TEACHING THE MOLE CONCEPT USING A CONCEPTUAL CHANGE METHOD AT COLLEGE LEVEL

DR. MUSA ÜCE

Ataturk Faculty of Education
Department of Science and Mathematics Education
Marmara University Istanbul, Turkey.

Chemistry is a subject area that is difficult to understand for some students as it contains abstract concepts, such as mole, molecule and particle. The mole concept is one of the most important topics in which students have diffuculty in understanding. There are many studies in the literature on the mole concept. Students who do not fully understand the mole experience difficulties in understanding the subsequent topics. Especially, results can be often incorrect in stoichiometry problems since the calculations revolve around the mole concept. The purpose of this study was to determine the effectiveness of using conceptual change strategy in teaching the mole concept to freshman general chemistry students. A pretest-posttest control group experimental model was used. The control group was lectured via traditional teaching method while conceptual change texts were used to teach the mole concept to the experimental group. An achievement test of multiple-choice questions was developed to gather data from both groups as pre and posttest. Analysis of the data was performed by using SPSS (Statistical Package for Social Sciences) software. The results demonstrated that the use of conceptual change method was more effective in promoting understanding of the mole concept compared to the traditional method. Developing similar teaching materials for conceptual change to improve teaching effectiveness and student success in the other topics of chemistry may be an effective approach.

Chemistry is the science that deals with chemical change processes involving the mole, molecule, particle concepts as well as mathematical computations. As it is well known, the mole concept is used as a unit to calculate the amount of substances involved in a chemical reaction and the products forming at the end. Thus, an informed understanding of the mole concept is essential to solve stoichiometry questions correctly (Schmidth, 1990, 1994). Numerous studies were carried out in the past regarding the teaching and learning of the mole concept (Dierks, 1981; Furio, Azcona, Guisasola & Ratcliffe, 2000; Gorin, 1994; Krishan & Howe, 1994; Lazsonby, Morris & Waddington, 1982; Nelsion, 1991; Staver & Lumpe, 1993-1995). It was found that students were having difficulties in understanding the mole concept and using it in solving related stoichiometry problems. In these studies efforts were made to elucidate the sources of lack of understanding.

It has long been known that, when firstly encountered, many students have difficulty in dealing with quantitative and semi-quantitative problems containing chemical formulas and the mole concept (Gabel & Sherwood, 1984; Genya, 1983).

The issue has been thought to occur due to the lack of abstract thinking and reasoning skills rather than the lack of proficiency in math (Friedel & Maloney, 1992). Abstract concepts are difficult to learn and this in due course slows down the subsequent learning. Conversely, conceptual learning facilitates the learning of abstract concepts and topics (Gover, Daniels & Lloyd, 1977).

Conceptual change has been a theme researched often in science education. As Duit (1994, 1996) highlighted, conceptual change has become a trademark in constructivist teaching and learning. Duit explained conceptual change as being a process of learning a concept starting from another concept. In chemistry, this process replaces chemical concepts with relevant concepts and improves the understanding of the learned concepts. There are numerous studies on conceptual change in chemistry education (Özkaya, Üce & Şahin, 2003; Özkaya, Üce, Sarıçayır & Şahin, 2006; Abraham & Williamson, 1994; Bargellini, 1997; Berkheimer, Anderson, Lee, & Blakeslee, 1988; Johnson, 1988). However, conceptual change studies concerning the mole and related concepts are not numerous in the science education literature. Case and Fraser (1999)'s study is one example and in this study the researchers worked with a sample of chemical engineering students. Clearly, more research is needed on using conceptual change in teaching the mole. In this study, we utilized conceptual change method to teach the mole concept to a sample of college students and evaluated its effect in terms of level of achievement in the subject.

Method

Study Design

In this work, the pretest-posttest control group experimental study design was used. The study took place in the 2006-2007 academic year with students in primary science education major in their first year at a university in Istanbul, Turkey. The two sections of students taking the General Chemistry course were randomly assigned to control and experimental groups (Fraenkel & Wallen, 2003; Karasar, 2003).

Both groups were taught by the same instructor during the study, the author of the article. The teaching period lasted 12 lecture hours, each 50 minutes, all completed in three weeks. In the control group, teacher-centered traditional method was used, while in the experimental group, conceptual change method was utilized. The instructor developed conceptual change texts to teach the mole concept in the experimental group. These texts included step-by-step procedures introducing and elaborating on the concepts and were projected onto a screen by an overhead projector.

The Science Achievement Test

To measure the level of achievement of the students in the subject of mole, a set comprising of 50 questions was developed. Some of the questions were taken from the past University Entrance Examinaton question sets (OSYM, 2008) and the rest were developed by the author. These questions were critically reviewed by an assessment and evaluation, and a subject area expert. Some questions were eliminated and others were revised. The number of questions was reduced to 33, which formed the Science Achievment Test (SAT). All assessments were made using these questions. SAT was applied twice during the study; once in the beginning (pretest) and once at the end (posttest). The purpose of the pretest was to assess the students' prior knowledge level in the subject matter and to find if there were any significant differences between the control and experimental groups. The posttest aimed to assess if significant differences in terms of subject matter knowledge between the groups had emerged. The same questions were administered in both tests, but the arrangement of the questions was changed in the posttest. The α-reliability coefficient was calculated as 0.86 for the SAT.

Conceptual Change Texts Used with the Experimental Group

To promote conceptual change in learning the mole concept, conceptual change texts were prepared by the instructor and used with the experimental group in five steps. Some exemplary parts of the conceptual change texts are as follows:

Step 1: Students were asked to define the term mole. Some of the student answers are given below:

- The atomic or molecular mass of a substance expressed in grams is 1 mole.
- Mass/molar mass or n = m/M (the ratio of mass to molar mass) is 1 mole.
- As many pencils as Avogadro's number (NA) is 1 mole.
- 16 gram of oxygen atoms are 1 mole.

All of the statements above are correct, but none of them is the correct definition of the mole. The instructor made the correct definition of mole after receiving these answers from students. *"A mole is an amount of substance that contains the same number of elementary units as there are ^{12}C atoms in 12.00000 g ^{12}C."*

Step 2: In this step, the sudents were asked to define the atomic mass unit (amu). The following are some of the answers received from the students.

- The mass of any single atom is 1 amu or 1 amu = m/M.
- 1 amu=1/NA (correct but not the definition of amu).
- 1 amu=NA.

All of the statements above are correct, but none of them is the correct definition. The instructor gave the correct definition after receiving these answers from students. *"1 amu is 1/12th of the mass of one ^{12}C atom. According to this definition, the mass of one ^{12}C atom is 12.00000 amu"*.

Step 3: The relationship between Avogadro's number, atomic mass unit and mass was explained in the following way: It was determined experimentally that there are as many ^{12}C atoms as Avogadro's number in 12.00000 gram ^{12}C, and the mass of one ^{12}C atom was accepted as 12 amu according to the definition of amu. Given that 12 gram ^{12}C is 1 mole (according to the definition of mole), the number of ^{12}C atoms in 12 gram ^{12}C is 6.02×10^{23} (experimentally calculated). Then,

How many gram is 1 amu? (1 amu = ? gram)

$12(\text{gram})=(12\text{x}6.02\text{x}10^{23})$ amu (when both sides are divided by 12), $1(\text{gram})=6.02\text{x}10^{23}$ amu, and hence, 1 amu$=(1/6.02\text{x}10^{23})$ gram $= 1.66\text{x}10^{-24}$ gram.

Step 4: Relationship between molar mass and relative atomic mass was explained. Why is the number standing for molar mass in grams for any atom the same with the number standing for the relative mass in atomic mass units for a single atom?

Let us consider an argon atom. The true mass of an argon atom is 10/3 times the true mass of ^{12}C atom. Namely, the relative mass of an argon atom is 40 amu (12 amu x 10/3=40 amu). According to the definition of mole, $6.02 x 10^{23}$ Ar atoms is 1 mol. Hence, the mass of 1 mol Ar atom is equal to 40 x NA amu. Because 1 gram=NA amu, 1 mol of Ar atom is 40 gram. As a result, relative mass of 1 Ar atom is 40 amu and mass of 1 mol Ar atom is 40 gram.

Step 5: The relationships between molar mass and relative atomic mass, and between mole and atomic mass unit were explained. Several assumptions for the definitions of mole and atomic mass unit are as follows:

Assumption 1: Let us assume that 1 amu is defined as 1/6th of the mass of ^{12}C instead of 1/12th of the mass of ^{12}C atom. In this case, the mass of ^{12}C would be accepted as 6 amu instead of 12 amu.

In this case, what would be the relative atomic mass in amu (with respect to the mass of a ^{12}C atom) and the molar mass in grams of an argon atom?

Since the mass of an argon atom is 10/3 times that of ^{12}C; the relative atomic mass would be 20 amu, (Relative mass of Argon atom=6 amu x 10/3=20 amu). On the other hand, 12 gram=$(6 \times 6.02 \times 10^{23})$ amu. If both sides are divided by 12, 1 gram is equal to 3.01×10^{23} amu (1 gram=3.01×10^{23}), and hence, 1 amu would be 3.32×10^{-24} gram.

By definition, 6.02×10^{23} Argon atom is 1 mole. Because 1 gram is 3.01×10^{23} amu, the mass of 1 mole Ar atom would be again 40 gram (1 mole Ar atom=$20 \times 6.02 \times 10^{23}$ amu $\times$ $1/3.01 \times 10^{23}$ gram/amu=40 gram).

Result: The relative mass of 1 Ar atom is 20 amu. The mass of 1 mole Ar atom is 40 grams.

Assumption 2: Let us assume that 1 mole is defined as the amount of matter that contains as many chemical entities (atoms, molecules etc) as the number of ^{12}C atoms in 6 g ^{12}C instead of in 12 g ^{12}C. In this case, 6 gram ^{12}C would be 1 mole, but the number of ^{12}C atoms in 6 gram ^{12}C would be $3.01 x 10^{23}$ rather than $6.02 x 10^{23}$ (resulting from experimental calculations); that is, $3.01 x 10^{23}$ particles would be 1 mole.

In this case, what would the relative atomic mass in amu, and the molar mass in grams of an Argon atom be?

Since the mass of Ar atom is 10/3 times the mass of ^{12}C, again, its relative atomic mass would be 40 amu (relative atomic mass of Ar=12 amu $\times$ 10/3=40 amu). On the other hand, 1gram is 6.02×10^{23} amu, therefore, 1 amu would be 1.66×10^{-24} gram (1 amu=$1/6.02 \times 10^{23}$ gram=1.66×10^{-24} gram).

According to this definition, the mass of 1 mole Ar atom is $40 \times 3.01 \times 10^{23}$ amu. Since 1 gram=$6.02 x 10^{23}$, the mass of 1 mole of Ar atom would be 20 gram.

Result: The relative mass of 1 Ar atom is 40 amu. The molar mass of Ar atom is 20 grams.

Assumption 3: Let us assume that 1 amu is defined as 1/6th of the mass of one ^{12}C atom instead of 1/12th of the mass of one ^{12}C atom, and 1 mole is defined as the amount of matter that contains as many chemical entities (atoms, molecules etc) as the number of ^{12}C atoms in 6 g ^{12}C instead of in 12 g ^{12}C.

In this case, the mass of one ^{12}C atom would be accepted as 6 amu instead of 12 amu. On the other hand, 6 gram ^{12}C would be 1 mole; but the number of ^{12}C atoms in 6 gram ^{12}C would be 3.01×10^{23} instead of 6.02×10^{23}, since 3.01×10^{23} particles would be 1 mole.

What would the relative atomic mass in amu, and the molar mass in grams of an Ar atom be according to these assumptions?

Because the mass of an Ar atom is 10/3 times the mass of ^{12}C, the relative mass of Ar would be 20 amu (Relative mass of Ar atom=6 amu × 10/3=20 amu). On the other hand, 1 gram=3.01×10^{23} amu, therefore, 1 amu would be 3.32×10^{-24} gram (1 amu=1/3.01×1023 gram=3.32×10^{-24} gram).

According to the assumed mole definition 3.01×10^{23} Ar atoms would be 1 mole, and hence, 1 mole Ar atom would be ($20\times3.01\times10^{23}$) amu. Since 1 gram is 3.01×10^{23} amu, the mass of 1 mole Ar atom would be 20 gram.

Result: The relative mass of 1 Ar atom is 20 amu, The molar mass of an Ar atom is 20 grams.

Conceptual change texts are summarized in Table 1.

Table 1. Conceptual change texts used in the study with the experimental group.

True Value	1 mole	12 gram ^{12}C
	1 amu	Mass of one ^{12}C atom/ 12
	Relative mass of Ar atom (amu)	40
	Molar mass of Ar (gram / mol)	40
Assumption 1	1 mole	12 gram ^{12}C
	1 amu	Mass of one ^{12}C atom/ 6
	Relative mass of Ar atom (amu)	20
	Molar mass of Ar (gram / mol)	40
Assumption 2	1 mole	6 gram ^{12}C
	1 amu	Mass of one ^{12}C atom/ 12
	Relative mass of Ar atom (amu)	40
	Molar mass of Ar (gram / mol)	20
Assumption 3	1 mole	6 gram ^{12}C
	1 amu	Mass of one ^{12}C atom/ 6
	Relative mass of Ar atom (amu)	20
	Molar mass of Ar (gram / mol)	20

Results

The data obtained from the study was analyzed by SPSS (Statistical Package for Social Sciences) software. The statistical confidence level was set as being at least 0.05. The results are given in the tables below.

The pretest means for the experimental and control groups are 12.215 and 12.176, respectively (Table 2). The probability value is greater than 0.05 (t= -0.100; p=0.921). The pretest mean scores for the control and experimental groups are very similar. These results indicated that there was not a statistically significant difference between the control and experimental groups at the beginning of the study in terms of the students' chemistry knowledge on the mole concept.

The pretest and posttest mean scores for the control group are 12.176 and 21.313, respectively (Table 3). The probability value is smaller than 0.05. There was a significant difference between the pretest and posttest results of the control group. This demonstrated that student achievement improved through the traditional method of teaching.

The pretest and postest mean scores for the experimental group are 12.215 and 24.431, respectively (Table 4). As seen from the table, there is a statistically significant difference between the pretest and posttest results.

The mean score of the experimental group is 24.431 while that of the control group is 21.313 (Table 5). The probability value is smaller than 0.05. As that value indicated, there was a statistically significant difference between the groups. These results demonstrated that teaching using the conceptual change method signifcantly improved student achievement more than the traditional teaching method.

Table 2. Independent t-test results for the comparison of SAT pretest scores for control and experimental groups.

Groups	N	Mean	ss	Sd	t	p
Experimental group	51	12.215	2.220	0.311	-0.100	0.921
Control group	51	12.176	1.717	0.240		

Table 3. Dependent t-test results of the SAT pre and posttest scores for the control group.

Test	N	Mean	ss	Sd	t	p
Pretest	51	12.176	1.717	0.240	33.471	0.000
Postest	51	21.313	1.048	0.146		

Table 4. Dependent t-test results of the SAT pre and posttest scores for the experimental group.

Tests	N	Mean	ss	Sd	t	p
Pretest	51	12.215	2.220	0.311	40.976	0.000
Posttest	51	24.431	1.878	0.263		

Table 5. Independent t-test results for the comparison of SAT posttest scores for control and experimental groups

Groups	N	Mean	ss	Sd	t	p
Experimental group	51	24.431	1.878	0.263	-10.347	0.000
Control group	51	21.313	1.048	0.146		

Conclusions and Implications

In this study, the effect of teaching the mole, atomic mass, relative atomic mass and molar mass concepts, an essential part of the university freshman general chemistry curriculum, by using conceptual change method on student success was investigated.

According to the SAT results, teaching supported by conceptual change texts improved the students' success in learning the mole concept compared to traditional teaching.

The pretest means of the control and experimental groups were very similar to each other, as expected (Table 2). Both groups received a mean score of 12 within decimal points of each other. The reason the groups could answer mole questions prior to any teaching at the university level was that they had seen the subject in high school. High school chemistry curriculum in Turkey includes teaching the mole concept in Grades 9 and 10 for 8 lecture hours.

The pretest and posttest mean scores for the contol group are 12.176 and 21.313, respectively (Table 3). There is statistically significant difference between the students' prior knowledge and post-teaching knowledge. The results show that the sudent achievement improved through the traditional teaching by ~9 mean points.

According to the dependent t-test for pre- and post-SAT results for the experimental group, the mean scores are found to be 12.215 and 24.431, respectively. This indicates that the increase in the posttest mean scores (by ~12 mean points), is greater for the experimental group where conceptual change texts were used, than that for the control group. In other words, teaching supported by conceptual change texts signifcantly improves student achievement and therefore may be used as an alternative teaching method.

Students may become bored due to the abstract terms and concepts in chemistry and therefore they may lose their interest and concentration in the course. Ability for critical thinking is not likely to improve in students who lose interest in science courses. Yet, the enthusisasm toward science courses can be easily improved by supporting teaching by texts that facilitate conceptual understanding. This method could also help alter the difficuites students face while learning chemistry and make their learning more enjoyable.

Chemistry lectures should not be based only on practice examples and problem solving; instead, the concepts must be explored appropriately to ensure informed understanding by the students. For an effective utilization of conceptual change method, instructors need to first determine the prior knowledge level of the students, prepare the conceptual change texts accordingly, and integrate them in lectures.

In conclusion, chemistry in general is a subject built upon abstract terms. In science courses, students need to research cause-effect relationships and strengthen their knowledge by understanding the concepts well. This can be accomplished by well-designed, complete conceptual texts; knowledge gained in this way could be lasting. Conceptual change approach to teaching may be useful in facilitating learning in chemistry as in other science courses (Özkaya, Üce, Sarıçayır & Şahin, 2006).

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