JOURNAL OF CHEMICAL EDUCATION

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# Inconsistent Language Use in Online Resources Explaining the Mole Has Implications for Students' Understanding

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Cite This: *J. Chem. Educ.* 2022, 99, 2446−2450 Read Online

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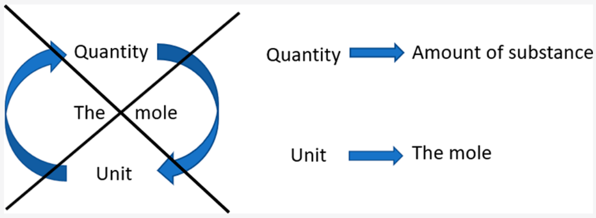
**ABSTRACT:** The quantity amount of substance (symbol "*n*") and its SI unit, the mole (symbol "mol"), are unfamiliar to novice chemistry students. Developing a good understanding of this quantity and its unit has previously been demonstrated to be problematic. In this paper, we analyze 14 different online resources in terms of how they define and apply the mole. Our findings show widespread use of the mole as a quantity rather than as a unit in mathematical expressions as well as in text. This leads to the absence of reference to the quantity amount of substance and is inconsistent with how other quantities (such as mass) and their units (g) are represented. This practice is also evident in wider pedagogic contexts and can cause confusion for students developing understanding of the mole. We provide recommendations to address this issue through the consistent use of the mole as a SI unit for the quantity amount of substance.




**KEYWORDS:** *High School/Introductory Chemistry, Internet/Web-Based Learning, Communication/Writing, Nonmajor Courses*

## ■ INTRODUCTION

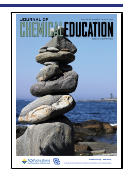
Amount of substance (symbol "*n*") and its SI unit, the mole (symbol "mol"), are unfamiliar to novice chemistry students. Unlike other, more familiar, quantities and their units such as length (m), mass (kg), and volume ($cm^3$), the first and only time students come across and apply amount of substance is when studying chemistry. Furthermore, quantities such as mass, volume, or temperature can be directly measured with the appropriate equipment. Amount of substance, however, cannot be directly measured, and its value is derived indirectly by calculation.

Understanding of amount of substance and its unit, the mole, can be problematic and has been the subject of many studies.[1,7,9,10,12,13,15,19,21,23,26,29] These studies highlighted several challenges for students such as understanding the relationship between the mass of a substance, the number of elemental entities (atoms, molecules, etc.), and the practical application of this knowledge to calculations and experiments. In addition to confusion among students, Tullberg, Strömdahl, and Lybeck[27] have provided evidence that educators do not have a clear understanding of amount of substance and the mole with only 3 out of 28 teachers using the correct definition of the mole. However, not using the correct definition does not necessarily indicate a lack of understanding. The educators' own conception of the mole was found to be a decisive factor in determining the teaching approach with logical contradictions identified during the teaching. Furio et al.[10] concluded that confusion exists among educators and textbooks about amount of substance and the mole and students use definitions of the mole as a mass or the Avogadro number and avoid amount of substance.

## ■ REDEFINING THE MOLE

Use of the term mole in chemistry can be traced back to the end of 19th century, originating from the German word Molekül (molecule). The mole referred to the mass of a substance in grams that was numerically equivalent to its molecular weight.[20] Furthermore, the mole has been used as a collective noun referring to a number of particles equivalent to the Avogadro number.[11] In 1971, the mole was the seventh base unit added to the International System of Units (SI) by the 14th General Conference of Weights and Measures to resolve confusion between mass equivalent units (such as g-mol or g-atom) and g (the mass unit) and to introduce quantity calculus into chemistry.[15] The quantitative calculus method treats each physical quantity as the product of a numerical value and a unit.[30] However, the addition of amount of substance as the seventh base quantity has caused confusion for chemistry educators with the official definition perceived as incompatible with practice in the analytical laboratory.[6] The definition remained unchanged until January 2018 when IUPAC recommended a new definition of the mole[16] that was adopted in 2019.[3] This definition stems from the stated intention, in 2011, of the International Committee of Weights and Measures to revise the entire SI by linking all seven base units to seven fundamental physical constants rather than to

**Received:** March 7, 2022
**Revised:** June 1, 2022
**Published:** June 14, 2022



physical artifacts such as the International Prototype Kilogram. The defining constants are fundamental constants of nature such as the Planck constant ($h$) and the speed of light ($c$) and have a fixed numerical value. The seven constants were chosen in such a way that any unit of the SI can be written through a defining constant itself or through products of defining constants. In the case of the mole, the unit is defined in relation to the Avogadro constant ($N_A$) thus:

*"The mole, symbol mol, is the SI unit of amount of substance. One mole contains exactly 6.02214076 × $10^{23}$ elementary entities. This number is the fixed numerical value of the Avogadro constant, $N_A$, when expressed in $mol^{-1}$, and is called the Avogadro number."*[3]

This new definition defines the mole as the unit for amount of substance and 1 mol contains a specific number of elementary entities. This contrasts with the previous definition where the mole was defined as containing the number of elemental entities in 12 g of carbon-12. The new definition emphasizes that the quantity, amount of substance, is concerned with counting entities rather than measuring the mass of a sample. If the mole was defined as a number, then it could not be a base unit in the International System of units (SI).[3] This new definition aims to achieve the stated aim of Mills et al.[17] that the definitions of the base units be comprehensible to students and teachers.[15]

However, debate continues as to the suitability of this definition. Schmidt-Rohr,[23] for example, argues that the mole must be a number when applied to countable discrete entities, analogous to dozen representing 12. These different interpretations are compounded by the suitability of the name of the quantity "amount of substance", which is not universally considered a good choice[14] with Marquardt et al.[16] recommending that "a thorough examination of a potential alternative name for the quantity amount of substance, *n*, has to be performed." The historical meaning of words and their use can persist for many years, and Giunta[11] highlights that there is limited use of amount of substance in the chemical literature with "number of moles" being much more frequent. In language, established usage takes precedence over logic.[24] Several of the SI Base quantities are one word nouns (mass, length, time), or they are typically abbreviated to one word nouns (e.g., thermodynamic temperature, temperature; electric current, current). "Amount of substance" is a phrase built from a noun describing a noun and is not readily abbreviated to one word. Furthermore, the general use of "amount" and "substance" in English can confuse the meaning with the specific sense of the quantity amount of substance. Marquardt et al.,[16] for example, state "the amount of chemical substances is traditionally measured by mass or volume." In this context, both "amount" and "substance" are being used in a general sense and are semantically differently from the specific context of "amount of substance". Some teachers, for example, avoid the use of "amount" because students will lose marks in exams if they use amount generally rather than referring to the specific quantity such as mass or volume.[8] "Chemical amount" has been accepted as a synonym for amount of substance[14,22] but may still be considered to present similar difficulties.

The definition of amount of substance states:

*"The amount of substance, symbol n, of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles."*[3]

Schmidt-Rohr[23] argued that this definition is based on an outdated continuum substance concept (that mass is continuously distributed within matter and there is no empty space) and the meaning of amount of substance is unclear. In addition, he highlights the difference in how the phrase "amount of" is used in Standard English compared to in a chemistry context.

Marquardt et al.[16] state that while the full name of the quantity is amount of substance, "substance" should be considered as a placeholder and should be replaced with the name of specific substance concerned. For example, "amount of water molecules" rather than "amount of substance of water molecules." Too often, however, this distinction is not made in practice and "mole" is used to replace "amount of substance", which is inappropriate.[14]

## ■ HOW DO ONLINE MATERIALS DEFINE AND APPLY THE MOLE?

In response to the new definition and the challenges associated with understanding the mole, we analyzed how the mole is defined and applied in a range of online materials. The sample for our analysis consisted of 14 online resources presented in English (7 text based web sites and 7 videos) that were identified using the search term "the mole chemistry" and were highly ranked in Google. Our goal in using this basic search string was to try to mimic the search as it would be undertaken by the target audience of the resources (i.e., a student aged approximately 13−15 years old encountering the mole for the first time). We discounted alternative search strings such as "the mole chemistry explained", "what is the mole chemistry", etc. in favor of the most basic option which we felt aligned most closely with what students would actually search for.

## ■ MOLE AS A QUANTITY

Marquardt et al.[16] noted the inappropriate use of the mole in place of amount of substance, conveying the meaning that the mole is a quantity rather than a unit. Thirteen out of the 14 resources analyzed showed this language use in mathematical expressions or text.

## ■ MATHEMATICAL EXPRESSIONS

Seven resources referred to mathematical expressions that used a combination of units and quantities with the unit, moles, in place of the quantity, amount of substance. There were four examples of different mathematical expressions where the mole (symbol, mol) was used but the other components of the equation are quantities.

Five resources referred to the equation **mol = mass/$M_r$**. Each part of this equation is neither semantically nor mathematically equivalent in terms of quantities and units. As "mol" is the symbol for moles, the SI unit of amount of substance, the other parts of the equation should use terms with equivalent meaning for the quantities to which they are referring. Therefore, "g" or "kg" for mass and $M_r$ should be replaced by the units for molar mass, g $mol^{-1}$ (because $M_r$ is a unitless comparative value). Similarly, in the expression **volume = moles × 24**, referred to by three resources, volume (a quantity) is given equivalence with the mole (a unit). Volume is shown without units, moles is shown without quantity, and the multiple, 24, is shown without units. Six resources referred to the expression **moles = concentration ×**


https://doi.org/10.1021/acs.jchemed.2c00199
J. Chem. Educ. 2022, 99, 2446−2450

Table 1. Alternative Mathematical Expressions Relating Amount of Substance to Mass, Gas Volume or Concentration Demonstrating Consistent Use of Quantities and Their Units[a]

| original expression | expression using quantities and units | expression using symbols for quantities | expression using symbols for units |
|---|---|---|---|
| mol = mass/$M_r$ | amount of substance (mol) = mass (g)/molar mass (g $mol^{-1}$) | $n = m/M$ | mol = g/g $mol^{-1}$ |
| volume = moles × 24 | volume ($dm^3$) = amount of substance (mol) × 24$dm^3$ $mol^{-1}$ | $V = n \times 24$ $dm^3$ $mol^{-1}$ | $dm^3$ = mol × 24 $dm^3$ $mol^{-1}$ |
| moles = concentration × volume | amount of substance (mol) = concentration (mol$dm^{-3}$) × volume ($dm^3$) | $N = c \times V$ | mol = mol $dm^{-3}$ × $dm^3$ |

[a]One resource[5] also described the ideal gas equation $PV = nRT$ as pressure × volume = **number of moles** × gas constant × temperature. This is an example of the substitution of *amount of substance* (symbol = $n$) with *number of moles.*

**volume**. In this instance, moles is a unit while concentration and volume are both quantities.

Mathematically, the expressions do not make logical sense and are confusing because of the mixture of quantities and units. From the students' perspective, the meaning of the mole appears equivalent to other quantities in the expression that the student is more familiar with, such as mass or volume. The occurrence of this nonequivalence of terms in mathematical expressions was observed in resources that also made a clear statement about the quantity, amount of substance and its unit, the mole. Alternative semantically and mathematically correct forms of these expressions using quantities and their corresponding units, only symbols for quantities or only symbols for units are shown in Table 1.

## IN TEXT

Pekdağ and Azizoğlu[21] highlighted that it is semantically incorrect, and considered inappropriate by IUPAC, to use the phrases "number of moles" or "how many moles" (because the name of the unit appears in the name of the quantity) and has been acknowledged as illogical usage. However, prior to the establishment of the quantity amount of substance, there was no formal name and these phrases continue to be used and are appropriately understood by chemists.[11] Pekdağ and Azizoğlu[21] recommend that amount of substance should be used. For example, the question "how many moles are in 6 g of the element sodium, Na(s)?" should be phrased as "What is the amount of sodium atoms, in moles, in 6 g of the element sodium, Na(s)?" The preeminence of the unit as the subject of the sentence leads to the quantity, amount of substance, being ignored. In effect, "number of moles" and "how many moles" become substitute phrases for amount of substance.

Ten resources showed instances of sentences where the unit, moles, is the subject of the sentence and amount of substance is not stated. For example:

*"Calculate the **number of moles** of carbon dioxide molecules in 22 g of $CO_2$."*

This contrasts with the next worked example, directly below, which asks:

*"Calculate the **mass** of 2 mol of carbon dioxide ($CO_2$)."*[2]

In the first question, **number of moles** is the focus of the sentence, and in the second question **mass** is the focus.

The same inconsistency is observed when asking the student to calculate volume of gases from amount in moles with the quantity "volume" and the unit "moles" being the focus of their respective sentences.

*"Calculate the **volume** of 0.5 mol of carbon dioxide at rtp."*

*"Calculate the **number of moles** of hydrogen that occupy 6 $dm^3$ at rtp."*[2]

Seven resources used moles in sentences that implied equivalence with other quantities, e.g., "the mole enables us to connect the number of particles, moles, mass, and volume".[4] This syntax implies that number of moles, mass, and volume have equivalence of meaning and moles becomes associated with meaning a quantity rather than a unit.

## ABSENCE OF THE QUANTITY AMOUNT OF SUBSTANCE

One consequence of using the mole in this way is that it is possible to discuss the mole and relevant calculations without actually requiring an explanation of amount of substance. Indeed, 10 resources did not refer to the quantity amount of substance or the mole as its unit. These resources define the mole as a number (Avogadro number) rather than as unit for a quantity. For example, "A mole is defined as 6.02214076 × $10^{23}$ of some chemical unit, be it atoms, molecules, ions, or others."[5] The relevant quantity, amount of substance, is not mentioned, and this contrasts with definitions for the kilogram and the meter on the same resource that begin "the Kilogram (kg), basic unit of mass" and "Metre (m), also spelled meter, in measurement, fundamental unit of length". Consequently, the meaning of the mole is not appropriately contextualized as a unit for a quantity in the same way as it is for other units.

## CONCLUSIONS

Inconsistent language use in explanations and application of amount of substance and the mole compared to other quantities makes it more challenging for novice students to develop appropriate understandings. The findings reported here highlight how the mole is used interchangeably as a quantity and a unit in a range of contexts. This can result in the absence of reference to amount of substance and lack of contextualizing of the mole as an SI unit. To address this situation, we recommend the consistent use of quantity and unit in the development of online resources and pedagogical practice more widely. The mole should be introduced as the unit for the scientific quantity amount of substance. It should not be used as a substitute for the quantity in mathematical expressions and sentences. The quantity amount of substance should be explicitly defined as a measure of the number of elemental entities. Sentences should avoid referring to moles in the same context as other quantities and amount of substance should be used instead. For example, "this equation shows how moles and mass are connected" should read "this equation shows how amount of substance and mass" are connected. Calculation questions should refer to the quantity amount of substance rather than the mole as the subject of the sentence. For example, the question "how many moles are in 2 g of carbon?" should read "calculate the amount of substance, in moles, in 2 g of carbon, C." Mathematical expressions should be used where each term has the same dimensional meaning such as



https://doi.org/10.1021/acs.jchemed.2c00199
J. Chem. Educ. 2022, 99, 2446−2450

amount of substance (mol) = mass (g)/molar mass (g $mol^{-1}$)

To reinforce the meaning of the mole as a unit, we recommend that the analogy is made to other quantities and their units that the students would be familiar with such as mass and kilogram or time and seconds. Awareness of this appropriate language use is also beneficial for teachers selecting and recommending suitable resources to students.

Amount of substance has been criticized as the name for the quantity measuring number of elemental entities[18] and has been recognized as a source of confusion.[11,14] It is a noun phrase with both "amount" and "substance" having meanings that are more general in vernacular English than the specific context of chemistry. Pedagogically, there is a strong case to develop an alternative name for the quantity measuring numbers of elemental entities. However, despite these difficulties, it does not justify avoiding the use of amount of substance but rather that it should be introduced appropriately and applied consistently.

Several of the resources analyzed were produced by practising teachers and are a reflection of the prevalence of these practices more widely in chemistry education.[25,28] Practitioners, who have themselves been successful in their chemistry education, are very familiar with the expressions and phrases that they and their teachers used. However, we suggest that this inconsistent language use can lead to confusion for students and should be avoided.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00199.

List of online resources analyzed (PDF, DOCX)

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### Notes

The authors declare no competing financial interest.

## ■ REFERENCES


(1) Akçay, H.; Tüysüz, C.; Feyzioglu, B. A sample for effect of computer assisted science instruction on student's achievement and attitude: Mole concept and Avogadro number. *Turkish Online J. Educ. Technol.* **2003**, *2* (2), 57−66.

(2) BBC *Formula mass and mole calculations*, 2022. Available at https://www.bbc.co.uk/bitesize/guides/z84wfrd/revision/2 (accessed 2022-02-10).

(3) BIPM (Bureau International des Poids et Measures). *Dimensions of Quantities. The International System of Units*, 9th ed.; France, 2019; section 2.3.3.

(4) Bozeman Science. *Mole*, 2022. Available at https://www.youtube.com/watch?app=desktop&v=Pft2CASl0M0 (accessed 2022-02-10).

(5) Britannica.com. *Mole*, 2022. Available at: https://www.britannica.com/science/mol-chemistry (accessed 2022-02-10).

(6) De Bièvre, P. Clarity about the base quantity "amount of substance" is required before (re)definition of the associated base unit mole is meaningful. *Accred Qual Assur* **2015**, *20*, 441−443.

(7) Fang, S. C.; Hart, C.; Clarke, D. Unpacking the meaning of the mole concept for secondary school teachers and students. *Journal of Chemical education* **2014**, *91* (3), 351−356.

(8) Flynn, S. [@flynn_simon]. I'm sure I'm not the only one who struggles to get students to avoid using the word 'amount'. *Twitter*, April 3, 2021. https://twitter.com/flynn_simon/status/1378299688449871881.

(9) Furio, C.; Azcona, R.; Guisasola, J.; Ratcliffe, M. Difficulties in teaching the concepts of'amount of substance'and'mole'. *International Journal of Science Education* **2000**, *22* (12), 1285−1304.

(10) Furio, C.; Azcona, R.; Guisasola, J. The learning and teaching of the concepts 'amount of substance'and 'mole': A review of the literature. *Chemistry Education Research and Practice* **2002**, *3* (3), 277−292.

(11) Giunta, C. J. The mole and amount of substance in chemistry and education: beyond official definitions. *J. Chem. Educ.* **2015**, *92* (10), 1593−1597.

(12) Gorin, G. Mole, mole per liter, and molar: A primer on SI and related units for chemistry students. *J. Chem. Educ.* **2003**, *80* (1), 103.

(13) Khang, N. G.; Sai, C. L. Secondary School Students' Difficulties in Learning the 'Mole Concept' — A Preliminary Study in Singapore. *Singapore J. Educ.* **2008**, *8* (1), 80−88.

(14) Lorimer, J. What is a Mole? *Chem. Int.* **2010**, *32* (1), 1.

(15) Marquardt, R.; Meija, J.; Mester, Z.; Towns, M.; Weir, R.; Davis, R.; Stohner, J. A critical review of the proposed definitions of fundamental chemical quantities and their impact on chemical communities (IUPAC Technical Report). *Pure Appl. Chem.* **2017**, *89* (7), 951−981.

(16) Marquardt, R.; Meija, J.; Mester, Z.; Towns, M.; Weir, R.; Davis, R.; Stohner, J. Definition of the mole (IUPAC Recommendation 2017). *Pure Appl. Chem.* **2018**, *90* (1), 175−180.

(17) Mills, I. M.; Mohr, P. J.; Quinn, T. J.; Taylor, B. N.; Williams, E. R. Redefinition of the kilogram, ampere, kelvin and mole: a proposed approach to implementing CIPM recommendation 1 (CI-2005). *Metrologia* **2006**, *43* (3), 227.

(18) Mills, I.; Milton, M. Amount of substance and the mole. *Chem. Int.* **2009**, *31* (2), 3−7.

(19) Novick, S.; Menis, J. A study of student perceptions of the mole concept. *J. Chem. Educ.* **1976**, *53* (11), 720.

(20) Ostwald, W. *Hand- und hilfsbuch zur ausführung physiko-chemischer messungen*; W. Engelmann: Leipzig, 1893.

(21) Pekdağ, B.; Azizoğlu, N. qSemantic mistakes and didactic difficulties in teaching the "amount of substance" concept: a useful model. *Chemistry Education Research and Practice* **2013**, *14* (1), 117−129.

(22) Renner, T. *Quantities, units and symbols in physical chemistry*; Royal Society of Chemistry, 2007.

(23) Schmidt-Rohr, K. Analysis of Two Definitions of the Mole That Are in Simultaneous Use, and Their Surprising Consequences. *J. Chem. Educ.* **2020**, *97* (3), 597−602.

(24) Schoenfeld, R. *Chemist's English. Vch*, 1989.

(25) Seeber, E. M. Five steps to help students master mole calculations. *Education in Chemistry*; Royal Society of Chemistry, 2019. Available at https://edu-rsc-org.ezphost.dur.ac.uk/ideas/five-steps-to-help-students-master-mole-calculations/3010333.article (accessed 2022-02-02).

(26) Staver, J. R.; Lumpe, A. T. A content analysis of the presentation of the mole concept in chemistry textbooks. *Journal of Research in Science Teaching* **1993**, *30* (4), 321−337.

(27) Tullberg, A.; Strömdahl, H.; Lybeck, L. Students' conceptions of 1 mol and educators' conceptions of how they teach 'the mole'. *International Journal of Science Education* **1994**, *16* (2), 145−156.
(28) Turner, K. Five ways to explain titration. *Education in Chemistry*; Royal Society of Chemistry, 2020. Available at: https://edu-rsc-org.ezphost.dur.ac.uk/ideas/5-ways-to-explain-titration/4012500.article (accessed 2022-02-02).
(29) Ünlü, Y. Effect of explicit method of problem solving accompanied with analogies on understanding of mole concept. Master's thesis, Middle East Technical University, 2006.
(30) White, M. A. Quantity Calculus: Unambiguous Designation of Values and Units in Graphs and Tables. *Journal of chemical education* **1998**, *75* (5), 607.


https://doi.org/10.1021/acs.jchemed.2c00199
*J. Chem. Educ.* 2022, 99, 2446−2450