The mole misunderstood

Karen Moss* and
Amisha Pabari
Centre for Effective Learning in Science (CELS)
Nottingham Trent University
Clifton Lane
Nottingham
NG11 8NS
***karen.moss@ntu.ac.uk**

Abstract

In every area of science there are some ideas that many students find difficult to grasp. A lack of understanding of key ideas can limit a student's ability to grasp and apply fundamental principles of their discipline. Previous work in this area, by Taber, has focused on this problem at school level. However, little work has been done to systematically investigate and analyse this phenomenon in undergraduate science programmes, beyond the anecdotal. A previous study involving students and staff from a range of scientific disciplines at our university identified that the mole (and its associated applications) was a difficult area for a wide range of students. The mole shows characteristics of being a 'Threshold Concept' for students. Having identified the mole as a problem, the aim here was to explore why it is difficult and whether the conceptual issues can be systematically overcome, by using multiple perspectives. A sequence of questionnaires was used to survey over 100 people, involving school students aged 14-17, first-, second- and third-year university students, and secondary school teachers, in detail about the mole. We considered respondents' learning preferences and the type of activities in science lessons from which they felt they learned the most. Over 50% of respondents reported problems with the mole at some stage of their education. Further insights into how people conceptualise the mole were explored through the use of an educational research technique called 'Hot Pen Writing'. The outcomes of the research identified some of the reasons for student's lack of understanding of the mole concept including poor teaching in schools, difficulty in relating the concept to real-life situations and, not surprisingly, the fact that it involves maths. We consider what this suggests about how and when the mole should be taught within school education.

Introduction – chemistry a challenging subject

Chemistry as a subject divides people: some love it and others find it exceptionally difficult[1]. As it is perceived by many students to be hard[2], a significant percentage of good students in science fail to take the subject further - in 2009, only 55.7% of students that achieve an A* in Chemistry at GCSE and 35.9% of students that achieve an A grade go on take Chemistry as an A-level subject.[3]

> *'11-year olds arriving at secondary schools are keen to study science, and enthusiastic about the prospect of practical work in exciting laboratories. Some maintain this interest over the next five years, but sadly the majority find science lessons boring and irrelevant compared with other subjects'*.[4]

School chemistry often includes two very different types of learning experience: one involves bangs and smells, pouring coloured liquids and collecting gases, and using equipment such as test tubes, balances and Bunsen burners; the other comprises mole calculations, balancing equations, learning atomic and molecular structures or considering how blast furnaces work. For many secondary-age students the first type of chemistry lesson is fun; the second type is confusing and boring; significantly students make limited connections between 'fun' chemistry and 'boring' chemistry. Taber challenges us to consider that when we blithely state *'chemistry is a practical subject'*, what we really mean is *'chemistry is a practical subject... as well as a theoretical subject'*.[1]

Programmes which use a context-based approach, (e.g. Salters A-levels), teaching science through everyday contexts can encourage engagement with the underlying principles and concepts; but this is only a partial solution- there is also the need to address the deeper issues of how people learn chemical concepts.

Programmes which use a context-based approach... teaching science through everyday contexts can encourage engagement with the underlying principles and concepts; but this is only a partial solution- there is also the need to address the deeper issues of how people learn chemical concepts.

Previous research suggests learning difficulties in chemistry arise because of the challenges such as:

- Chemical concepts are presented in the classroom as the solutions to problems in which the learners have little interest in or have never experienced[5] - conceptual material that was developed over decades or even centuries, invented to solve particular chemical issues for chemists! This is a real disadvantage of chemistry as many of the key concepts are not immediately highly significant in children's lives and its applications to real life tend to be less obvious than for other subjects. Examples include: i) a focus on 'pure substances' rather than everyday materials that students are familiar with such as fabrics, plastic, wood and air; ii) the basic explanatory framework of chemistry is in terms of atoms, electrons, molecules and ions (and how they interact and are arranged) which is very different to the everyday nature of matter as students experience it: as Kind[6] found:

  'When students cannot 'see' particles they cannot really understand chemical reactions and so the fabric of chemistry is lost to them in a haze of impenetrable events completely at odds with their every day experiences of a 'continuous' world.'

- Students are given examples to demonstrate the 'solution' however they are unable to see how this 'solution' was constructed or to understand the importance of it which makes the idea abstract and so students commonly fail to grasp the intended meaning of many concepts.[1]

- When chemistry is taught there are constant shifts between talking about actual substances that can be seen or touched and explanations in terms of abstract models. This is one of the major causes of learning difficulties in chemistry as a real understanding involves bringing together these conceptual ideas meaningfully[2]. One example is the confusion between the macroscopic scale and the molecular scale. Talanquer's work describes examples of alternate student conceptions such as perceiving an atom of copper to be red in colour. Students will frequently believe the following:

  'Atoms and molecules have macroscopic properties: they expand and lose weight when heated, have uniform densities and well-defined colours, are malleable, change shape under pressure, etc.' [7]

- The working memory space in our brains has limited capacity – typically 5-7 pieces of information at once- so when students are faced with new and complex material which is usually abstract, they can have difficulty organising these ideas together which leads to an overload of the working memory space and then students resort to memorising rather than understanding (work of Johnstone, Reid etc.)[8]

  'This limited space is a link between what has to be held in conscious memory, and the processing activities required to handle it, transform it, manipulate it, and get it ready for storage in long-term memory.'

- Language also contributes to information overload and is an additional complication when students are learning chemistry. Typical issues include:
  - Specialist language explained: words/forms of language that are unique to the subject and teachers explain these to students.
  - Tacit language not explained: this is specialist language which teachers assume that students understand them from previous work or that they use without realising.
  - The language of science which incorporates not just words but a multitude of signs and symbols, graphs, charts, diagrams, equations and chemical formulae.[1, 5]

- An example of where unfamiliar and misleading vocabulary is used is the world 'volatile' which in everyday life students understand as unstable, explosive or flammable, however its scientific meaning is 'easily vaporised' which students are unfamiliar with but science teachers are used to.[2]

- Mathematical ability - The Higher Education Academy Physical Sciences Centre carried out research on chemistry undergraduates in England and Scotland to explore the difficulties university staff experience when teaching undergraduates. The largest problem was said to be the level of mathematical skills that students have. Students who have the potential to learn chemistry but are hindered by poor backgrounds in mathematics will panic when faced with problems. When students were asked what they were worried about before starting a chemistry course, the response of one of the students was *'Maths- absolutely petrified of the math and the conversions.'* [9]

- When a student has different ideas to the accepted models they are expected to unlearn these ideas – this can happen (a *labile* idea) but other misconceptions may be very stable and more difficult to modify. For more info consider Keith Taber's work on 'alternative frameworks' and 'alternative conceptions.' [5]

For university students, topics that cause students problems were previously identified to include electrochemistry, chromatography, bonding, functional groups, spectroscopy, chemical equations, analytical science, dilution factors, structural formulas and the mole.[10] The mole concept has been recognised as difficult by a number of researchers. A survey with Irish first year university students revealed that this was the topic that most students perceived as being difficult.[11] A teacher states:

> *'Moles as a concept is too alien for most to cope with and so many students give up trying to understand the real concepts... and end up rote learning the equations and applying them...this means that they can't cope with anything out of the standard question.'* [12]

Specific research on the mole[6, 13-14] reveals:

- Teachers can be confused about this concept, and transmit it incorrectly.
- Mathematical approaches to the mole obscure its chemical meaning, especially the use of ratio and proportion calculations.
- Difficulties in visualising Avogadro's number which cannot be 'seen' cause problems with learning.

The concept of the mole was first introduced by Oswald in 1890 when he was seeking the chemical formula of 'oxygenated water.' His 'mole' was:

> *'The normal or molecular weight of a substance expressed in grams.'*

Its meaning has since changed and the IUPAC (International Union of Pure and Applied Chemistry) defines the term as:

> *SI base unit for the amount of substance (symbol: 'mol'). The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles*.[13]

Into the conceptual arena has stepped a new theoretical framework across a wide range of subject areas: *Threshold Concepts* and *Troublesome Knowledge* (Meyer and Land[15]). A *Threshold Concept* is a 'core concept', a conceptual 'building block' that leads to progression in understanding of the subject. It can be described as:

- *Transformative* or seismic: once 'got' its effect creates a significant shift in the student view of a subject.
- *Irreversible*: once 'got' this different view is unlikely to be unlearned.
- *Integrative*: understanding it exposes relationships with other areas.
- *Bounded*: it affects other new concept areas.

Potentially areas of *troublesome knowledge*.
Troublesome Knowledge is defined by Perkins[15] as topics which are major barriers to learning if not understood: students are able to perform mechanical tasks and techniques, yet fail to understand the underlying concepts and the bigger picture. Students typically show behaviour such as:

- *Ritual knowledge*: perform superficial tasks and techniques to get a result but fail to understand the complexity that lies behind it.
- *Inert knowledge*: concepts are understood but not actively used or connected to the 'real world' and so there is a failure to see the 'big picture'.
- *Conceptually difficult and alien knowledge*: concepts are found difficult to grasp due to their counter-intuitive or complex nature.
- *Troublesome language:* problems caused by the type of language used during any teaching e.g. a word can have two meanings.

Threshold concepts and troublesome knowledge can cause students to become stuck in an 'in-between state' where they oscillate between their own less sophisticated idea and the understanding required by the teacher.

The mole concept is a very important topic and failure to understand the concept fully causes difficulties in understanding subsequent topics especially stoichiometry problems including volumetric calculations and concentration of solutions.[11,14] We would therefore suggest that the mole shows all the characteristics of being both a *Threshold Concept* and *Troublesome Knowledge*.

What do we do about this? Current research in threshold concepts is exploring exactly this point. Our aim was to consider why students at different stages of their education felt this way about the mole and to explore ways in which we can support students in understanding and applying the concept correctly.

Our approach

Questionnaire Design

Three questionnaires were designed to survey teachers, secondary school and university students in depth about topics in chemistry and specifically about the mole. Many of the questions on the three surveys were in common, with specific questions added or removed depending on their relevance to the respondents. All three questionnaires looked at which science-related subjects they found most difficult, their preferred learning styles and most beneficial activities during chemistry lessons, the importance of linking science concepts to real-life and the use of practical activities, the most difficult topics in chemistry and questions about their knowledge of the mole and the importance of the mole concept.

- The school student questionnaires asked about the educational background of the students, when the mole concept was first introduced, whether they found it difficult and what improvements could be made to help their understanding of the concept.
- The university student questionnaires also aimed to find out how difficult they found the transition between GCSE and A-level and reasons behind this.
- The teachers were asked about their routes into teaching and the length of their teaching experience. They were also questioned on how difficult they find topics to teach, what resources they use when teaching the Mole and how they would help out students and new teachers that were struggling with the concept.

The questionnaires were semi-structured and included a range of open and closed questions. One of the techniques used was 'Hot pen writing.' This was a type of open question that involves asking the respondents to write down as much as they can about a certain topic (the mole) in a certain time-period (5 minutes).[25] The responses provide an indication of what people do and do not know about the topic.

The closed questions in the survey included dichotomous questions (e.g. yes or no) and category questions in which respondents have to choose from a range of categories. The survey also included list questions, which required choosing more than one response from a list of options and Likert-type scales, which involved ranking chemistry topics in order of difficulty using a scale of 1-10. Closed questions tend to be preferred by respondents as they are less time-consuming but in order to gain further explanations it was essential to also include open questions. Ethics approval for the questionnaires was gained prior to their distribution.

The results from the survey were both quantitative and qualitative. Quantitative data was analysed using statistical tests and qualitative date required coding. All the responses had to be organised into a smaller number of categories which were then used to form frequency tables.[26]

In addition bibliographic research was used in this study to research how different text books present the mole to students and also how the content of the mole varies in common GCSE specifications. The specifications were all found on the websites of the examination bodies which are also used by teachers in schools and hence these documents are authentic and representative for the purpose of this study.

Participants
University student questionnaires were distributed to first year, second year, third year and fourth year chemistry students' as well as to other students at Nottingham Trent University with a background in chemistry. These questionnaires were handed out using opportunity sampling to all students during specific lectures and also in the Student Union and the library to students willing to participate. The remaining questionnaires were handed out to some students at different university libraries such as DeMontfort University and the University of Leicester. This was to ensure a wide range of responses were received from a variety of participants. The university students who responded had all previously studied chemistry further than GCSE level in the form of A-levels, access course or other equivalent qualifications.

Two secondary schools were chosen using opportunity sampling. Two tutor groups were randomly selected from each of the two schools (one year 10 group and one year 11 group from each). The students were then given the questionnaires to fill out during their tutor periods. The remaining questionnaires were distributed randomly to AS level chemistry students at a college, who had completed science GCSE exams a year ago and so still remember the contents that they had studied. This was done by giving one chemistry teacher the questionnaires who distributed them during different classes which ensured that students with different levels of ability were surveyed to avoid bias. This was also maintained in the secondary schools as a tutor group contains a range of students with different science abilities.

Teacher questionnaires were also distributed to randomly selected teachers whilst at the schools and college and also to lecturers at university. All the teachers and lecturers surveyed teach science. The period of time they have been teaching varied from less than 1 year to 15 years.

Results
Of 270 questionnaires handed out, a total of 111 responses were received a response rate of 41%. The profile of respondents was 61 university students, 44 secondary school students and 6 teachers/ lecturers. The subject profile of the university students is shown in Table 1.

Table 1: Degree titles of university students surveyed.

Degree title	Frequency
Pharmacy	5
Chemical Sciences	4
Pharmaceutical Science	3
Chemistry	45
Forensics	1
Childhood Studies	1
Biosciences	1

Popularity of subject choice amongst 14-17 year olds surveyed
Some results showed similar outcomes to previous work[3]. For example, all the respondents felt that physics was the most difficult subject of the three core science subjects, with biology the easiest and chemistry in between. The secondary school students revealed that 38% of them were studying or planning to study science A-levels (Figure1).

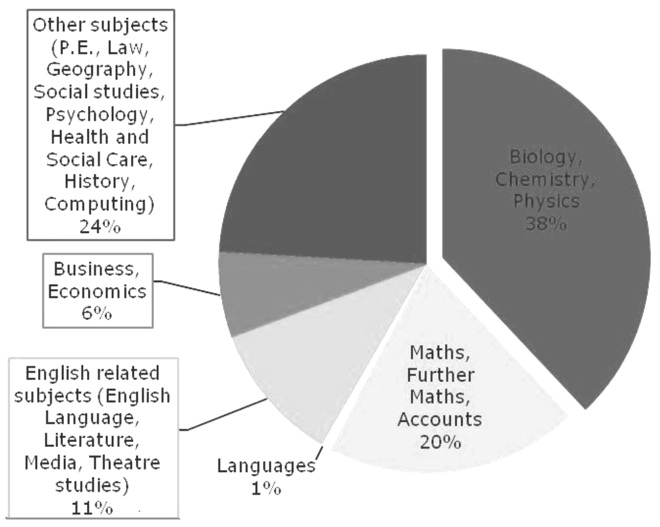

Figure 1: Popularity of science subjects at A-level amongst 14-17 school respondents.

Difficult Topics
When asked 'In your experience what are the most difficult topic(s) in chemistry to learn?' Chemical calculations, the mole and organic chemistry were topics mentioned by all groups as difficult topics (Table 2), in line with previous studies.
The mole and chemical calculations were also shown as the

Table 2: Ranked list of the most difficult topics in chemistry cited by respondents.

Teachers	University students	Secondary school students
Chemical/Mole calculations	Physical Chemistry	Chemical/Mole calculations
Organic chemistry	Chemical/Mole calculations	Bonding
Electronic configurations	Organic chemistry	Titrations
Thermodynamics	Reaction mechanisms	Organic chemistry
Quantum mechanics	Kinetics	Balancing equations
Bonding	Thermodynamics	Redox
Isomers	Quantum mechanics	Periodic table
Thermal decomposition	Transition metal theory	Chemical reactions
Balancing Equations	Energetics	Electronic configurations

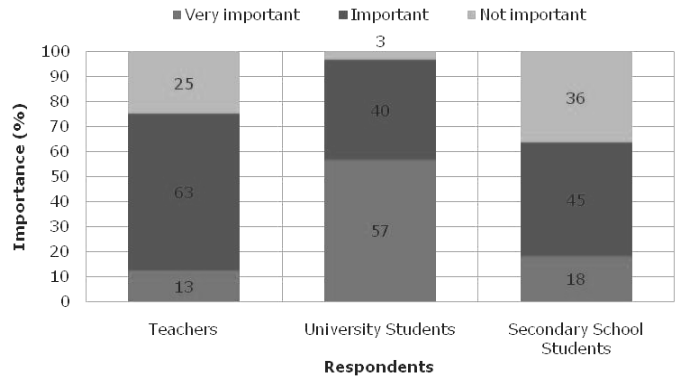

Figure 2: How important respondents feel it is to understand the mole.

most difficult chemistry related areas when the three groups of respondents were asked to rate certain topics according to difficulty using a scale of 1-10, where 1 is very easy and 10 is most difficult. Teachers scored the mole at 7.3 for difficulty in understanding, whilst pupils rated it as 5.8. University students scored it as 4.1, which implies that most chemistry students do eventually overcome issues with the mole. This needs to be considered, however, in the light of the answers to the question *"Have you ever struggled to understand the concept of 'the Mole'?"* 68% of GCSE and A-level students and 55% of the university students (who had studied the mole) stated they had struggled with this concept at one time or other.

Reasons cited by each group for this difficulty were:

- For GCSE and AS level students – "*poor resources in lessons", "confusing text books", "poor teaching", "the concept itself is confusing", "complicated", "new", "difficult to understand", "not enough lesson time is spent on the topic", "it involves maths".*
- Similar results were obtained from university students, 30% of the respondents cited *"poor teaching"* and 22% said *"it was a difficult concept to understand"*. Also cited were *"poor maths ability", "confusion", "difficulties in remembering and manipulating the equations", "no direct definition of the mole provided"* and *"difficult to relate to real life"*.

Perceptions of importance of the mole

Given that the mole is problematic how did respondents view its importance? In Figure 2 there are clearly differences in perception here (acknowledging that our teacher sample was small compared to the student sample). Explanations for these views, where given, are listed in Table 3 for students. It became obvious after our analysis that we should have explored this aspect in more detail with teaching staff.

When is the mole studied at GCSE?

The answer is 'it depends'.

- The new OCR specification *Twenty First Century Science 'features many of the major theories of science, presented in a way that will encourage young people to appreciate their significance.' 'Students explore the key science explanations which help us to make sense of our*

Table 3: Reasons stated for rating how important it is to understand the mole.

Reasons	Frequency of secondary school students	Frequency of university students
NOT IMPORTANT		
do not understand how it is related to chemistry	2	0
not used in everyday life	4	0
not going to study chemistry in future	1	0
only need to know how and where to use it	0	1
never used	0	1
IMPORTANT		
useful to calculate concentrations and volumes	3	4
need to know	2	1
important to chemistry	2	5
used in calculations	2	5
used for balancing equations	2	0
used a lot throughout degree	0	2
VERY IMPORTANT		
fundamental in calculations	1	13
a lot of chemistry revolves around it	1	9
in exams	1	2
Required to study/understand chemistry	0	7
a lot of other topics expand on knowledge of mole	0	3
required to design reactions in industry	0	1

lives...these are what we want students to take with them from the course and carry with them into their adult lives, whether or not they use science in their work.'[16] This course has proved successful in making science more relevant to students and there has been a 30% increase in the number of students taking up AS-level science subjects after taking this GCSE course[17] but nowhere in the course is the mole concept introduced to students unless they are taking triple award science in which they are required to carry out an extra module (C7) known as *Further Chemistry*. This introduces the idea of carrying out calculations using concentrations and volumes to calculate the mass but the term 'mole' is not introduced at this level.

- The OCR Gateway specification[18] encourages GCSE students to learn about the mole in module C5 called 'How much?' Foundation students are required to have a basic knowledge about the mole and higher students need to understand the concept in more detail, but all students will be familiar with the concept.
- The Edexcel GCSE specification requires students that are taking triple award sciences to have an even more extensive knowledge of the mole than the other specifications mentioned previously.[19]
- The AQA GCSE specification requires higher students to have a basic understanding of the mole but they are not required to carry out any calculations.[20]

Students' knowledge of the mole at GCSE level will, therefore, be dependent on what science specification their school follows and whether they have studied triple award science. This will also effect when the concept is first introduced to them. Of the school students, 50% of the total group had studied the mole, a majority of this group were AS students and relatively few of the year 11 students had any mole experience. Of the university students surveyed, as expected, 100% of them had learnt about the mole, 44% had first done the mole at GCSE, 48% had studied the mole during A-levels. (The rest had either studied it before GCSE or once they started their degrees; this is typical for Access students, for example.)

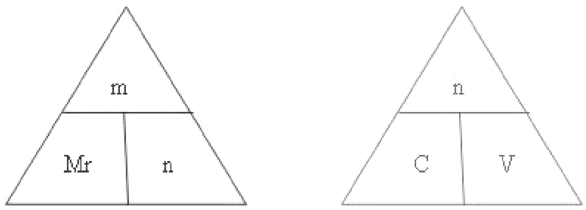

Figure 3: Mole equations in triangle forms.

Students who study, or have studied, triple award science GCSEs are more likely to have studied the mole compared with those students that took double awards and single awards. Only 34% of 15-18 year olds surveyed have taken or are taking triple science. Of these students, 78% have studied the mole at GCSE level and therefore these students will have an advantage over the other students. There is a mixture of students who have studied different specifications, taken triple award exams, double award exams and other access courses that take up chemistry at A-level. This can lead to confusion when this topic is studied more in depth at A-level. Those that have never learnt about the mole will struggle and this can lead to the student never gaining a proper understanding of the mole. When asked for ways of improving the understanding of the mole, some AS level students suggested that the concept was taught to everyone at GCSE level.

This is the sort of issue reflected in the views of 44% of university students who said that they found the transition between GCSE and A-levels difficult or very difficult and one of the reasons for this was bad preparation by their previous school. Many students also felt that their knowledge was lower or slightly lower compared to their peers due to having poor background knowledge and to teachers expecting a high level of understanding from all students. Could ensuring that all the students learn the basic concepts at the same level overcome this problem?

Hot Pen Writing

For this section respondents were asked to write down as much as they could about the mole in 5 minutes. The responses were then coded. The reason this approach was used was to use a non mathematical way of assessing conceptual understanding. Table 4 shows a summary of the coded responses that were given.

The results show that key words from the IUPAC definition were mentioned frequently by all the respondents; no secondary school students referred to the mole symbol. The most popular response given by university students was the equation relating moles with mass and molecular weight (n = m/Mr). This response was also common with teachers and secondary school students. A lot of responses also showed the relationship between the mole and Avogadro's constant and the equation n=c x v. The most common response by secondary school students was the link with the number of atoms in 12g of carbon-12.

All three groups of respondents showed a standard knowledge of the mole. A key point though is that most people just wrote down the equations that were associated with the mole and some of them gave these in the forms of triangles. Very few people explained them in written form. Just stating equations does not always show that people understand the theory behind the concept as they did not often provide clear definitions. Such behaviour could be labelled as 'ritualistic' according to Perkin's 'Troublesome Knowledge' model.

If this emphasis on equations is because the mole is only being taught mathematically then this will increase the difficulties of students with poor maths ability. Some students are not able to manipulate and rearrange the equations easily to the format that is required. The triangle form of the mole equations as shown in Figure 3 can be an easier format to handle but this is not necessarily true for all students. Some students prefer a written explanation of how to carry out the calculations as they do not respond as well to symbols.

Table 4: Results from hot pen writing technique about the mole.

Secondary school frequency table		
mole knowledge	**Frequency**	
number of atoms in carbon-12	7	
used to calculate concentration	4	
equal to mass number	3	
certain number of atoms in an element	2	
unit of measurement	1	
amount of substance	4	
Avogadro's constant (6.02×10^{23})	3	
Titrations	1	
gas equation	1	
EQUATIONS:		
n = m/ Mr	5	1 in triangle form
		4 in equation forms
n = c x v	1	
Teacher and lecturer frequency table		
Mole knowledge	**Frequency**	
relationship to Avogadro's constant	2	
6×10^{23} (Avogadro's constant)	3	
relationship to amount of a substance	6	
mol (unit)	1	
example of number of moles in a molecule	3	
used to carry out chemical calculations	1	
symbol (n)	2	
useful in titrations	1	
EQUATIONS :		
n = m/ Mr	5	1 in triangle form
		2 written explanations
		2 in equation forms
gas equation	1	
n = c x v	4	
University students		
Mole knowledge	**Frequency**	
relationship to Avogadro's constant	19	
Avogadro's constant (6.02×10^{23})	24	
relationship to molecular weight	9	
weight of an element/ compound	3	
amount of substance	13	
large number	1	
number of atoms in 12 g of carbon	11	
symbol (n)		
unit (mol)	2	
EQUATIONS :		
n = m/ Mr	37	3 written explanations
		4 in triangle forms
		20 in equation forms
n = c x v	23	5 written explanations
		5 in triangle forms
		13 in equation forms
gas equation	1	

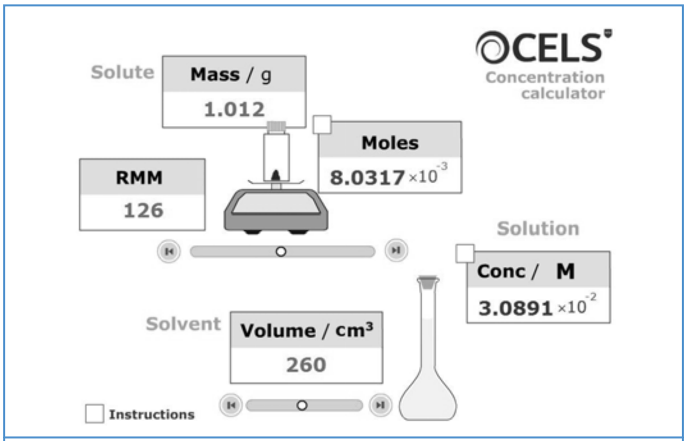

Figure 4: The CELS mole calculator.

What did students think could be done to improve their understanding of the mole?

They said (in order of popularity);

University students

- Practice questions regularly.
- Introduce the concept earlier at a simple level.
- Worked examples.
- Provide a clear definition.
- Regular review of the fundamental principles.
- Useful diagrams and animations.
- Smaller classes.
- Develop a phrase or rhyme to remember the equations.
- Reminder of calculations before starting a degree.

School students (14-17)

- Provide a clear explanation.
- Practical activities.
- Teach to everyone at GCSE level.
- Revision.
- Clear explanation in text books.
- Better teaching.
- More time spent learning the subject.
- Make learning more fun.

Recommended mole resources

- The Letts GCSE AQA revision guide[21] gives a good simplified explanation of the mole, it makes good use of colour and presents information in a simplified form. The equations are presented in full word form and worked examples are provided. Whilst not a teaching aid it was the only book commonly found during the research that explained the mole in a simple and effective way and related the mole to ideas that the students are familiar with.
- Interactive resources such as the CELS mole calculator (and dilution factor tool)[22] allows students to practice the calculations involved in the concept (Figure 5).
- The BBC GCSE Bitesize website[23] also provides a range of interactive activities for a range of different topics. The chemical calculations activity involves a step by step visual and verbal explanation that contains useful animations and diagrams to help bring the learning to life but it only covers some of the concepts involved with the mole. A resource like this to cover the whole of the topic would be particularly useful for students as it is fun, interactive and starts with the basics and builds on these.

Summing up – where next?

These findings reinforce previous findings that calculations, especially those including the mole, are amongst the most difficult subjects in chemistry to understand and to teach. We have looked at different perspectives, using a range of techniques. Students stated that they struggled with the mole because of poor teaching and poor resources. It is important that students' learning styles are taken into account when teaching and also when selecting resources to aid students' learning. That there can be a mismatch in how material is delivered by teachers versus how students prefer to learn is shown in Figure 5 (recognising this is a small teacher sample).

Our student cohort preferred to learn by working in groups with colleagues and visually, whilst the teachers surveyed tended to prefer individual working and verbal delivery. Calculations should be taught in a way that embraces multiple formats so students can learn from their preferred method and for those that struggle with mathematics, step by step examples should be worked through. The theory of the mole as an amount of substance should also be emphasised to help develop understanding of the concept.

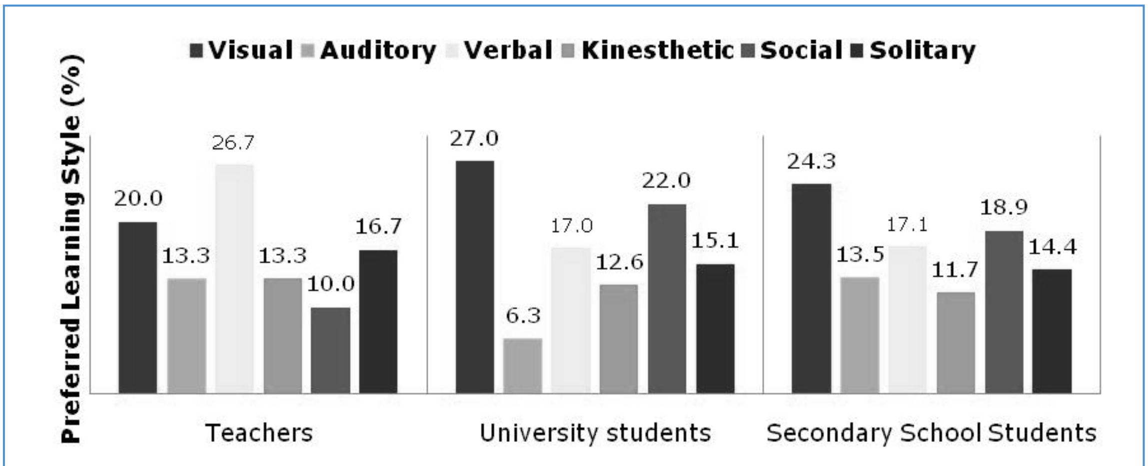

Figure 5: Preferred learning styles for students & preferred teaching styles of teachers.

Based on our survey results we suggest that by adjusting how and when the mole is taught the problems we identified could be overcome if we:

- expose all students to the mole at same time, ideally early in GCSE.
- the concept is taught from a basic level using words and analogies.
- ideas are developed stepwise as the students' education progresses.[11]
- students are shown the importance of the mole and its relationship to real-life.
- extra support is provided to students who struggle with maths.
- a variety of learning styles and resources are used to make the learning more interactive and fun.
- frequent checks on understanding are made using a range of assessment tools.
- don't assume prior knowledge and full understanding of the concept.

Why introduce early in GCSE? All our student cohorts suggest an earlier introduction to the idea of the mole. We would recommend representing the mole as a 'number of items' during year 9 or 10 regardless of the specification being studied. Using a purely word format, one can emphasise the idea that the mole represents a (very large) number of items in exactly the same way that the dozen is a way of representing 12. On this first encounter we would recommend not using any equations. Once the concept of a 'number of items' has been grasped then attempts to introduce calculations could be made. It is obvious that the mole as a concept is affected by transitions in education. It is also clearly a transformative Threshold Concept: once people have 'got it' they move on and then the whole thing becomes just part of their background.

There are issues here over what is appropriate to be taught within the GCSE science curriculum, acknowledging that not everyone will take the study of chemistry further, a landscape complicated by the seemingly perpetual changes in syllabus and increasing popularity of both applied science and triple award science. However if students stop at GCSE science we feel it would be better they leave with a qualitative understanding of the mole as number of atoms rather than a muddle of misarranged equations.

Further research is needed to look at how effective the suggestions of this study are for improving students understanding of the mole concept. There is also similar research to investigate the other areas of chemistry that students find difficult and investigate what can be done to improve them. Further work should look at a wider selection of teachers and academic staff as learning is about the students and staff working together to tackle learning difficulties, as Piaget's said '*it is not just about what is taught, but how it is taught that matters*.'[24]

References

1. Taber, K. S. (2009) *Misconceiving chemistry: the mismatch between chemical concepts and student thinking,* School Science Review, **91**, 87-96.
2. Sirhan, G. (2007) *Learning Difficulties In Chemistry*. Journal of Turkish Science Education [online], **4** (2), 2-20. Available at: <www.tused.org/internet/tused/default13.asp> [Accessed 07 February 2010].
3. (a)Mansell, W. (2003) *Where have all the scientists gone?* The TES [online], 15 August, 2003 Available at: <www.tes.co.uk/article.aspx?storycode=382871>;
   (b) Miline, J. (2007) *Science A-levels tougher than most*. The TES [online], 16 March, 2007 Available at: <www.tes.co.uk/article.aspx?storycode=2357606>;
   (c) Bloom, A. (2009) *Top pupils shun physics A-level*. The TES [online], 6 November, 2009, Available at: <www.tes.co.uk/article.aspx?storycode=6026950>;
   (d) Mansell, W. (2008), *Science – girls passing up the chance of a science career.* The TES [online], 17 October, 2008, Available at: <www.tes.co.uk/article.aspx?storycode=6003860> [Accessed 08 June 2010].
4. Reiss, M. (2007) *Comment: Bottom of the class,* New Scientist [online], 12th January 2007. Available from: Academic Search Elite [Accessed 28 January 2010].
5. Taber, K. (2002) Chemical Misconceptions – Prevention, Diagnosis and Cure*,* vol.1, London: Royal Society of Chemistry.
6. Kind, V. (2004), Beyond Appearance: Students' misconceptions about basic chemical ideas ,London: Royal Society of Chemistry, 2nd edn., 50-54. Available at: <www.rsc.org/education/teachers/learnnet/pdf/LearnNet/rsc/miscon.pdf> [Accessed 07 February 2010].
7. Talanquer, V. (2006), Commonsense Chemistry: A Model for Understanding Students' Alternative Conceptions, J Chem. Ed., **83** (5), 811-816.
8. Johnstone, A. (2006) *Chemical education research in Glasgow in perspective* Chemistry Education Research and Practice, **7** (2), 49-63.
9. Gagan, M. (2020) *Undergraduate chemistry – points of view,*. Education in Chemistry*,* **47** (1), 25-28.
10. Moss, K. Greenall, C., Rockcliffe, A., Crowley, M., Mealing, A. (2007) *Threshold Concepts and Troublesome Knowledge in Chemistry,* Proceedings Variety in Chemistry Education 2007, University of Leicester, Available at: <www.heacademy.ac.uk/assets/ps/documents/events/vce07presentations/moss.pdf> [Accessed 12 November 2009
11. Sheehan, M. & Childs, P. E. (2009) *What's difficult about chemistry? An Irish perspective*, Chemistry Education Research and Practice, **10**, 204 – 218.
12. Norfolk-Teacher, (2008) *Hard to teach topics*. TES Forums [online], 21st December, 2008. Available at: <community.tes.co.uk/forums/p/274030/4077519.aspx#4077519> [Accessed 07 February 2010].
13. Furio, C., Azxona, R., Guisasola, J. (2000) *Difficulties in teaching the concepts of 'amount of substance' and 'Mole'*. Journal of Science Education*,* **22** (12), 1285 – 1304.

14. Uce, M., (2009) *Teaching the Mole Concept Using a Conceptual Change Method at College Level*. Education [online], 22nd June. Available at: <my.uen.org/mydocuments/downloadfile?userid=missvoeks&documentid=6172183> [Accessed 12 November 2009].
15. Meyer, J.H.F.& Land, R. ed. (2006) Overcoming Barriers to Student Understanding. Oxon: Routledge.
16. Anon (2002) Twenty First Century Science, Oxford: Oxford University Press, 2002. Available at: <www.21stcenturyscience.org/the-courses/core-science-science-for-scientific-literacy,907,NA.html> [Accessed 13 March 2010].
17. Marley, D. (2009), *Vilified GCSE boosts science uptake*. *The TES* [online], Available at: <www.tes.co.uk/article.aspx?storycode=6021537> [Accessed 13 March 2010].
18. Anon,(2009), Science A Twenty First Century Science Suite specification, Cambridge: Oxford Cambridge and RSA Examinations, Available at: <www.ocr.org.uk/download/kd/ocr_10009_kd_l_gcse_spec.pdf> [Accessed 13 March 2010].
19. Harrison, S. (2007) Specification September 2007 GCSE. Mansfield: Edexcel Publications. Available at <www.edexcel.com/migrationdocuments/Current%20GCSE/UG018535_Science_2101new.pdf> [Accessed 13 Marc 2010].
20. Anon (2008) Science A 4461 2010, Manchester: Assessment and Qualifications Alliance, 2008. Available at: <store.aqa.org.uk/qual/pdf/AQA-4461-W-SP-10.PDF> [Accessed 13 March 2010].
21. Lonsdale, (2009) GCSE Essentials AQA Chemistry Revision Guide, London: Letts and Lonsdale.
22. Moss, K. (2009) *What is effective learning in science? Impact and outcome from a CETL*, New Directions [online], **5**, 22-25. Available at: <www.heacademy.ac.uk/assets/ps/documents/new_directions/new_directions/issue5/moss.pdf>
23. BBC, (2010) Chemical Calculations Activity, available at BBC Bitesize GCSE website: <www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/chemcalc/chemcalcact.shtml> [Accessed 9 June 2010]
24. McNally, D. (1973) Piaget, Education, and Teaching, Sussex, UK: New Educational Press Ltd.
25. Sharp, J. (2000) Achieving QTS Primary Science: Teaching Theory and Practice. Exeter: Learning Matters Ltd, 2nd ed, p. 93.
26. Wilkinson, D. (Ed) (2000) The Researcher's Toolkit, London: Routledge Falmer.

We would recommend representing the mole as a 'number of items' during year 9 or 10 regardless of the specification being studied. Using a purely word format, one can emphasise the idea that the mole represents a (very large) number of items in exactly the same way that the dozen is a way of representing 12.