The role of multimedia in understanding extremely small and large numbers in chemistry education

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Abstract: This research aimed to investigate the difficulties in understanding extremely small and extremely large numbers while learning the concepts of mole and atom in elementary school students and investigate the effects of multimedia applications to overcome this problem. The sample comprised 125 elementary school students from Novi Sad, Serbia (aged 13-14). Difficulties in understanding small and large numbers related to concepts of mole and atoms were identified. The traditional teaching approach was applied in the control group of students; in the experimental group, multimedia was used in teaching. The obtained results indicate that students had difficulties learning the mole mentioned above concept. When multimedia material was used, it contributed to the higher academic achievement of students in overcoming issues related to atomic sizes and masses, the constant definition of a mole and visualization of the given amount of samples of different substances.

Keywords: atomic properties; multimedia-based learning; chemical education research; elementary school science

1. Introduction

Mathematical abilities are essential in chemical education in performing and understanding chemical calculations. It has been proven that students lack the basic mathematical skills necessary for chemical calculations [1] and that the lack of mathematical skills impacts chemistry topics that students perceive as challenging or difficult [2].

In chemistry, maneuvering between the different representations requires fluency with concepts of scale. To succeed in chemistry, students should be able to use visual—spatial and proportional-reasoning skills to generate meaningful representations. The most relevant application of scaling concepts in chemistry falls into either "macroscopic/particle"

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or “number sense” categories (or combinations of both, called “scale”), generating meaningful representations. The most relevant application of scaling concepts in chemistry falls into either “macroscopic/particle” or “number sense” categories (or combinations of both, called “scale”) [3]. Since the objects at the nanoscale cannot be seen, it is necessary to rely on numerical scales to conceptualize how small they are [4].

One of the few studies of students’ concepts of scale examined elementary, middle, high school, and graduate students’ concepts of scale [5]. They found that students tend to hold distinct conceptual categories of size and that these categories differed across the different ages and levels of schooling. This research showed that when students could experience a size or scale kinesthetically, they understood more accurately.

In chemistry education, extremely small and extremely large numbers can cause students’ misconceptions, especially in understanding the atomic structure of substances. Due to the extremely small size of atoms and molecules, the visible amounts of substances contain an enormous number of particles, which are very difficult to grasp. Thus, the concept of mole and Avogadro constant have also proven to be some of the most difficult to understand [6].

Although the concept of the atom is one of the basic concepts studied at the beginning of science education, research has shown many difficulties in understanding it [7,8]. The confusion concerning the actual size of the atom is widespread and probably originates from a student’s trend to conceptualize the atom relative to everyday objects. It is often observed that students make inappropriate comparisons. Atoms are described as something ‘very small’, ‘too small, or something with a size similar to a ‘point of a needle’, a ‘head of a pin’ or a dot” [8]. Also, a common misconception is underestimating atomic size compared to the nucleus [9,5]. Two-dimensional pictures of historical and scientific models of the atom are most common in textbooks and are often used by teachers to explain atomic concepts. Those pictures usually show an atom with an oversized nucleus. Although students learn that the atom is mostly space in studying the results of the Rutherford gold foil experiment, teachers’ drawings and textbook illustrations make students perceive that nucleus is only a few times smaller than the atom itself [9].

The mole concept has been recognized as difficult for students due to its complex nature and abstraction [6,10,11]. Over 55% of university and 68% of secondary students admitted they struggled to understand the mole concept [11]. Previous research has pointed out the common mole misconception among secondary students – they do not associate the qualitative meaning of the amount of substance with counting particles [6]. Numerous studies have identified the same mistakes concerning the mole [10,12]: students are often confused about whether to treat a mole as a number or a quantity of matter; students believe that the mass of one mole of atoms or molecules equals the mass of one atom or molecule in

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grams; mole is more associated with mass or volume rather than amount; students use the mole, molecules, molar mass, mass, and Ar/Mr alternately.

Since the mole measures the number of particles in a specific amount of a substance, a constant expressing the number of particles in one mole had to be introduced. In May 2019, the International System of Units (SI) was revised to change the definition of the mole so that it is defined by using a fixed number of elementary entities. This number is the fixed numerical value of the Avogadro constant, which is the defining constant of the unit mole. The revised definition states, "The mole, symbol mol, is the SI unit of amount of substance. One mole contains exactly $6.02214076 \times 10^{23}$ elementary entities. This number is the fixed numerical value of N_A, when expressed in mol^{-1}, and is called the Avogadro constant"[11]. Working with such large numbers as the Avogadro constant is very difficult for students who cannot visualize it. Although they understand the scientific notification of the Avogadro constant and know how much it is, they have problems relating this value to any number they encounter daily.

The cognitive requirement for understanding the concept of the mole is very high. Students must establish the relationship between the amount of substance, a macroscopic quantity, and the number of particles that are too small to be seen, counted, or weighed directly [6]. For a better understanding of mole, it is recommended to use a concept map that connects the atomic/molecular concept and a mole concept [12] by linking two ideas: the number aspect of the SI definition and the connection between relative atomic–molecular mass and molar mass or apply systemics in the introductory chemistry courses [13].

In recent years, multimedia-based learning in classroom instruction increased widely in all subjects of natural sciences [14–17]. The use of technology in the education system not only facilitates teachers in the teaching process but also can attract students' interest to learn by using a new method that is more enjoyable[18]. To overcome students' difficulties, various multimedia tools have been designed to help visually spot non-visible chemical entities (e.g., atoms or molecules) represented by chemical symbols to better understand the relationship between the submicroscopic, macroscopic, macroscopic, and symbolic levels [19,20].

Though relatively few studies have examined students' understanding of ''size and scale'' in the science context, a consistent finding is that people have difficulty omprehending and comparing sizes, particularly small or large ones[21–23].

This investigation aimed to determine the major difficulties that Serbian elementary school students have in understanding and representing the size and mass of an atom and its constituents, and the amount of substance. Can using technology for visualization and representing analogies improve student understanding of abstract concepts in chemistry, which includes dealing with extremely large and small numbers?

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2. Method

2.1. Sample

The sample comprised 125 elementary school students in Novi Sad, Serbia (46% male and 54% female), aged 13-14. Participants were divided into control (N = 65) and experimental (N = 60). The criteria for equality of the groups was their average midterm grade in chemistry ($t = 0.024$; $df = 123$, $p > 0.5$). Students voluntarily participated in the research. They could give up at any moment without any consequences.

2.2. Instruments and Procedures

For this study, a knowledge test was constructed, which consisted of 17 questions. These questions aimed to assess students' perceptions of atomic size and mass, knowledge, and understanding of the meaning of mole. Questions were designed as multiple-choice questions, and each correct answer was appointed one point. Students were also asked to provide explanations and comment on their answers. They had 45 minutes to solve the test.

The test was administered at the end of the second semester as a part of the annual review. The same test was re-administered after the pedagogical experiment, in which the given content was reviewed using multimedia (presentations, movies, pictures, etc.) in discussion with the experimental group. In contrast, the control group reviewed the content traditionally, using the chalk-and-blackboard technique.

Pre-test and post-test quality standards were calculated to assess the validity of the knowledge test. The text was evaluated and declared valid by six experts in the area of chemistry teaching (one full professor at the University of Novi Sad, one teaching assistant, and four schoolteachers) in terms of meaningfulness of requirements, comprehensibility, and respect for the teaching contents of the test.

Multimedia material was prepared for the experimental group. Pictures, animations, and videos were used to show the historical development of atomic models, to illustrate the relative size of a hydrogen atom and its nucleus, and to compare the size of atoms to some objects from the macroscopic world. Scientific notation of large and small numbers was explained in a movie, starting with parts of the human body and gradually getting to the microscopic (cells, cell parts, DNA) and submicroscopic levels (molecules, atoms, subatomic particles). The size and mass of atoms were shown by calculating the number of lead atoms in a cube with an edge of 1 cm and comparing it to the imaginary cube of the same size consisting only of nuclei of lead atoms. Pictures were used to discuss and show that, unlike other physical units that are easy for students to visualize, the mole represents the number

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of particles. The size and mass of this amount of substance differ depending on the type of substance. Analogies were used to represent the physical meaning of the Avogadro constant so that students could understand how large that number is. Students measured the volume of a single popcorn, calculated the height of a layer of 1 mole of popcorn spread over the Earth's surface, and calculated the number of chocolate bars that could fit into their classroom. Also, the thickness of the pile of $6 \cdot 10^{23}$ sheets of writing paper was compared to some astronomical distances. In performing these calculations, pre-programmed Excel forms were used. Pictures were shown to students representing 1 mole of certain substances (sulfur, mercury, sugar, etc.); conclusions were drawn on the sizes of atoms and molecules compared to macroscopic objects. The relationship between mass and amount of substance was investigated on some examples. Students were prompted to visualize one mole of different substances and compare these amounts with the presented images.

2.3. Data Analysis

Data analysis included several steps. First, a t-test for independent samples was used to examine possible differences (pre-test) in chemistry achievement between the control and experimental groups. Second, descriptive statistics of learning difficulties that students experienced were calculated. Finally, an independent-sample t-test was used to examine the differences in the post-test between the control and experimental groups. All statistical calculations were performed using IBM SPSS Statistics v. 23.

3. Results

3.1. Results of the pre-test

Both groups achieved similar scores on the pre-test (Table 1). Using the t-test for independent samples, the statistical significance of the difference in the achievement of the students of the control and experimental groups was tested. The results showed that the difference was insignificant ($t = 0.47$, $df = 123$, $p > 0.5$).

Table 1. Results of the pre-test for the control and experimental group of students

Group	N	Min	Max	M	SD	Skewness	Kurtosis
Control	65	0	12	5.80	2.08	0.25	1.04
Experimental	60	2.5	11	5.96	1.62	0.36	0.78

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3.2. Results of the post-test

In this paper, multimedia was applied for visualization and presenting analogies to overcome the difficulties of understanding abstract concepts in chemistry, including dealing with extremely large and small numbers when learning the concept of mole and atomic size. The results obtained in the post-test are shown in Table 2.

Table 2. Results of the post-test for the control and experimental group of students

Group	N	Min	Max	M	SD	Skewness	Kurtosis
Control	65	1.50	13.50	7.12	2.53	0.23	0.09
Experimental	60	4.00	16.50	9.46	2.50	0.08	0.15

Based on the arithmetic means of student achievement, it can be noticed that the experimental group students achieved higher than the control group students. This difference was tested using a t-test for independent samples and proved statistically significant ($t = 5.18$, $df = 123$, $p < 0.0001$). The results show that the application of multimedia has contributed to a better understanding and giving physical meaning to large and small numbers related to the concept of mole and the size of atoms.

Fig. 1 shows the arithmetic means of the achievement of the experimental group students for each task on the initial and final test. Paired sample t-test was used to compare the differences between the achievements of the experimental group in pre-test and post-test. Results indicate statistically significant progress in the post-test at $p < 0.01$ level in assignments 1, 2a, 2b, 2c, 8, 10, and 11, and at $p < 0.05$ level in assignments 5, 14, and 15. Fig. 1 points out the parts of the material that the students have better adapted to using multimedia.

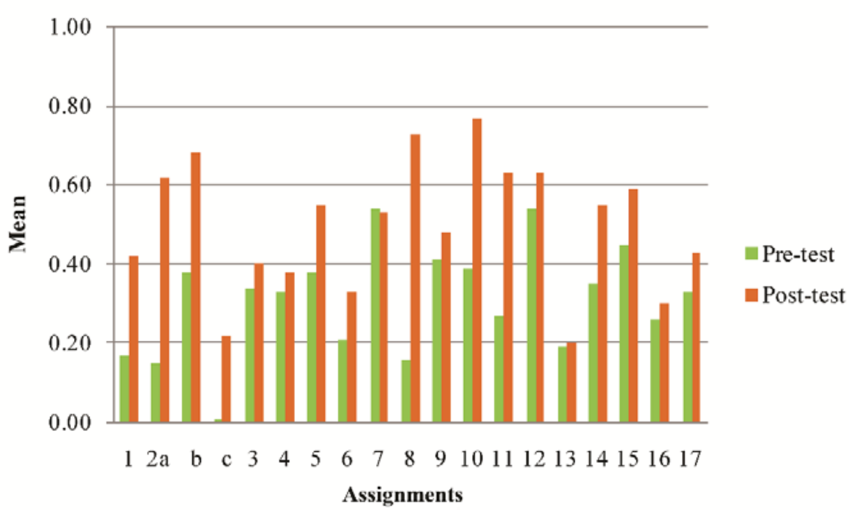

Figure 1. Mean achievements of the students of the experimental group for each task

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4. Discussion

After administering the pre-test, the analysis exhibited difficulties understanding the size and mass of atoms identified in the whole student sample (both groups). Only one-third of students knew that the mass of an atom is determined by the number of protons and neutrons in the nucleus, and 32% believed that it depended on the number of protons and electrons in an atom. Some students even thought that the mass of an atom depended only on the number of protons (7%), only neutrons (7%), or only electrons in it (11%). Also, only 19% of students knew that the nucleus is very small compared to the size of an atom, and that makes less than 1% of the atomic volume.

These difficulties in representation are also illustrated with the following two examples of the mental experiment. Students were asked to compare the lengths of an imagined row containing 100 atoms of iron, closely packed next to each other, and the row consisting of 100 nuclei of iron atoms. A little more than half of the students (54%) chose the correct answer; 15% believed that the lengths of the two rows were the same, and 24% thought that the row containing nuclei should be longer. However, when asked to compare the masses of the same two rows, only 27% selected the correct answer; 42% of students believed that nuclei were lighter than whole atoms, and 24% thought that 100 nuclei had larger masses than 100 atoms of iron. This shows that students are unaware that the mass of the nucleus, although very small compared to the size of an atom, determines the mass of that atom.

Students could also not understand and visualize the extremely small size of atoms. They were asked to estimate the number of closely packed gold atoms in a 1 cm^3 cube, given the diameter of an Au atom (288 pm), by choosing among four given answers (1 gold atom, 42 atoms, $4.2 \cdot 10^{22}$ or $4.2 \cdot 10^{-22}$ gold atoms). Only 26% of students were able to select the correct answer.

Only 19% of students could correctly define the unified atomic mass unit (AMU) as an average nucleon mass; others believed that it corresponded to the mass of an electron or a mole of protons or electrons. One-third of students selected the correct value of AMU, and 33% confused it with the value of the Avogadro number - they thought it amounted to $6.02 \cdot 10^{23}$ g. To check if students understood the physical meaning of AMU, they were asked to estimate if the sample containing 1000 iron atoms (m = 5580 AMU) had the same, larger, or smaller mass than the 1g of iron sample. Approximately the same fractions of students chose one of the three given options.

Students also had difficulties understanding the concept of a mole. When asked to define"mole", only 16.8% of students gave the complete and correct definition. Some students gave partial definitions, defining the mole as 'a physical value', 'a basic SI unit', 'unit for the amount of substance', or 'Avogadro number of particles. Most students, however, gave

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completely incorrect answers, showing that they misunderstood its meaning, as illustrated by the answer: 'Mole is the number which shows how many times the mass of a carbon isotope ^{12}C is bigger than the mass of any another atom'. This answer also shows the lack of differentiation between macroscopic and submicroscopic levels of representation in chemistry. Some of the students could not differentiate between the amount, mass, and molar mass of a substance or number of particles (e.g., mole is: 'unit for the mass of substance', 'unit for the mass of atoms', 'a molar mass', 'part of the molar mass', 'unit for the number of molecules).

Students exhibited erroneous opinions that the mole is the particle or the substance itself – such opinions include definitions of a mole as an 'a compound of all existing atoms', 'the smallest particle', and 'the substance which illustrates Avogadro number'. For some students, the term "mole" means "something very small" - 'the smallest possible amount of substance', 'amount of substance that cannot be seen under the microscope', 'the smallest existing number', and some relate the mole to stoichiometric calculations: 'Mole is a number which stands in front of the formula or a compound'. Only one-third of the students' sample knew that a mole of any substance always contains the same number of particles, while the same percentage believed that a molar mass of 1 mole of a substance always had a constant value; 14% thought that one mole of any substance had the constant mass, and 18% chose the answer "None of the above is correct". When asked to apply this generalization to the example of 1 mole of iron and 1 mole of aluminum, 33% of students answered correctly that these two samples contained the same number of atoms but had different masses.

Looking at these findings, it is unsurprising that most students stated that they did not understand the definition of"mole". For only 14% of all participants, the definition of the mole is completely clear or quite clear, and more than 60% said they couldn't understand it.

Students could relate the term "mole" to the Avogadro number ('It's the amount of substance which contains the Avogadro number of particles', or even 'It has something to do with the Avogadro number, doesn't it?'). However, less than half of them (38%) knew its numerical value, 15% could label it "NA", and only 0.8% could write the correct unit (mol^{-1}).

Most students couldn't define "molar mass" correctly. Only 21% knew that it is the mass of a mole of a substance, expressed in g/mol; 58% of students confused it for the term "relative molecular mass", while 11% believed that it is a mass of a single molecule; 10% did not answer.

The following example illustrated the inability to relate the amount of substance to its physical meaning: students were presented with five images showing: a drop of water, a small glass containing approximately 20 ml of water, a large plastic container with cca 10 liters of water, a swimming pool and a large lake. Students were asked to imagine one mole of water and choose a picture closest to the amount they envisioned. The majority of the students (67%) chose a drop of water, explaining their choice by the fact that 'this is the

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smallest given quantity, and one mole is a very small amount', or 'because water molecules are tiny', 'because one mole is a small mass', 'because the mole is the smallest amount of substance', and 'because, after atoms, mole is the smallest part of water'. Only 16% of all students gave the correct answer.

The inability of students to convert between the amount of substance and mass can be illustrated by the two following tasks. When given the example of two samples of different substances (32 g O_2 and 34 g NH_3), more than half of the students (54%) could tell which sample contained more molecules. However, only one student could provide the proper explanation for his conclusion. The reasons other students listed for choosing the answer "NH_3" were: 'Because it is heavier.', 'Because 34 g is more than 32 g.', 'Because the molecule is a number after a formula, so O_2 has two molecules, and NH_3 has three molecules.', 'Because behind O is number 2, and behind N is number 3.', 'Because it contains more elements.'

In the second example, students were provided with the relative atomic mass of copper and then asked to estimate if the sample of 100 g of copper wire contained exactly one mole or less or more than one mole of copper. Those students who believed that there was exactly on mole of copper in the given sample of wire (35%) explained that 'wire contained only one element, so it is one mole of copper', 'because the molar mass of copper is 100 g', 'because one mole of any atom has a mass of 100 g', or 'because it is impossible to have more than one mole of any substance'. The other wrong answer – that the wire sample contained less than 1 mole of copper – was given by 24% of students, followed by the explanation that 'being a metal, copper must have a larger mass', or 'because 100 g is not enough for 1 mole of copper'. The correct answer was given by 41% of students, but their explanations tended to be incorrect. For example, students said that the sample contained more than 1 mole of copper 'because that is a lot of wire', 'because copper atoms are very small, so there are many of them in a wire', or 'if 1 mole is a drop of water, it is logical that in a wire there is more than 1 mole of copper'.

All these results indicate that students have difficulties related to different aspects of the mole concept, size and mass of atoms, unified atomic mass unit, the definition of the mole, Avogadro constant and molar mass. One of the reasons for these difficulties is reflected in the lack of understanding of large and small numbers. Students cannot attribute physical meaning to these numbers, visualize amounts of different substances or understand the relative sizes of atoms and subatomic particles.

The existence of difficulties in learning the mole concept has been confirmed in other studies that have established the existence of misconceptions [6,11,24]. Research examining the reasons for misconceptions about the mole concept has shown that it can result from poor teaching in schools, difficulty relating the concept to real-life situations, and, not surprisingly, the fact that it involves mathematics [11].

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The results post-test show that the application of multimedia has contributed to a better understanding and giving physical meaning to large and small numbers related to the concept of mole and the size of atoms. This also indicates that mathematical abilities are very important for understanding these concepts, as confirmed in some previous research [11].

To determine the effect of the multimedia intervention on the understanding of the given concepts, independent sample t-test was applied to compare students' achievements in the control and experimental group in the post-test (individually for each assignment). Although students in the control group also made progress in the post-test after reviewing the content, statistically significant differences were found in assignments 1, 2a, 2c, 8, 9, and 11. This can only be explained by implementing the experimental factor, i.e., multimedia, in explaining the concepts of mole and atoms. The most significant progress has been observed in the visual representation of given amounts of substances, which was assessed using assignment no. 8.

Also, the results showed that the application of multimedia contributed to a better memorization of the Avogadro constant label, its numeric value, and its unit (assignments 2a and 2c). Namely, students often make mistakes when writing the value of the Avogadro constant in an exponential number because they write $6 \cdot 10^{-23}$, which indicates that they do not even distinguish whether it is an extremely large or small number. The application of multimedia and visualization contributes to understanding the physical meaning of this large number which is extremely important for understanding and learning chemistry.

Assignment no. 9: "A sample of copper wire with the mass m = 100 g contains exactly/more than/less than 1 mole of copper": was used to establish the level of understanding of the relation of amount and mass of the substance. The results show that multimedia intervention contributes to a better understanding of this relationship.

In the post-test more students of the experimental group were able to give a correct and complete definition of the mole, compared to the pre-testing results (assignment 1).

The multimedia intervention has also proven efficient in understanding the physical meaning of the values for the mass of atoms and subatomic particles. After visuals (images and video clips) representing atomic structures were shown, more students were able to compare masses of atomic nuclei and atoms themselves (such as in assignment 11, where students were asked to compare masses of a sequence of gold atoms and a sequence of nuclei of gold atoms). It can be concluded that multimedia contributes to understanding the physical meaning of extremely small numbers related to the size and mass of atoms and subatomic particles.

The application of multimedia has not proved effective in understanding the unified atomic mass unit. In addition, the results showed that students did not achieve better in the tasks in which the understanding of the relationship between the mass of the sample and the

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number of molecules was assessed. This finding is unexpected and could be the subject of future research to establish the reasons and possible ways to overcome these difficulties.

However, this research has several limitations that need to be noted. The first limitation concerns the sample. For the results to be generalized, expanding the sample to include students from different schools taught by different teachers is necessary. Also, in future research, other topics requiring mathematical skills and containing different numerical values should be included. It should also be noted that the research was conducted before the revised definition of the mole, which is expected to be easier to understand, entered chemistry textbooks for elementary schools.

The obtained results imply that multimedia contributes to eliminating difficulties in giving physical meaning to extremely small and large numbers in learning the concept of moles and sizes and masses of atoms and subatomic particles. They also provide a new direction for further research on difficulties in understanding numeric values to overcome them.

5. Conclusions

This research is focused on examining the existence of difficulties in understanding extremely large and small numbers in learning the concept of mole and atoms, as well as the effect of multimedia applications on their overcoming. It was examined whether students know the physical meaning of small and large numbers, understand the actual and relative size of atoms and subatomic particles, and visualize a given amount of a substance. The results showed that students have difficulty learning different concepts of a mole and an atom that require understanding extremely large and small numbers, such as the size and mass of atoms and subatomic particles, unified atomic mass unit, Avogadro constant and molar mass. Students cannot attribute physical sense to these numbers, visualize amounts of different substances, and understand the relative sizes of atoms and subatomic particles. The multimedia application, including visualizations and analogies, contributes to higher academic achievement and overcoming problems related to understanding the sizes and masses of atoms and subatomic particles, the Avogadro constant, the definition of a mole, and visualization of certain samples of substances. On the other hand, multimedia has not proved effective in understanding the unified atomic mass unit and the relationship between mass and the number of molecules in a sample.

This research contributes to identifying issues related to understanding the concept of moles and the size and mass of atoms and subatomic particles due to not understanding large and small numbers. In addition, the effectiveness of multimedia in overcoming difficulties in understanding these numeric values and concepts was examined. The results indicate that multimedia can contribute to a better understanding of scale.

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References

[1] F. J. Scott, “Is mathematics to blame? An investigation into high school students’ difficulty in performing calculations in chemistry,” *Chem. Educ. Res. Pract.*, vol. 13, no. 3, pp. 330–336, 2012, doi: 10.1039/c2rp00001f.

[2] P. E. Childs and M. Sheehan, “What’s difficult about chemistry? An Irish perspective,” *Chem. Educ. Res. Pract.*, vol. 10, no. 3, pp. 204–218, 2009, doi: 10.1039/b914499b.

[3] J. M. Trate, P. Geissinger, A. Blecking, and K. L. Murphy, “Integrating Scale-Themed Instruction across the General Chemistry Curriculum,” *J. Chem. Educ.*, vol. 96, no. 11, pp. 2361–2370, 2019, doi: 10.1021/acs.jchemed.9b00594.

[4] S. Swarat, G. Light, E. J. Park, and D. Drane, “A typology of undergraduate students’ conceptions of size and scale: Identifying and characterizing conceptual variation,” *J. Res. Sci. Teach.*, vol. 48, no. 5, pp. 512–533, 2011, doi: 10.1002/tea.20403.

[5] G. Papageorgiou, A. Markos, and N. Zarkadis, “Understanding the Atom and Relevant Misconceptions: Students’ Profiles in Relation to Three Cognitive Variables.,” *Sci. Educ. Int.*, vol. 27, no. 4, pp. 464–488, 2016.

[6] C. Furio, R. Azcona, and J. Guisasola, “The Learning and Teaching of the Concepts ‘Amount of Substance’ and ‘Mole’: A Review of the Literature,” *Chem Educ Res Pr.*, vol. 3, no. 3, pp. 277–292, 2002, doi: 10.1039/b2rp90023h.

[7] A. G. Harrison and D. F. Treagust, “Secondary students’ mental models of atoms and molecules: Implications for teaching chemistry,” *Sci. Educ.*, vol. 80, no. 5, pp. 509–534, 1996, doi: 10.1002/(SICI)1098-237X(199609)80:5<509::AID-SCE2>3.0.CO;2-F.

[8] A. Cokelez, “Junior High School Students’ Ideas about the Shape and Size of the Atom,” *Res. Sci. Educ.*, vol. 42, no. 4, pp. 673–686, 2012, doi: 10.1007/s11165-011-9223-8.

[9] K. Adbo and K. S. Taber, “Learners’ Mental Models of the Particle Nature of Matter: A study of 16-year-old Swedish science students,” *Int. J. Sci. Educ.*, vol. 31, no. 6, pp. 757–786, 2009, doi: 10.1080/09500690701799383.

[10] C. J. Giunta, “The Mole and Amount of Substance in Chemistry and Education: Beyond Official Definitions,” *J. Chem. Educ.*, vol. 92, no. 10, pp. 1593–1597, 2015, doi: 10.1021/ed5007376.

[11] K. Moss and A. Pabari, “The mole misunderstood,” *New Dir. Teach. Phys. Sci.*, no. 6, pp. 77–86, 2016, doi: 10.29311/ndtps.v0i6.392.

[12] S. C. Fang, C. Hart, and D. Clarke, “Unpacking the meaning of the mole concept for secondary school teachers and students,” *J. Chem. Educ.*, vol. 91, no. 3, pp. 351–356, 2014, doi: 10.1021/ed400128x.

[13] T. Hrin, D. Milenković, S. Babić-Kekez, and M. Segedinac, “Application of systemic approach in initial teaching of chemistry: Learning the mole concept,” *Hrvat. Časopis Za Odgoj Obraz.*, vol. 16, no. Sp. Ed. 3, pp. 175–209, 2014.

[14] Erchan, “The Effects of Multimedia Learning Material on Students’ Academic Achieveme...,” *J. Balt. Sci. Educ.*, vol. 13, no. 5, pp. 608–621, 2014.

[15] B. Radulović, M. Stojanović, and V. Županec, “The effects of laboratory inquire-based experiments and computer simulations on high school students‘performance and cognitive load in physics teaching,” *Zb. Instituta Za Pedagoska Istraz.*, vol. 48, no. 2, pp. 264–283, 2016, doi: 10.2298/ZIPI1602264R.

[16] B. Radulović and M. Stojanović, “Comparison of teaching instruction efficiency in physics through the invested self-perceived mental effort,” *Vopr. Obraz.*, vol. 2019, no. 3, pp. 152–175, 2019, doi: 10.17323/1814-9545-2019-3-152-175.

[17] V. S. Županec, B. N. Radulović, T. Z. Pribićević, T. G. Miljanović, and V. G. Zdravković, “Determination of educational efficiency and students’ involvement in the flipped biology classroom in primary school,” *J. Balt. Sci. Educ.*, vol. 17, no. 1, pp. 162–176, 2018, doi: 10.33225/jbse/18.17.162.

Citation: S. Olić Ninković et al., AIDASCO Reviews 1, 2 (2023) 46-58. DOI: https://doi.org/10.59783/aire.2023.26

[18] M. R. Matthews, “Models in science and in science education: An introduction,” *Sci. Educ.*, vol. 16, no. 7–8, pp. 647–652, 2007, doi: 10.1007/s11191-007-9089-3.
[19] H. K. Wu, J. S. Krajcik, and E. Soloway, “Promoting understanding of chemical representations: Students’ use of a visualization tool in the classroom,” *J. Res. Sci. Teach.*, vol. 38, no. 7, pp. 821–842, 2001, doi: 10.1002/tea.1033.
[20] M. Stieff and U. Wilensky, “Connected Chemistry—Incorporating Interactive Simulations into the Chemistry Classroom,” *J. Sci. Educ. Technol.*, vol. 12, no. 3, pp. 285–302, 2003, doi: 10.1023/A:1025085023936.
[21] S. Swarat, G. Light, E. J. Park, and D. Drane, “A typology of undergraduate students’ conceptions of size and scale: Identifying and characterizing conceptual variation,” *J. Res. Sci. Teach.*, vol. 48, no. 5, pp. 512–533, 2011, doi: 10.1002/tea.20403.
[22] M. G. Jones, A. Taylor, J. Minogue, B. Broadwell, E. Wiebe, and G. Carter, “Understanding scale: Powers of ten,” *J. Sci. Educ. Technol.*, vol. 16, no. 2, pp. 191–202, 2007, doi: 10.1007/s10956-006-9034-2.
[23] T. R. Tretter, M. G. Jones, T. Andre, A. Negishi, and J. Minogue, “Conceptual boundaries and distances: Students’ and experts’ concepts of the scale of scientific phenomena,” *J. Res. Sci. Teach.*, vol. 43, no. 3, pp. 282–319, 2006, doi: 10.1002/tea.20123.
[24] K. S. Taber, *Alternative Conceptions in Chemistry*. London: Royal Society of Chemistry, 2002.

Citation: S. Olić Ninković et al., AIDASCO Reviews 1, 2 (2023) 46-58. DOI: https://doi.org/10.59783/aire.2023.26