they use analogies to illustrate the concept. We already knew from previous studies, that conceptual method was not in use. Also, to find out about student participants' cultural and other forms of capital and social status, whey were asked for their parents' highest qualifications and occupations (Sullivan, 2002), but we already knew what to expect from their access to HE and other prior information. Sometimes the questions were semi structured and direct, like asking the student participants if they use mainly formula method in solving mole concept problems. This tells us if they learn procedurally, in confirmation of previous studies which had already found that, instructors prefer procedural method of teaching the mole, because it is less time consuming and easy for accountability (Chiu, 2004).

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Apendicies

Appendix I: Interview Transcript;

Focus Group

Present:
5 participants

- Mary (MY)
- James (JS)
- Oprah (OH)
- Jacob (JB)
- John (JN)

2 Moderators

- Dr S
- Charles Agbor (CA)

Dr S opened the session,
CA - explained the reasons for the research
A list of 8 questions was displayed on the screen to help participants narrate their mole concept stories by using the questions as a framework.

Mary (MY);
From the first question,
I learned chemistry in school, in high school,
I usually liked what I am told about it, so to solve problems, always watching YouTube, reading the books chemistry, asking my friends to help me ahh, for the questions,
Question no. 5, I didn't have the public exam, so I don't know,
From questions 6 to 8,
It was my own decision to go to university
Because in Poland I was like the sports woman, so I had the injury on my knee, it was the reason why I decide like to choose sports therapy and I found the Metropolitan University, and I decide to try to do the foundation year, and I enjoy it,
And I really like it and this is the reason why I chose Metropolitan University, eh and what else, eh, eh,
Do I sometimes go to galleries and theatres?
Yes, I am a fan of theatres and concerts and of course now we have the corona virus, and I hope fingers crossed, that everything goes back as soon as possible to normal life and back to social life, and I am sorry I hope to help you, I have to go back to work, I have just tried to help you,
So, do you have any question to me?
CA - Yes, have you solved any mole concept problems before, ever?
MY - No, No, never, it's first time for me, it's first time for me,
CA - Is it the first time you've heard of the mole concept, here and now like this?
MY - Yes, in UK, because I am from Poland so,
CA
In your course, have ever come across mole concept before?
MY
No, No, In this course no,
CA - Have you ever heard of millimoles or in hospitals when the take blood samples and other stuffs, they measure them in W/V / millimoles?
MY - No, No
CA - So, your parents' occupation did not influence your learning at all and your parents' education as well?
MY - Yes, my parents' education, actually I fell on my parents because they show me the way on what I suppose to choose, to be honest, but their way was getting to my choice of this course sports therapy because my father, he is a sailor on the ships as a ship captain, so a completely different way,
Emm, emm, but always they support me and they always support my decision, so even if they are still in Poland, and I decide to move to the UK, they still support me, they still support my decision, they are still important, my family,
CA - Okay, thank you

Jacob (JB)

Okay, this going to be interesting,
I was taught mole concept in high school,
Was I taught the historical context and meaning of the word mole concept in Greek/?
Emm, I probably was in high school, however because of how long ego it was, I cannot say for certain if I was,
Ehm I am going to air in the side of no, because I am not confident in my etymology of the mole,
So, question 2, most people solve mole concept problems by substituting values into formulars'
Ehm, yeah, I think this is how I was exposed to the mole, Ehm, and now of course having to use ehm, part of the concept in chemistry, ehm, it seems familiar and also feels new as well, so I am sort of trying to get the bearings with the concept, ehm,
I don't believe I have been taught other methods of solving mole concept problems, ehm,
In terms of mole concept analogies, I don't recall any instances of being taught any analogies,
In terms my current course of study, ehm, I suppose the foundation year counts as an access course of some means because I couldn't go straight to the dietetics 'course that I would have liked to go on to because of course London Met uni is the only university in the country to offer such a pathway, so I am quite pleased,
And also, the fact that my older brother, is also on the same course, so that did influence my decision,
Ehm, my parents' occupations and academic qualifications were, they are very different,
My dad is more sort of a unskilled engineer while my mum is more unto caring so it's kind of unrelated to the path I am and wish to following, ehm,
As far as other people influencing my Uni choices, Ehm, when I use to work for a insurance software company, there was a person in the office who,
He didn't directly influence my university choices, however because my own dietary lifestyle changed, then I was influenced by that, it sort of let me go into me going unto Uni then follow the dietetics pathway, soon it became an interest,
Emm, when it comes to galleries, theatres and concerts, I don't normally attend concerts, in terms galleries and theatres, I find it to be very enjoyable with other people as a change of scenery is nice to sort of understand how parts of civilisation and the creativity that artists are able to express either on a canvas or with their hands and especially as my girlfriend seems to have a good interest in this as well,
It is nice to be able to share that.

Oprah (OH)

Okay so, going by the first question, were you taught the historical context of the word mole?
Ehm for me, the only time I remember first learning about the mole was actually when I did the foundation course to this degree that I am on,
I am doing pharmaceutical science, and for me that's the time I can remember,
I am not sure whether I came across this before during my "A" levels oh during my GCSE because that was many, many years ago, ehmmm, more than 10 years ago, 15 years ago maybe, so I have no recollection of this particular concept,
Ehmm, yes for me I solve the mole concept problems by substituting values into formula, ehm, that's in the chemistry that we are doing in our first year, in our foundation year, ehm, my introduction of the mole, remembering Dr S ehm, explaining it to us and referring to Avogadro's number, so I have always got that in me, and ehm, that's the way I deal with it.
Especially when we have been doing combustion analysis, ehmm, calculating the weights of certain compounds that are missing, and those kinds of problems solving.
And then ehmm, for number three I am actually still getting to understand the mole concept, ehm in more dept as I practice you know, the work that we are doing in chemistry for now,
Ehm, I don't think there are a lot more mole concept analogies that I know yet, except in what I have explained for number three.
I gained access into my current course through, the minimum qualifications that, they, they, were required for it, and I do look at the foundation courses sort of like an access course in itself, because I am, so yes I do look at the foundation course that I did last year as an access course, because without that, I don't think I would have gain access to a course such as the course that I am doing right now,
Ehm, although I have also been working in the scientific field, but not really ehmm, hands-on scientific,
Ehmm, I have been working in clinical trials, clinical research, reviewing protocols, reviewing

justifications of you know, studies ehm, reviewing statistical analysis, plans, working with Biostatisticians and also other scientific people, but I have not been the main scientific purpose, I have been looking at it from a regulatory point of view, because that's what I was working at.
So, through that constant you know constant working with scientific people and handling scientific information and sometimes sitting at the table, with making decisions over that, ehmm, I just validate that side of my work, and so because of other things that were going on in my personal life, I thought I should, studying is a good way of stabilising my situation and also building on my interest,
My parents were not academics at all, they were more business minded people, and they ran businesses all through their lives, ehm, although my grandmother was very, involved in natural practice ways in traditional medicine,
From where I come from, she knew all the plants, how to mix things, she did pass some of the information and it will be interesting to see whether when I do my drugs discovery modules, whether I will be able to kind of link what I know from my most practiced tradition to actually ehm, ehm,
For me, my parents did not go university and did not influence my choices at all,
I did study prior to doing this course that I am on, ehm, but it was purely just me making decisions I grow up in life and that,
Yes, I do go to galleries, theatres and concerts, I am actually as a side thing, I am actually very interested and involved in making music, I like classical music and play instruments and my immediate family, my husband and my children, we do a lot of music orientated things and so my daughter is into drama and acting and so she is involved, she is training in that, but she does work in some London theatres and here in Essex, and yes, we are very much interested in that artistic side of things in life,
You know, is it the right brain, or left-brain things, but ehmm, it was part of my life growing up, it was important going to the yearly shows, yearly festivals and being exposed to art and music and those kinds of things, yeah.
That's it for me, do you have any more questions?

John (JN)
So, basically, I came across mole, I believe in 7^{th} grade, it wasn't actually chemistry, it was physics and as much as I remember from that period, it was you know, how many particles in 12 grams of $carbon^{12}$ isotope I mean, that was like in high school level,
And basically, I mean, when I think about mole, the first thing that comes to my mind is mass over molar mass, so and then we know about the number of particles in such amount of substance,
And I mean the other thing that came across when we talk of the mole, was when we talk about concentration, so we can actually calculate molarity based on the number of moles over the volume, eh pretty much that's what I know about the mole so far, from my earlier studies and foundation year,
Basically yes, I access the course through foundation year, I did general science, so I didn't choose any medical science, any specific course, just to be able to, to decide what I want to do in future,
Basically, my parents yes, they are all teachers and they never really pushed me towards science, but they always pushed me towards higher education,
So, because of this I did my first degree in hospitality management, and I worked the last 15 years in the business, but I mean, in high school I always studied, including chemistry, physics, maths, so I was like eh, I wouldn't really want to go back to the past, and eh, that's why I chose something science,
And basically, I remember the first day, because I did the science ehm course, I have to choose already about biochemistry and eh, what's the other one? Eh psychology and by saying like, if I want to do maths and Biology and chemistry, then I picked biochemistry,
And basically during the course I remember, we had a dissection practical with Dr [redacted], and until then I was only thinking about going into biomedical science, because I mean I had the 70 or 75% average, but that was the day I actually changed my mind and choose chemistry, because, there was those two girls, I am sorry about that, I was like, she brain and I was like nahh, it was too much, so basically that was one of the reasons and the last question?
We used to have with the family I have back home, we use to have like eh, a premier membership to be in the local theatre you know, so we use to go every month for the new plays,
And eh, in my city, summertime they always build like huge open theatres, stage, seats and everything and we had like, membership for there, as well,
And I also danced for like eight years, so we regularly performed in theatres all over the country to honest, so ehh, very much that's it.
CA - Have you heard of any mole concept analogy?

John - To be honest I would say no.

James (JS)
DrL read what “James” wrote
I heard about the word mole when I was in high school if I’m not wrong, this has been a long time since I left school,
When I was in college, I didn’t follow the basic course in high school, I followed a professional course in college,
Second question [most people solve mole concept problems by substituting into values into formulas’], the most I can remember is what I have been doing during the year in biology and chemistry about moles, most of the information about moles is into formulas,
So, I get into moles concept from what I have been learning this year,
I gain access to my course through a foundation year, which is what we are basing at the moment,
My parents’ occupations are not based on academic studies, my mum is into more care and cleaning and my father is construction,
Ehmm, number, I got the choice into sports therapy because, because of what I have been doing for my whole life, as I played football from since I was a kid, ehm till 3 or 4 years ago,
So I decided to go into fitness and sports industry, as I see it as my passion.
I love to go to concerts and galleries.

ONE-TO-ONE INTERVIEWS

Emma [PhD] (EA)
Attendance;
DrL
CA

CA - explained the social research context of the interview.
EMMA -
I am “Emma”, I graduated last year and now I am doing PhD pharmaceutical science at London Met.
CA - Right, where did you first hear about the mole concept and what are the different levels that you had encountered the mole concept?
EA - The first time I can remember learning about moles was during “A” levels in college,
Ehm, that would have been a long time ago now, there was a big gap between my “A” levels and my degree,
So, for me the first time I heard about the mole would have been probably about 15 to 16 years ago,
It would’ve been in an ordinary state college, during chemistry “A” levels,
CA - And have you encountered it since?
EA
Yes, yes, absolutely, from the beginning of the first year in pharmacology and ehm, honestly doing mole calculations all the time throughout my studies,
CA - Okay, well we will come back to that, what level of help and support you got from your family, not necessarily on mole concept, generally as you grow up, from your home schooling, or extra tuition and those types of things?
EA - Ehh! Well, for primary school, I went to a private school and then I moved into a comprehensive secondary, ehm, and my parents and family were very supportive generally and ehm,
My parents don’t have much of a background in chemistry, ehm when they were at school, there wasn’t a national curriculum, actually they didn’t learn any chemistry at school,
Yes, so lots of general support, but in terms of specifics to the mole concept, it’s a new idea to them, as well as new to me,
CA - Where they influential to your current choice of study? Or did you have any influence from teachers, friends, how did you arrived at choosing this course?
EA - Ahh, well, having done pharmacology for already for the previous 3 years, I worked with Dr [redacted] during my 3rd year project, and he is now my PhD supervisor, so it was mostly his influence, I would say, that’s why I am doing the course now.
CA - Okay, so in your family situation, would you describe it as being economically disadvantaged?
EA - Well, it’s such a difficult question because, I am going to be 35 his year and I live with my husband in our own home, eh, so my parents, are not quite relevant to that,
Ehm, I say my husband works full time, so we are sort of in the middle, we are not badly off, and we are not wealthy either I would say.
CA - So in this case your family situation, your father and mother, where you grow up, I want to really understand where you group yourself, working class, middle class or?
EA - Ehh! Again, that’s a good question, eh! I suppose we were quite probably middle class when I was growing up at primary school, but then my parents were made redundant from work, so we probably moved to working class from then on.
CA - So what is their level of qualifications?
EA - My dad has a degree in computer science and my mum, I think she did “O” levels, but she didn’t move to university.
CA - So they organise private or home tutoring, or did they help you themselves?
EA - No, when they were working, they worked long hours, so I use to just came home and my homework will be done by the time they returned home.
Emm, but I didn’t struggle very much at school, I was fortunate I was able to find the motivation; I find it interesting to do the work on my own.
CA - Before you moved to higher education, what influences did your friends have, did you chose the subjects your friends were choosing, or did they have any sort of influence at all?
EM - Actually, a lot of my peers went into different subjects, and they went into mostly computing, I thought of going into computing as well, but I decided to go my own way, which is the science.
CA - Did you have good teacher student relationship?
EA - Em, yes, I did, I was a kind of a swot at school, so the teachers turned to like me, yes so I got

on well with my teachers.
CA - So, who is the main person that you can pinpoint who influenced your course of study/
The course I am doing right now, is Dr [redacted], who is my supervisor,
Ehh to go to the pharmacology BSc previously, that was just my own decision, I made the decision quite quickly, I applied through clearing, em, it's just something I decided to do I suppose.
CA - Coming back to the mole concept, were you taught the historical basis of the mole, how the name came about etc?
EA - Ehhh! I am struggling to remember from "A" levels if they taught us the historical concept or not, but during the BSc we were definitely taught about the history.
CA - So, how was the mole concept taught, did you just have a series of formulas to substitute values into?
EA - Emm, well "A" levels, I would say they didn't really go into what Avogadro's number was, but they just said, it's this number, it's to do with carbon^{12}, just forget about it.
We just focussed on balancing equations and that kind of thing and during the BSc, it was probably more involved with balancing equations, working out concentrations and combustion analysis, that kind of thing.
CA - Did they ever mentioned any analogies that can bring the whole concept to life?
EA - Eh, the teacher had a stuffed mole, things like a flush mole, that's all I can remember,
I am not sure if I can remember the analogy too well, because the concept may sort of returns to me quite quickly.
CA - Did they try to distinguish between the definition of a physicist and that of a chemist, on the mole concept?
I am not sure, I don't know what definition a physicist would use quite frankly, what's the difference?
CA - Yes, you mentioned it before, you mentioned a name.
EA - What? Avogadro?
CA - Yes, then the differences between Avogadro's number (physicist) and Ostwald (chemist) definitions were explained, using water in a glass analogy.
EA - Eh! They sort of go together, don't they? I suppose I never think of them as separate things.
CA - Okay, how was the course assessed?
EA - "A" level's there was definitely some coursework and some exams, I don't think there were any assessments that were specific to the mole concept, it was just the calculations required, with some understandings, but at the BSc level, it was just the same kind of thing,
We would have had practical's write-ups with some exams, and then going forward in chemistry, you know, we are using moles all the time,
CA - Explained formative and summative assessment,
CA - Do you sometimes go to galleries, concerts and theatres?
Eh! Especially not at the moment, to be honest, not really, we usually just busy.
CA - Did you gain access to your course through the traditional route, "A" levels?
EA - Ehh! For "A" levels I just applied to the college with my GCSE results, and all was all standard.
For the BSc I applied through clearing, as a mature student, that was perhaps a little bit less reassured.
For the postgraduate right now, I applied through the university with the proposal; I suppose that is the standard route.
CA - Where you taught other methods of solving mole concept problems?
EA - Ehh!, I think it was mainly just the usual chemistry.
CA - I explained the conceptual and procedural methods, citing previous analogies.
EA - I would say possibly the BSc, during the university, it was probably explained through the history as in to calculate the numbers tied to carbon^{12}, the practicing the calculations.
CA - Have you heard of millimoles before?
EA - Yes!
CA - Is it predominantly in the course you are doing right now?
EA - Yes, that's the unit I am using most of the time when I am testing compounds,
Yes, I suppose I first started using it during my 3rd year's project, when I was using millimoles.
CA - Did we talk about your parents' employment before?
EA - Employment history? Yes, my dad was in IT (software engineering) for his whole life, he is retired now,My mum has been a librarian and a clinical data analyst, and she is also retired now.
CA - Explained the award of a token, a puzzle I invented (Periodic Puzzle).
End.

Isa (IA)

CA - Explained the aim of the research
CA - When did you did first hear about the mole concept?
IA - I heard about the mole concept when I joined the access to science, a year before, so say, two years before, in a study back, because I had a gap year, because my knowledge at secondary school, wasn't that great.
I think I have that memory in my hand and think I learnt a lot in the mole concept in access to science, so this is saying I have quite an understanding, during those pass two years.
CA - Can you just state your name and the course you are currently doing?
IA - I am doing the Biomedical foundation in Biomedical science, and my name is IA, so it is a foundation in biomedical science.
CA - Did they ever teach you the historical background to the mole concept?
IA - Long pause. They did mentioned few, but not in-depth, just to grasp where it originated from,.
CA - Did you ever encounter the mole concept anywhere else before now,, say in secondary school?
IA - I did encounter it in my secondary school, but it was very small amount of teaching, not in-depth.
CA - How did you gain access to the course you are doing now?
IA - I did access to science, before this foundation year in biomedical, Yes currently doing foundation year.
CA - What other levels of studies have you done before?
IA - I did GCSE in English and maths, those are primary which I need to have, skills for life I should say, from there onwards, I had a huge gap in which I was working,
I had a huge gap from education. So, from that second school to the access course, I had that gap where I did not go back to study, I was working by then.
CA - What is your family situation like, did you have support at home, what sort of job did your parents do?
IA - My parents do part-time jobs like kitchen assistant and in terms of support, there are two types, financial and educational, both of them were quite average I would say, they were helping me out, during this time, but then again, I step out myself to go and get a part-time job, during those gap years.
CA - Do your parents have formal qualifications, academic qualifications?
No, not at the moment, they are currently studying at the GCSE levels at the moment, so…
CA - When you were in school, did you have any form of support like private tutoring?
IA - Oh yes, I am from Somalia, so they organised a Somali tutor to teach me in our language, so for example, I was struggling in maths like back before in secondary school, so I had a tutor to help me with maths in my own language.
CA - The first time you heard about the mole, was it in this country or was it in Somalia?
IA - No, I first heard about the mole in this country.
CA - Did you have tools at home like a little library with books etc?
IA - The books I am using at the moment are from my brothers and sisters, who have finished university, they also did science course, specialising in biology, and I have a close library in my community where I can just pop in and get a book.
Unfortunately, what is happing at the moment (Covid-19), we can only go to WebLearn and do research on Google.
CA - What did your brother and sister study?
IA - They had books from "A" level science, both biology and chemistry books.
CA - What are their current qualifications now have finished studying?
IA - No, they are still currently studying, one is nursing and the other one English he just finished.
CA - Okay, what were your entry qualifications to the foundation year?
IA - I entered through the access course; I had the qualifications to join the foundation year but not the first year, my points were not enough to go straight into the first year.
CA - Did any friends, teacher, or anybody like that, help you in deciding to do the course that you are doing now?
IA - Ever since I had interest in the laboratory, I had one week experience while I was doing the access course in a chemistry lab in one of those calls in Romford that inspired me a lot to study the access course. Unfortunately, with low grades, I couldn't join the first year.
CA - Did they teach you how to solve mole concept problems at all?
IA - Yes, in the access course, yes, well in general, mole is just a unite, we use it to measure chemical values, or chemical amounts and we know that one mole of any chemical is actually equivalent to this value of 6.02 times ten to the power of 23, and that is Avogadro's constant

number.
And there is a triangle where if you write it, it's actually easier to read, where you divide by the grams with EMR the molar mass to get the moles or do the opposite or the reverse.
But not the history, I am still unsure about the history since most of the teaching go in-depth into calculations rather than explaining where it came from.
Well, I understand that it came from the person with that name, but not the in-depth history about it.
CA - Did they differentiate the definitions at all, from what the physicists would call it, from what the chemists would call it?
IA - No, No. That didn't come up to my mind, No
CA - I explained the differences between chemist's definition of the mole and physicists' definition, using a glass of water analogy and the West African market analogies.
IA - There was no differentiation between the physicists and chemists' definitions; just the chemist's definition of the mole was used.
CA - The aim of the research as a sociological study was explained. Did your teachers help you at all, in choosing your course?
IA - Well, to be honest I chose the course myself.
At that time, I decided to at least progress and you know graduate as a biomedical scientist. So I had to play right from the very beginning.
CA - Have you ever heard of any mole concept analogies, like the ones I just explained a few minutes ago?
IA - Well, your explanation is a bit different because you are explaining both points of views, while we are just getting a general chemistry explanation on the lectures.
CA - On assessing mole concept, what types of questions were asked, were they just direct questions.
IA - No, they gave us a scenario, they say, assuming that there is 60 grams in a beaker of this substance, and they give you the periodic table where you can use to research the molecular masses from the atomic masses, then use the triangle formula for the mole, to find out the number of moles.
It is a scenario base where we just need to work out, they will give the quantity and want you to find the moles, or they may give it in reverse and want you to find the grams. So, you just need to do the reverse triangle calculation.
CA - So, have you ever heard of millimoles before?
IA - No.
CA - Millimoles was explained to him as one over a thousand of a mole, using analogies.
CA - Do you sometimes go to galleries, theatre, concerts and those types of things?
Back in secondary school I was.
I go to libraries and read New Scientist magazine, but not galleries or theatres, no.
End.

Drita (DA**)**
CA - Started by explaining the aim of the study
CA - Can you state your name and your current course?
DA - States her names, then continues that,
I am doing biomedical science; my degree will last for four years because of the foundation year.
CA - Were you taught the historical context or the meaning of the word mole, at any stage of your studies?
DA - I was first introduced to the mole concept when I was in my seventh grade I think, when I started to do chemistry for the first time.
CA - What is the equivalent of the seventh grade?
DA - I have done my primary education and my secondary education in Albania and basically, we started doing chemistry in the seventh grade, that was when I was first introduced to the mole concept.
That was when I was introduced to chemistry in general and the mole concept, with one mole, two moles etc
CA - At what other levels of study did you encounter the mole, after seventh grade?
DA - Yeah, I mean, when I went to secondary school, I started to use the mole more, because we were doing stochiometric exercises like calculating the number of moles, for example, when you have a reaction between two reactants, in the end we have to calculate the number of moles that were used or that were formed, kind of this way. So, in secondary school we started to get more in-

depth with the concept of moles.
CA - So did you use moles in the practical sense and theoretical sense as well?
DA - Yeah, we use mole in the lab as well during some practical's when we performed some reactions, I can't remember exactly because this happened about two years ago, and in the end we had to calculate the mass, since we knew how many moles were used and we had in the end to calculate the mass in grams of a specific product.
CA - Did you use mostly the formula method to do this or another method?
DA - Yeah, the formula M is equal to grams over molar mass.
CA - How was your work assessed?
DA - This was more like in tests, during tests we had to do calculations, and we were also assessed during the practicals that I told you, as we have to do calculations and observations based on that experiment. So, there have been constant assignments and tests which have included exercises from the mole and also know that we are doing the foundation year, during which we are having exercises with moles, so it is a concept that we are broadly using even now.
CA - So would you say that the institution attaches a lot of importance to this concept?
DA - Yes, of course because most of the students that are currently in the foundation year, are students that have had a gap in their education like more than five, seven, to eight years, so basically the teacher is trying to explain not only the mole concept, but other concepts not only in chemistry but like in biology and biochemistry, but also in mole concept, the teacher is constantly working with exercises and also the success coaches are also working with the mole concept, because some of the students find them hard to understand, so I can see that the teacher is constantly helping us with it.
CA - So, have you heard of millimoles before?
DA - Yeah,
CA - In what context?
DA - Can you tell me the difference between moles and millimoles? Is it the volume over number of moles, right?
CA - An explanation of millimoles was given, using sodium chloride example.
DA - Yeah, I now understand.
CA - Most people solve mole concept problems by substituting values into a formula, is that your experience?
DA - Telling you the truth, I have never had any problems with working the moles, I can't remember having any problems.
I just usually workout from the known values to what I don't know, like with sodium chloride, I will start by working out the molar mass, since the grams will always be given, I mean in the case where we are required to find out the moles, so basically I will first find out the molar mass, and then the mass will be given, so I will directly replace them into the formula and workout the value
CA - Were you taught any other methods of solving mole concept problems, other than what you have just explained now?
DA - No, I think this is the only method.
DA - Where you ever taught the mole using analogies?
No, for example the Avogadro's number which is related to this, but no other analogies.
CA - What do you make of the Avogadro's number?
DA - I know it is six point zero times ten to the power 23.
CA - Were you taught other definitions of the mole, other than the Avogadro's definition?
DA - The Avogadro's number is the number of atoms, ions or molecules, that are found in one mole of a particular species.
CA - Did you know that Avogadro was a physicist? Yes, of course, and this is why we call it Avogadro's number in honour of him.
CA - Have you heard of a man called Ostwald before?
Have you heard of the mole being the amount of substance equivalent to twelve grams of carbon^{12}?
DA - I don't understand.
CA - Repeated the question and added did anyone ever differentiated the physicist from the chemist definition of the mole?
DA - To be honest I have never heard before that in physics and in chemistry there was a difference between the definitions of the mole. I know that there were the same. I heard about Avogadro because basically we have used them since I was like eighth or ninth grade and also now in foundation year, but not that I knew there was a difference between physics and chemistry of the mole.
CA - Okay, did you gain access to your course with formal qualifications like GCSE's and things

like that?
DA - Ehh, I haven't done GCSE's, basically I finished my secondary education in Albania and with the formal qualifications that I had, I started the foundation year so that I could complete the equivalent to "A" levels through the foundation year.
CA - About your parents' occupation, what did they do for a living?
MGD - My parents did not finish university; they are self-employed doing private business.
CA - So, what are your parents' highest qualifications?
DA - So basically, they had to finish their qualifications in Albania and their highest qualification in Albania if you do not go to university, is a diploma. They have that one.
CA - Did your parents assist you at home with your work, hire private tuition or anything like that?
DA - Yes, I had private tuition since I was like in my first grade for maths, for language and for English and when I went into secondary, I had private tuition for Biology, chemistry, maths and like for all those other subjects, I always had private tuition.
CA - Do you have a mini library at home or a bookshelf where you can read extra books?
DA - Yes, especially for sciences such as physics, biology I have always had books, and also for literature because in Albania, I don't know how literature is done here in England because e we had to read like ten books every academic year, so I have always had a library full of books and science books when I went to secondary school.
CA - Can you describe yourself as being economically disadvantaged?
DA - Well, we have like stable economic, yes, we have been economically stable, family, because my parents have been providing money and food being enough for us and also have holidays like normal family.
CA - Did your parents, teachers or friends influence your university choice?
DA - To tell you the truth, my story is more complicated, when I was in Albania, I was an excellent student, I won a place for the medical school, so if I was in Albania I would have been in a medical school.
It was me who chose the place in the university, but I had to move to England, but when I came here, the universities didn't accept my qualifications because basically didn't have "A" levels and also other qualifications that I had to choose. So, from my cousins, I heard that you could do biomedical sciences and that can give you access to do medicine.
When I came here it was late September and no universities had clearings left and London Metropolitan had clearings, so this is how I joined this university.
CA - From what you have just said, you sound like a good student, are all the students in your class in Albania as good as you?
DA - So basically, in my class, there were three students who were the same like me, we all got places into the medical school.
CA - Did your teachers use extra recourses to motivate your learning?
DA - Yeah, for all the class, especially during our last year that we have to work more with our desk, the teacher will always give us extra materials especially in literature which was one of the hardest subjects was literature, where we had to work with lots of pass papers, analysing poetry, or fragments from different books and also in maths, because maths was the hardest, so basically in maths and literature we had a lot of extra papers.
CA - Did you work with your friends a lot, including sharing notes, doing homework etc?
DA - To tell you the truth no, I have always been the person who tries to do things on my own, I can share notes in class, but not more. I have always had private tuition, so if needed any help, they can help me.
CA - Do you sometimes go to galleries, cinemas, theatres, concerts etc?
DA - When I was in Albania, yes, but not in England I have never been yet to galleries or theatres, because they are closed due to covid-19.
End

Gisela (GA**) 1-2-1**
I.2.4; Gisela (GA) 1-2-1
CA - Introduced the mole concept, stating its aim.
GA - My names are "Gisela', and I am the biomedical science foundation year, just finishing it now.
CA - Were you taught the historical context and the meaning of the word mole in Greek, during any stage of your studies?
GA - I believed it was briefly discussed yes, but I don't remember what it means in Greek anymore.
CA - When you did first encounter anything concerning the mole concept?
GA - I think that was in chemistry, in my boarding school in Germany. It must have been around

two thousand and thirteen.
CA - What level of study was that/
GA - It was the English equivalent to “A” levels.
CA - Did you encounter the mole concept at any other level of study?
Yes, at the foundation year.
CA - Have you ever used it in practical terms?
GA - That depends if you mean in conversations with my mother in practical terms, yeah, then actually to put it in practice in a laboratory, No.
CA - But have you done some laboratory work?
GA - No, just school experience.
CA - Have you heard of millimoles before?
GA - Yes, millimoles, Yes, I think it’s a hundred
CA - Okay, so what do you think it was?
GA - It would be moles divided by ten to the power of four, or the to the power of three, I am not quite sure anymore, but milli means a hundred, so that would be a hundredth of one mole.
CA - Yes, it’s a thousandth, and explained with water example.
So how much importance was the mole in your current course?
GA - I think it’s very important, even though I haven’t putting much attention as I should, it’s very important since it handles all the concentrations and dilutions and it measures how many molecules you have basically so, I think it’s very important for what I am about to do with my life I guess.
CA - Most people solve mole concept problems by substituting into a formula, was that your experience?
GA - Yeah, usually we have formulas that handles moles, in the beginning in school I was taught that one mole was a particular number, then you can relate that to the periodic table where you have the relative atomic mass.
So that’s how I learned it, through that formula and relating it to the periodic table.
CA - There are two definitions of the mole, were you taught any of them?
GA - Definition of the mole, I only learned it in terms of the number, I can’t think of the other definition what that may be. I only think of it in terms of numbers.
CA - Have you heard of Avogadro?
GA - Yes, the Avogadro’s number
CA - I explained the difference between the definitions with water analogy, differentiating Avogadro’s definition from Ostwald’s definition of the mole, including a NaCl example.
GA - I usually prefer the mathematical equations, because I am mathematically inclined.
CA - The mathematical method using formulas, will that give you more understanding of the problem you think?
GA - Yeah, equations are usually very clear, since you are putting things equal to each other, so you can work out what you are missing.
CA - Were you ever taught other methods of doing mole concept problems?
GA - Yes, yes, I was.
CA - How did you gain access to your current course? Was it through GCSE or access course?
GA - I have German equivalent to “A” levels, because I went to school in Germany, it is kind of like GCSE’s we have the same, or its equivalent to a Baccalaureate, we have the same kind of classes, we have a focus on three different subjects, so it would be equivalent to “A” levels.
I am not sure if that is GCSE’s that’s why I am giving you this long answer.
CA - Can you state your parents’ occupation again, I know you did fill in the questionnaire, can just do it again?
GA - Yes, my mother is an auditor for pharmaceutical companies, she works for the government, I think it’s a governmental, firm and my dad is an engineer, it’s very broad, because he works with water waste, he works for big factories everywhere,
So, it’s quite broad, I would call it a machine engineer.
CA - And your dad’s highest qualifications
GA - Yeah, he has two diplomas I believe.
CA - Did your parents assist you at home with your schoolwork?
No, I received little help, except the books that they had in their library, because they are in Germany, and I am over here.
CA - I mean help when you were growing up in primary and secondary schools?
GA - I was part of a boarding school, so I lived at the school and only saw my parents during weekends, so we didn’t really talk too much about school or the concept or maths or those kinds of topics.

It was usually just, we talk very little time to spend with each other, so unfortunately that didn't happen, but I had a lot of mentors and tutors in the boarding school that I was at, who were with us twenty-four-seven, so there was a lot of help there that was basically substituted our parents, I am not sure how you can put that into your questionnaire, I am very sorry.
CA - Did you have a library in your home you said earlier?
GA - Yes we had a library with excess materials.
CA - Would you say that your current course now was inspired by your parents, or was it friends and teachers?
GA - I think my parents definitely influenced the choice of my current course, from their occupation and from what they have laid around because that's the kind of environment that I have been exposed to.
CA - So, from this I can deduce that you are not from an economic disadvantaged home at all?
GA - No, not really but, it's only the materials, only the books, if I didn't pick the books, I would never learn about this, I would never had chosen biomedical science
CA - Did you receive any form of motivation from your teachers to undertake your current course?
GA - No, I don't believe so, I don't think there was any particular push in that direction, I think there was a push towards literature and writing, I think more of the Arts.
CA - But your boarding school did help to solidify your foundation.
GA - Yes, they did help, very well, their science department is actually well developed, they had a lot of equipment, they had a lot of good teachers, a lot of good courses, I think that definitely influenced me in a way, just by the things that they were offering, not so much by the way that motivation was
happening, but more the equipment that were there and the teachers, the way that they were teaching.
CA - Were you also influenced by your friends, like doing homework together, or discussing thing etc?
GA - Yes, you could say that, you could definitely say that, there was influence there.
CA - Who suggested your current course?
GA - It was myself.
CA - Do you sometimes go to galleries, theatres and concerts?
GA - I did you know before Covid, but I now just attend the online events, I do try to stay up to date with those things though.
CA - From your responses, you have demonstrated that you have a good understanding of the mole concept, but why did you indicate in the questionnaire that your understanding of the mole was 1 out of 5?
GA - I think it was because I was really insecure about the mole concept, I didn't really understand what the mole concept means, I just understood what a mole is, but I thought perhaps it was some form of other information that I didn't know about, by making it a concept.
I found out what the mole is, I found out what Avogadro' number is and how it's used, but I thought there was more to it because it says mole concept, perhaps that was a mistake on my part.
CA - So now, between one to five, how would you rate your understanding of the mole?
GA - I would say four, because talking to you kind of validated my understanding of the mole.
End

I.3; LECTURERS INTERVIEWS

I.3.1; Dr. Luke (DrL)
CA - And what course are you currently lecturing?
DrL - I teach the BSc chemistry degree.
CA - At the level of lecturing, do you have to teach the mole concept?
DrL - No, currently I don't teach the concept of the mole.
CA - So have you taught the concept before?
DrL - Yes, previously before yes, I have.
CA - At what different levels did you teach the mole concept?
DrL - I taught it at levels four, which is first year undergraduate
CA - When teaching the mole concept, what types of students did you teach, were they non-traditional students / mature students?
DrL - It was a very diverse and different types of students in the first years' group that we have in the first year, so the first years module that I taught it on, included all of the biology students as well as the chemistry students and also pharmaceutical science, forensics science and pharmacology

etc, so every single first year between the bio sciences and the CPS cluster, would have been in the lecture.
So that gives you a range of different groups that are in the class, so there were mature students, males, females, different ethnicity, races, different disabilities as well, so it was a very broad range of people in the class.
CA - So, would you have had more non-traditional students who would have come in through access courses and not the traditional “A” levels?
DrL – Yes, I mean generally speaking, we have more non-traditional students group, so I will say more people come through access and NVQ qualifications than from “A” levels.
CA - Are most of the students from deprived backgrounds or not?
DrL - Again, usually the university generally has a high percentage use, I think the university is usually about sixty to seventy percent of students come from high multiple levels of deprivation, yeah! So, it’s a diverse cohort of students.
CA - Thanks, so what does the curriculum or course material prescribe for teaching the mole concept, or do you have the flexibility to do what you wish, or do you have a prescribed course to follow?
DrL - No, we have the flexibility to do whatever we wished
CA - Thanks, do you often teach the historical context of the mole concept?
DrL - What do you mean by that, or going back to who decided it or what?
CA - Yes, starting from the Greek word mole, did your students know where it came from, and what it means?
DrL - No, No, I never taught them that.
CA - Is it because the system did not require that?
DrL - Yes, it’s not a requirement, and also I don’t think it adds more to the gravitas of the concept, because something that happened so long ago students now are certainly not interested in facts like that, they are more interested in the applications of it.
CA - Do you think that, if the students know that the mole means a hip, like a hip of sand or that sort of thing, if they knew that information, would that have benefited their conceptual understanding?
DrL - No, I don’t think so.
CA - Okay, in teaching the mole, do rely mostly on the use of formulas, or do you use other methods?
DrL - Well I use to relate it into yields of reactions; we went through moles as part of that then working out percentage yields, so it’s like related to one of the lab classes they get on their Thursday afternoon module, so it’s like linking two modules together to show how the theory would help them with the actual practical aspects of working in the lab.
CA - Did you ever explained, or do your students know about millimoles?
DrL - They don’t specifically know that, but they should be able to convert between the two because they learn about the scientific notifications in the foundation year and again in the first year.
CA - What type of institution did you attend yourself, you just mentioned London Met during your BSc. was that the only one you attended?
DDS - No, no, I attended the University of Manchester for my degree and my PhD, I did some post-doctoral work there as well, and then I moved to Oxford and did some post-doctoral work there as well and became a teaching fellow.
CA - How did you assess the module, was coursework or tests or did you use both etc?
DrL - It would be in a mini test, in a small percentage test
CA - And the test would be mostly like a summative assessment where you ticked the right answers, that sort of thing?
DrL - Yes, mostly yes it would be the opportunity to do summative tests as well, so sample papers and tutorial questions to allow them to work out problems before they have an assessment on it.
CA - How did you learn the mole concept yourself, and was that different from the way you teach it now?
DrL - If I am perfectly honest, I can’t remember how I was taught the concept of the mole, it was a long time ago.
CA - Is the mole concept easily understood by most of the students you teach?
DrL - Yes, I would say so, yes.
CA - Do you sometimes use mole concept analogies to bring the topic to your students’ experience?
DrL - I use pictures of the moles in my lecture slides, to show them how to work out a limiting reagent in a reaction, so I relate it to the size of the mole and said you can’t obviously produce any more product than the amount of moles that you start with, so that related to the size of the mole

that was on the picture.
So, then we looked at which mole was bigger and then we decided that, that was the limiting reagent.
CA - Are you from an affluent family yourself?
DrL - Say that again?
CA - Are you from a middle class, upper middle class or working class, or how can you define yourself?
DrL - I will say working class.
CA - Thank you very much for taking part.
I will send you a copy of Periodic Puzzle, a puzzle game that I invented myself.
End

I.3.2; Dr. Kan (DrK) 1-2-1;
CA - I explained the bases and aim of the study.
What science subject are you currently lecturing?
DrK - So I do organic chemistry, that's my main field.
CA - And you are Dr Kan, isn't it?
DrK - Yeah!
CA - I saying this for the advantage of the recording, and I will also send you a consent form, as permission to use the data for the research.
CA - At what level of lecturing did you teach the mole concept?
DrK - I don't actually teach the mole concept, that's done by Doctor [redacted] at level four, but I teach all the levels all the way up to masters, [redacted] teaches the mole concept in the level that I am involved with.
CA - Okay, but have you ever taught the mole concept before?
DrK - Not in a lecture, I have done it in one-to-one sessions, but not in a lecture setting.
CA - That is still significant, okay, when you were teaching the mole concept, what types of students did you have to deal with? Were they more non-traditional students who came in through access courses, or were they traditional students?
DrK - They are all typical London Met students who come in through the non-traditional routes, so we are talking either through the foundation year, or access BTEC things like that.
CA - Okay, so would you know if most of the students are from deprived backgrounds
DrK - I don't know, but most of our students are from the high IMD so I would assume they were.
CA - Okay and how was their understanding of the mole concept?
DrK - So, the way that I do this, obviously they have been to the lectures, so they come for extra help, so the way I would do it would be doing worked examples with them, that's the way that they sort of understand it. Also starting to give them practical examples of something that they would have done in the lab. Like when we do the aspirin synthesis in the same week that they did the mole concept, we do an aspirin synthesis where they have to learn percentage yield.
So it's showing them an example where they have to balance the equations, so they get to write stoichiometry and then obviously working out the number of moles
CA - Okay, so most of the time, to work out the number of moles, do you teach them reasoning methods or do they use equations to get the answers?
DrK - In terms of working out the moles, the way it is taught is they use the "triangle", so they all know that mole is mass over molar mass, they all know that and that's how it's taught to them and because that's the way they understand it, that's the way we sort of go with it.
And then obviously we teach them number of moles equals concentration time volume as well, so they get both of those triangles, that's how most of them would learn that.
CA - So, have you ever dealt with millimoles before?
DrK - Emm, have they dealt with millimoles? Not at level four, we do practicals at levels five and six which are on smaller scales, so we are not actually directly teaching them the mole at that level, but they have to work at millimolar scales at levels five and six.
CA - What type of institution did you attend yourself?
DrK - My background is, I did an undergraduate MSc at Kings College and then I did my PhD at Birmingham university.
CA - In the assessment of the mole concept work, how do you assess the students, is it through course work, or tests.
DrK - Where we directly teach the mole concept, it's done through either a series of mini-tests and then the final exam, but obviously they apply it in coursework, like I was saying, they have practical on the same week that we teach and that's a written practical report, so there's coursework there

as well. So, it's a mixture of coursework and exams and tests.
CA - The way you are helping the students work out the mole concept, is that how you learned it yourself?
DrK - Yes, I was taught the triangle yeah, It got to the kind of way that I don't need the triangle anymore, but the way that I was taught the triangle to use that as well yeah.
CA - And would you say that the way you teach it most of the students understand it easily?
DrK - It's a difficult one, because I would say obviously when you teach them the concept, they can do a said method because that's how teaching them the method, they apply the method at later time, it's just for them to understand when and where. Obviously, the weaker students find it a bit more difficult, but most students can work out the number of moles if you ask them to.
I think the biggest thing for them sometimes when we teach level four, is the unit conversions, sometimes they have the mass in kilograms instead of grams or they may have the volume in millilitres instead of letters. Things like that, so that's where the common errors occur when we teach them.
CA - So do you sometimes use mole concept analogies to bring the problem to life or to the students' experiences?
DrK - No, because I don't teach, because whenever students come to me is because they want to me to go over a worked example, so I just go over the example. I don't use any analogies so to speak.
CA - About your background yourself, are you from an affluent background, what class system?
DrK - Yeah! I would say I am middle / working class yeah; my generation was the first to go to university.
CA - Your parents, were they middle classes?
DrK - Working class, my parents were not born in this country, they were not English.
They moved over about forty years ago or something like that and I was born in this country.
CA - We are trying to establish that the mole concept is socially constructed within the science community, because the physicist would think of it as a mathematical constant, while the chemist as amount of substance and the pharmaceutical and healthcare industry as millimoles.
Is this distinction made clear to your students?
DrK - We don't tell them directly, but in term of what you just said, we do use Avogadro's number to work out the number of particles or number of molecules using the mole concept, so we do, do that at level four with the students.
At level four like you said with the chemists, we go over the mole as a mole as well and then at level 6 where I do a practical, where the students are put into a situation with a pharmaceutical company where they have to do a synthesis, two different ways to make the same compound, they are told they had to consider the idea of working on small scale and then consider when you are making your own large scale industrial applications, so they understand the concept of going from millimolar scale to kilogram ton scale at level six, that's where I introduce that bit there.
To add one more thing, when DrL does teach the mole concept, we do have the partnership called learning science where we go through a step by step way of how to work out the number of moles and then we got worksheets that they provide, that actually randomise the numbers, then they can work through at their own time and then get instant feedback from doing these, so if they going wrong, they wouldn't get it wrong at the end because the worksheets wouldn't let them continue, so they would carry on doing it and they get feedback.
So, for example if it say what's the number of moles of X, if they don't get it right, then they'll get instant feedback from the worksheet and then they can do it again until they get the right answer. So we are giving them lots of examples as well, I think that is key to the students.
So, when we teach the mole concept, that's taught not only to chemistry students but to anyone who is doing one of the wet sciences, any of biology subjects, any of the chemistry and pharmacology related subjects.
CA - Okay, I liked the feedback element there because it introduces formative assessment.
When I ask about assessment, I was trying to see the summative and formative elements of assessment. So, it showed a good balance.
DrK - I think the student are loving as we do the examples and we have the tutorials and we have mini tests and then we have this formative exercises that we put up for them as sort of extra work that they can do and I guess one of the key things is, we don't want the students just to learn the mole concept in a module, so we try to have it across other modules as well, so I lead the module where DrL teaches the mole concept, but then we teach it in our lab science module in terms of the applicability of what we taught them in the module that I lead, so it's sort of cross taught, we want to be able to apply it, which is key, instead of just learning it.

CA - Thank you very much. very useful. I will send you a copy of Periodic Puzzle, a puzzle game that I invented.
END

I.3.3; Dr Paul (DrP)
CA - What science subjects do you lecture?
DrP - I taught chemistry, with Open University, (O.U.) also foundation level maths, physics, biosciences, earth sciences, communication skills.
CA - At what levels of lecturing do you have to teach the mole concept?
DrP - University foundation courses, PGCE chemistry teachers, all post 18 years.
CA - When teaching the mole concept, what types of students do you have to teach?

- Are they predominantly non-traditional / mature students?
- What proportion of traditional students are in your classes?

DrP - Apart from reinforcement of the concept to traditional student entry, some has been to non-standard entrants, such as O.U. and foundation, especially at London Met.
CA - Would you know if most of your students are from deprived backgrounds?
DrP - Backgrounds were never mentioned, discussed, or an issue unless a particular problem arose, which was extremely rare, and I cannot recall a particular example. except the occasional times when a student might request to leave early for childcare or medical appointment reasons. In fact, there were probably more diverse backgrounds originating from my 30 years of Open University tuition, and rarely made any issue at all, & were often the hardest working and most determined and successful. They just got on with their work, and I tried to encourage without fear or favour.
CA - Are your students easily teachable?
DrP - What do you mean exactly by “easily” teachable? I rarely, if at all (except for occasional noise) had discipline issues, some students understood quickly, other took longer, some never really made it. Success depended on interest levels, work ethic and desire to succeed, as was my case all those years ago. You get out what you put in.
CA - What does the curriculum or course material prescribe for teaching the mole concept?

- Does it give you flexibility in how you teach it?

DrP - You can be as flexible as you wish provided the concept is learnt, understood, appreciated, and can be applied correctly.
CA - Do you teach the historical context and origin of the mole?
DrP - In part, yes, but depends on the group of students. I went into a little of science history generally with my PGCE students. Otherwise, the mole was introduced as the chemical unit of quantity, the coefficients in a correctly balanced chemical equation showing the mole ratio, and from there, reacting masses and products can be deduced. See Q14.
CA - In teaching how to solve mole concept problems, do you rely mostly on the use of mole concept formulas, or do you use other methods?
DrP - After defining the mole as a unit of quantity, it was best just to go straight into worked examples which generally simplified the ideas. This requires a certain maths ability to understand powers of 10, fractions, ratios, proportions, and decimals.
This is all key material; you don't want a medic or similar giving you an incorrect dose. Does happen.
CA - How often does the students you teach deal with millimoles?
DrP - The ideas of relative magnitude was generally taught after the mole concept had, hopefully been grasped, often in future lab based modules involving practical or analytical chemistry. (e.g. Bioanalytical). The student might be given one reactant mass and have to work out the others and maximum product yield based on a correct chemical equation. As we generally deal with small quantities in analysis, then pico, nano, micro, milli, etc would all have been explained and used. Some of these ideas and associated numerical manipulations and conversions were not always found to be easy by some students. No easy way out. Just practise.
CA - What type of institutions did you attend (schools, universities etc)?
DrP - Do you mean where have I taught or where was I educated?
Virtually all my academic career has been in the University sector, Post Grad at Uni of Sussex, Uni of Herts, Open Uni, and after retirement, p/t at London Met, Uni of East London and Uni of London, Queen Mary College.
CA - How did you assessed the mole concept module, was there coursework or mainly test?
DrP - Assessments not generally done at Unis and courses requiring A level or equivalent entry, but might require reinforcement in practical classes, i.e. as in answer to Q9. At OU, no direct Q on moles, but calculations involving moles/ gas volumes etc could be part of longer questions. Work

based around the concept

For instance, burning natural gas:

CH4 + 2O2 = CO2 + 2H2O.

Energy is given out to cook, or heat, or power motor vehicles. The Chemist uses the unit of Joules per mole of methane, whereas a physicist uses Joules per kg of methane. This is a lot more methane. (Quite different answers, one mole methane is only 0.016 kg).

One analogy I have used, not so much in calculations, but to illustrate the magnitude of one mole and the smallness of atoms and molecules.

One mole of anything contains 6 x 10*23 identical 'anythings'. Mini motor cars if you want a mole of mini's !!!

To illustrate the smallness of matter, one mole of water is 18gms, about a teaspoon. This contains 6 x 10*23 water molecules. This is 100,000 greater than all the grains of sand on the Earth. So, you would need every grain of sand on hundred thousand Earths just to have same number of water molecules in one teaspoon of water. (By the way, atoms/molecules are huge compared to the particles that make them up. If an atom was scaled up to size of the Earth, the central nucleus, where the atom's mass is, would be size of a football).

The number 6 x 10*23 is also huge compared to number of seconds since the Big-Bang, assumed to be 14 billion years ago. The time that has elapsed since this event, (4 x 10*17) would have to happen a million times (10*6) over to equal the number of water molecules in a teaspoon.

All a bit staggering.

would be done in tutorials, often in classes of ten or less. Generally, OU students would grasp the ideas quickly. Also reinforced at Summer Schools. More formal assessment procedures for non-standard entrants, say on a Foundation course at London Met. Here there would be tutorials following lectures with lots of practise questions, and regular mini tests with feedback, + lab work.

CA - How did you learn the mole concept yourself and is it different from the way you are teaching it now?

DrP - Very different now. At school it was then called the gram-molecule, and from my poor memory was introduced via Boyle's Gas Laws. However, it was not really a big thing, and only when I worked in an analytical lab, pre-University, one of my peer group colleagues showed and explained ideas and calculations in words of one syllable. i.e. do this, do that, divide by this., etc.

(I was taught how to solve algebraic equations at school similarly, not from the teacher but the boy who sat next to me. He explained method in schoolboy language). We did run some London Met tuts that way with good, more advanced students helping in tutorials.). Seemed to work ok but wasn't continued.

Hi, more about the mole concept with reference to your questions 7 and 12.

I had been thinking, "how was I taught it", and realised I hadn't been, it was picked up in bits and pieces along the way.

When I was at school the mole was not a topic as such. We worked in equivalent weights and Normality. In this way all reactions became 1 to 1 so reaction (mole) coefficients became unnecessary in calculations. The reacting weight, (we now called mass), of material was divided prior to process according to how it reacted, so that no factors were involved in subsequent calculations.

Acid mass was divided by how many replaceable hydrogen atoms.

Eg Sulfuric acid, H_2SO_4, has 2 replaceable H, hence gram-molecular weight (what we now call molar mass) = 98, was divided by 2 when originally weighed out to take the factor of 2 into account. 98 divided by 2 = 49. This was called the equivalent weight of sulphuric acid.

For metals, equivalent weight was their gram-molecular weight, (GMW) divided by valency, thus magnesium, GMW =24, valency = 2 had an equivalent weight =12.

Equivalent weights of reagents such as Oxidants, e.g., potassium permanganate, $KMnO_4$, were determined by how the oxidising part changed during the reaction. Manganese, (Mn) changes in valency from +7 to +2, a change = 5, so equivalent weight would be GMW, (158) divided by 5.

For aqueous solutions of reagents such as sulphuric acid, potassium permanganate, the desired concentration would be prepared using not the GMW, (the mole), but from the Equivalent weight, and such solutions were termed "Normal".

E.g., a 1N solution of sulphuric acid would contain 49 gm of sulphuric acid per litre., a 1N potassium permanganate solution would contain 158 /5 = 31.6 g per litre.

Nowadays by direct use of the mole any reacting factor enters the calculation, solutions are made up using the mole, (molar mass) and are called molar, thus a 1M solution of sulphuric acid contains

98gm of sulphuric acid per litre. If we wanted to make an allowance for having 2 replaceable H atoms, we could still weigh out 49 gm per litre, but now solution would be labelled 0.5M The factor of 2 has to be taken into account in any subsequent calculation. Similarly, with potassium permanganate, a 1M solution would contain 158 gm per litre. Again, in practise, we could take the factor of 5 into account, and weigh out 31.6gm per litre, the solution would be labelled 0.2M, and reaction factor of 5 taken into account later, in any calculation.

You can see that the mole concept when I was at school was unimportant because it wasn't used directly as it is now. All analytical processes were 1 to 1 and factor taken into account in original weightings. Now factors appear in the calculation, but at least you know how much material is in the reagents irrespective of subsequent reaction. In the days of Normality and equivalent weights you needed to know in advance what the reaction stoichiometry (ratio) was in order to produce the 'Normal' solutions.

You will, I'm sure, be just as confused as I was at school, and all the above I have only really learnt subsequently, and the idea of moles and molarities (solution concentrations) only came slowly, the changeover point being much the same time as physicists changed from cgs to mks unit system, late 1960's. Hence, I was never really taught the mole concept as such, I just picked it up bit by bit, via experience, necessity, fellow students, and colleagues. Teaching a topic is the best way to learn it. I never understood Buffer solutions till I had to teach it!!!

CA - Is the concept easily understood by majority of your students?

DrP - Students may find it challenging to start, but once you start giving plenty of examples in tutorials, and lab classes, confidence grows, and most achieving students find it less demanding than some areas. They still may find calculations difficult, however, even if the mole part is ok.

CA - Do you sometimes use mole concept analogies to help your students learning?

DrP - Analogies can be helpful, as I said, the mole is just a non-standard unit of chemical quantity, as chemists work with numbers of reacting particles.

E.g. 2H2 + O2 = 2H2O tells us the 2 moles of Hydrogen react exactly with 1 mole of oxygen to produce 2 moles of water., or any equivalent fraction, say, divide all by 4. Then half mole of H2 reacts exactly with quarter of a mole of O2 to produce half mole of water.

We can then calculate using atomic/molecular masses exactly how much of each reactant we need and how much product will form.

Physicists do not use the mole. They only use the mass unit Kg. Hence, they cannot use chemical equations in the same way as chemists (and biologists) do.

In those days nothing stood in the way of academic success, state schools generally good and all free, with transfer between Grammar and Secondary modern for late developers, technical schools for less academic students, and all courses, e.g., O and A level were available in colleges post school. Also, City and Guilds, National Certificates, Uni and College degrees, no fees, and you got a grant, so poorer families were not discriminated against as they are now with £9000 per year fees. Awful.

Another thought that needs clarification.

Chemists and biologists) work using reacting particles, the mole.

Physicists work in kilograms.

Thus, chemists look at processes in terms of reacting particles, (mole ratio) and can make comparisons by keeping number of particles (the mole) constant, hence units of per mole (of substance.).

Physicists do not use reacting particle, they work by comparing reacting masses, (thus particles are not constant) with units of per kg.

Strangely, for a group of scientists known for their rigour, this, in my opinion, is an incorrect way to ascertain comparisons.

For instance, if you are comparing fuel energies, surely you must work by comparing the same number of reacting particles, irrespective of their actual mass. If not, the comparison is meaningless. That way, like subjective use of statistics, you can "prove" whatever you wish.

Thus, with central heating fuel, Methane, CH_4 1 mole = 16gm, contains 6 x 10^{23} methane molecules. When that burns $CH_4 + 2O_2 = CO_2 + 2H_2O$, and energy output is joules per mole of methane, i.e 16 gm (0.016kg), 6 x 10^{23} particles. Also, easy to calculate minimum amount of oxygen needed to ensure complete combustion (to avoid carbon monoxide formation which can cause death). As methane and oxygen react in 1 to 2 mole ratio, (from balanced equation), you need exactly 2 mole of oxygen gas, 2 x 32gm, = 64gm, as minimum requirement. So easy.

The physicist considers the energy output per kilogram of methane, (which is 1000 /16

62.5 moles, = 375 x 10^{23} particles). How can he calculate easily how much oxygen gas is needed if not working with simple mole ratios of reactants? The Physicist can't, without going back and converting all to moles, and using moles equation. So why not use moles in first place?
1kg = 1000gm, convert to moles, = 62.5, from equation need twice as many moles' oxygen as methane, hence need 2 x 62.5 = 125 mole oxygen gas for complete combustion, = 4kg.
For combustion of a petrol, $C_8H_{18} + 12½O_2 = 8CO_2 + 9H_2O$,
Here, 1 mole of octane, 114gm, 6 x 10^{23} particles of octane require 12½ moles oxygen gas for complete combustion, = 400gm. Note, as equation coefficients are moles, (half a mole would just be 3 x 10^{23} particles), fractions are fine. In the "old" days when we didn't use the mole, you could not have half a molecule, so you had to get rid of fractions.
The physicist uses 1kg of octane, (which is 1000/114 moles = 8.77 mole). Can only calculate how much oxygen by mass to mole conversion, then x 12½, = 109.62 moles, = 3.5kg.
Thus, the chemist can easily compare fuel efficiencies/ costs on a rational basis, etc as using constant number of particles but physicist can't, as different number of reacting particles per kg per different substances. Hope this helps, good luck,

Appendix II: Recruitment Questionnaire.

Understanding the influence of our previous studies on our experience of degree level Chemistry

Before you decide to take part, you should understand why the study is being done and why you have been asked to participate. Please take time to read the information below carefully. Participation is entirely voluntary.

All results and comments that are collected for this study are anonymous, with any outcomes being reported as summary statistics.

Background:

Purpose: We are undertaking this study to gain an understanding of the factors that contribute to students' attitudes to, and expectations of, their chemistry studies.

We are asking a wide range of level 3 and level 4 students to complete a short questionnaire to gather information about them and their attitudes to/experiences with their chemistry studies. The information collected will then be analysed to determine associations between various personal characteristics," the mole concept' and the factors that may influence attitudes to Chemistry.

By responding to the survey, you will be helping to improve your experience of studying at London Metropolitan University, and the experiences of other students. The findings of the survey will be a contributory element to a PhD the learning of the 'mole concept', as experienced by undergraduate chemistry students - Charles Agbor.

If you have any concerns about participating in the survey, or if you would like more information about the study, please contact Charles Agbor [e-mail: egbe_agbor@yahoo.co.uk] or Mary-Jane Poku [e-mail: m.poku@londonmet.ac.uk].

THANK YOU, your experiences make a difference and help us redesign our degree provision.

Appendix III

V1 Student Participants Consent Form

The socio-cultural aspects of the Mole Concept as experienced by undergraduate chemistry students.

The research aim is to understand the role of sociological factors such as habitus, field, and forms of capital in shaping undergraduate chemistry students' experiences of the mole concept.

OBJECTIVES;

In order to achieve the above aims I will;

1. Investigate how undergraduate chemistry students construct their understanding of the 'Mole Concept', by exploring their experiences of using the different methods of solving mole concept problems in the context of social justice.
2. Investigate cultural influences that helped to shape their home and choice of institution for study
3. Investigate forms of capital, including social and cultural capital, which may highlight the influences of their social groupings.
4. Explore students' highest family educational achievements, to highlight the above further.
5. Examined the form of assessment, to highlight further inequalities embedded in the teaching and learning of the mole concept.

RESEARCH QUESTIONS;

The principal research question for this study is:

How can we understand the socio-cultural influences that shape undergraduate chemistry students' mole concept experiences?

CONSENT FORM

I understand that:

- The aim of this project is to gather information on undergraduate chemistry students' views and experiences of studying the Mole Concept
- My participation in this project will be in an interview / online focus group which will be recorded and may last between 30 minutes to an hour.
- My participation in this project is entirely voluntary and that I can withdrain from participation at any time.
- The information gathered from me will be anonymous (no one will be able to identify which responses I have given).

I accept that the information gathered from me will be used solely for academic research purposes.

Signed:...

V2 Lecturer Participants Consent Form;

Deconstructing the mole using sociological filters to explore science students' mole concept experiences.

The research aim is to understand the role of sociological factors such as habitus, field, and forms of capital in shaping undergraduate chemistry students' experiences of the mole concept.

OBJECTIVES;

In order to achieve the above aims I will;

6. Investigate how undergraduate chemistry students construct their understanding of the 'Mole Concept', by exploring their experiences of using the different methods of solving mole concept problems in the context of social justice.
7. Investigate cultural influences that helped to shape their home and choice of institution for study
8. Investigate forms of capital, including social and cultural capital, which may highlight the influences of their social groupings.
9. Explore students' highest family educational achievements, to highlight the above further.
10. Examined the form of assessment, to highlight further inequalities embedded in the teaching and learning of the mole concept.

RESEARCH QUESTIONS;

The principal research question for this study is:

How can we understand the socio-cultural influences that shape science students' mole concept experiences?

<u>CONSENT FORM</u>

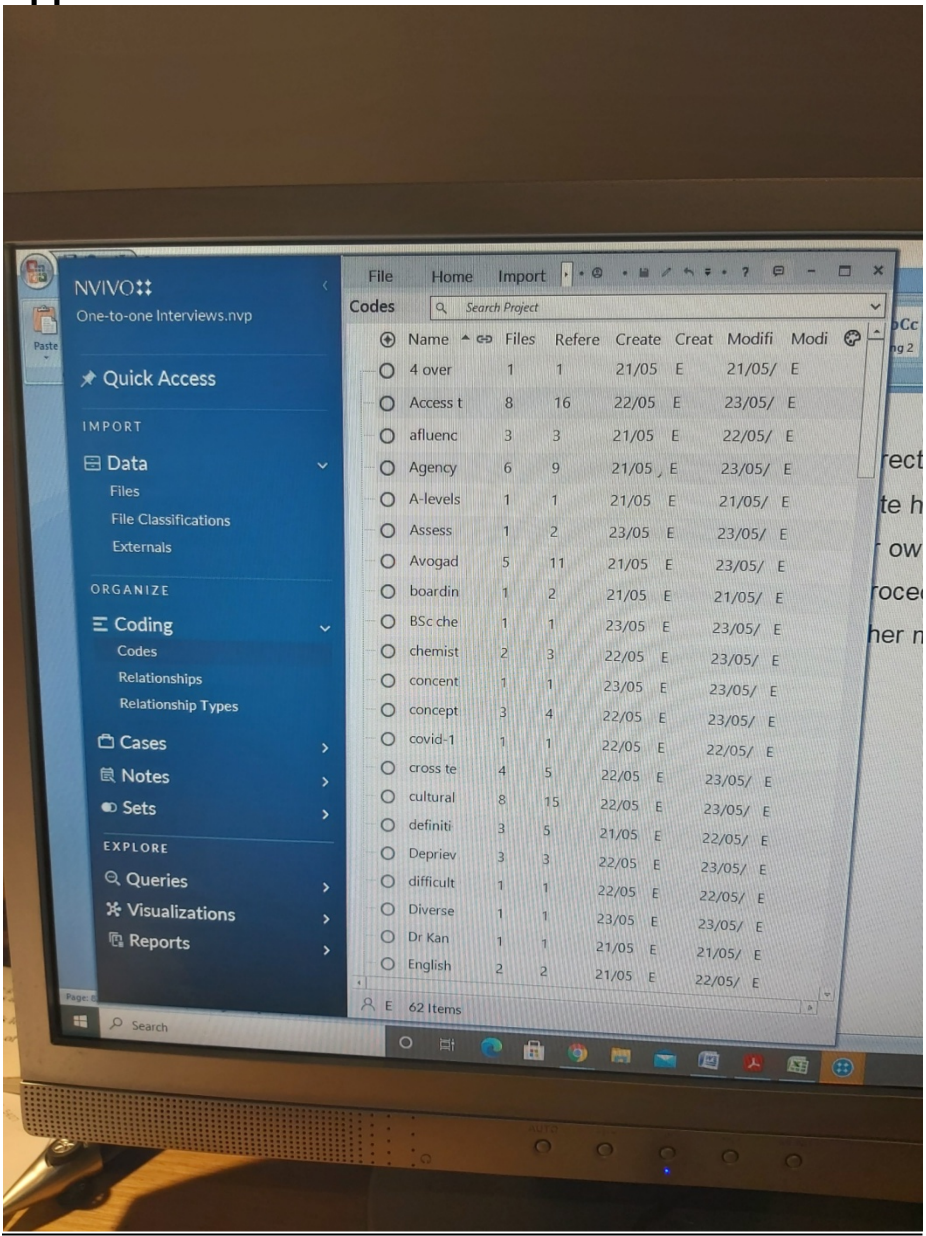
I understand that:

- The aim of this project is to gather information on science students'/ Lecturers' views and experiences of dealing with the Mole Concept
- My participation in this project will be in an interview which will be recorded and may last between 30 minutes to an hour.
- My participation in this project is entirely voluntary and that I can withdraw from participation at any time.
- The information gathered from me will be anonymous (no one will be able to identify which responses I have given).

I accept that the information gathered from me will be used solely for academic research purposes.

Signed:................................

Appendix IV - Nvivo Data Screen Shot



Appendix V: PowerPoint and Video from London Met Staff/Student Conference 2021 presentation.

Video can be found here: - https://youtu.be/w9DywFYT_bU

DECONSTRUCTING THE MOLE

by Charles Egbe Agbor

Using Bourdieu's Theory of practice (Habitus, Field & forms of capital) to understand science students mole concept experiences

Introduction

- Social Justice, (Inequalities in access, participation and outcomes.
- Means "heap" in Greek, S.I unite E.g. (length, mass, time etc)

- It is socially constructed within the science community (Oswald, 1900; Avogadro constant; millimoles).

- It's teaching and learning confuses both learner and instructor according to some studies.

- There have been numerous studies spanning several decades.
- Eg (Kolb, 1978; Niaz,1985; Januik, 1993; chui, 2005; Surif et al., 2012 etc)

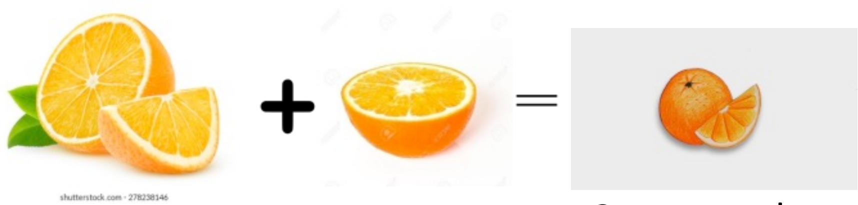
- Some studies highlighted 2 principal methods of teaching and learning the mole;

- Procedural and conceptual methods

Procedural vs Conceptual

$$\frac{3}{4} + \frac{1}{2} = 5/4$$

Procedural



Conceptual

Analogies for conceptual teaching and learning

Findings

- This study proposes the teaching of the mole in schools (KS2 or upper primary) conceptually
- The use of both procedural and conceptual methods at other levels.
- To address the inequalities
- Disparity in mole concept experiences between middle-class and working-class student participants

The study

- Qualitative narrative inquiry
- A wide range of 12 participants out of 26 respondents to a recruitment questionnaire.
- 9 science students (foundation year, BSc to PhD). 5 in a focus group and 4 in one-to-one interviews.
- 3 science lecturers with wide lecturing experiences

Questions asked to frame the narratives

- Parental occupations and highest academic qualifications to determine forms of capital and field.
- Home library to explore habitus;
- To explore the fields

Findings & Recommendations

- Habitus influences (build critical mass)
- Field influences (2^{nd} nature to middle-class students & porous thus changeable).
- Primary / KS2 conceptual teaching to address inequality (1mol H_2O = 18g ~ 18ml; salt=58g)

Acknowledgements

- Supervisors (both science & social research)
- Associate prof Sheelagh Heughs
- Dr Mary-Jane Poku

Previous;

- Dr Rossana Perez
- Dr Allison Heather
- Before;
- Prof Carole Leathwood (retired) social justice

Appendix VI: Ethics Whole document available on request

LONDON METROPOLITAN UNIVERSITY

LONDON MET RESEARCH ETHICS REVIEW FORM

For Research Students and Staff

Postgraduate research students (MPhil, PhD and Professional Doctorate): This form should be completed by all research students in full consultation with their supervisor. All research students must complete a research ethics review form before commencing the research or collecting any data and no later than six months after enrolment.

Staff: This form should be completed by the member of staff responsible for the research project (i.e. Principal Investigator and/or grant-holder) in full consultation with any co-investigators, research students and research staff before commencing the research or collecting any data.

Definition of Research
Research 'isdefinedasaprocessofinvestigationleadingtonewinsights,effectivelyshared. […] It includes workofdirectrelevancetotheneedsofcommerce,industry,culture,society,andtothepublicandvoluntarysectors;scholarship [[1]];theinventionandgenerationofideas,images,performances,artefactsincludingdesign,wheretheseleadtoneworsubstantiallyimprovedinsights;andtheuseofexistingknowledgeinexperimentaldevelopmenttoproduceneworsubstantiallyimprovedmaterials,devices,productsandprocesses, includingdesignandconstruction.Itexcludesroutinetestingandroutineanalysisofmaterials,componentsandprocessessuch asforthemaintenance ofnationalstandards,asdistinctfromthedevelopmentofnewanalyticaltechniques.Italsoexcludes thedevelopmentofteachingmaterialsthatdonotembodyoriginalresearch.'[2]

London Met's *Research Ethics Policy and Procedures* and *Code of Good Research Practice*, along with links to research ethics online courses and guidance materials, can be found on the Research & Postgraduate Office Research Ethics webpage:
http://www.londonmet.ac.uk/research/current-students/research-ethics/

London Met's Research Framework can be found here:
http://www.londonmet.ac.uk/research/current-students/research-framework/

Researcher development sessions can be found here:
https://student.londonmet.ac.uk/your-studies/mphil--phd-professional-doctorates/postgraduate-research-training-sessions/
https://www.eventbrite.co.uk/o/research-and-postgraduate-office-26844345187

This form requires the completion of the following three sections:

SECTION A: APPLICANT DETAILS
SECTION B: THE PROJECT - ETHICAL ISSUES
SECTION C: THE PROJECT - RISKS AND BENEFITS

[1] 'ScholarshipfortheREFisdefinedasthecreation,developmentandmaintenanceoftheintellectualinfrastructureofsubjects anddisciplines,informssuchasdictionaries,scholarlyeditions,cataloguesandcontributionstomajorresearchdatabases.'
[2] REF 2021, Guidance on Submissions (2019/01), p. 90