Activities to Enhance UNDERSTANDING OF THE MOLE AND ITS USE IN ChE

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Moles are a fundamental unit of measure in chemical engineering. Our students learn about moles (in the form of gmol) in chemistry, both at school and during their first year at university. In chemical engineering, we introduce them to the new units of kmol and lbmol, and the problems that arise highlight a general lack of understanding of the mole concept.

We have been aware for some time that our students have difficulty with moles, and this led us to tackle student understanding of moles as a research project in which we first quantified the nature and extent of the misunderstanding and then set out to design and implement a set of activities to promote conceptual change in this area. The intervention also dealt with a number of other concepts related to the mole. Following implementation of the intervention, students were again tested to measure the extent of improvement in their understanding.

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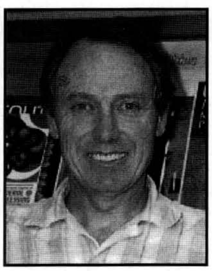

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All of this took place in the context of a new course for freshman chemical engineering students in which they are introduced to the basic concepts in chemical engineering as well as helped in developing certain key skills for the subsequent study of chemical engineering.[1] One of the skills developed is unit conversion, and the different mole units are introduced here. A central element of the course is introducing students to unfamiliar concepts through the use of familiar objects.

The full details of this research project are reported elsewhere.[2] The main objective of this paper is to present an overview of the test (used to determine understanding) and the intervention activities, together with evidence for their effectiveness in dealing with the misconceptions, with the hope that other chemical engineering educators would be encouraged to try them out or to use them in a modified form.

TESTING FOR UNDERSTANDING

Group interviews were used to explore possible misconceptions that students might hold about moles. Analysis of these transcripts identified three common misconceptions:

1. *The amounts kmol, lbmol, and gmol are seen as masses.*
2. *The amounts kmol, lbmol, and gmol are all the same, because they are all moles.*
3. *The volume of a gas is not seen as proportional to its amount.*

In order to be able to measure the extent to which these misconceptions were held in the class, a conceptual test was developed, based on the above research findings. For example, Question 1.2 tested misconception #1:

1.2	60 lbmol of N_2 weighs 60 lb.	True / False?

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Question 2.1 (in multiple choice format) is typical of a number of questions that probed misconception #2:

> **2.1** *Consider the following*
>
> | P | Q | R |
> |---|---|---|
> | 1 kmol of CO_2 | 1 lbmol of CO_2 | 1 gmol of CO_2 |
>
> *Which one of the following statements is true?*
>
> a) P, Q, and R all have the same number of molecules.
> b) P and R have the same number of molecules.
> c) P and Q have the same number of molecules.
> d) They all have different numbers of molecules.
> e) None of the above statements are true.

Question 3.1 tested misconception #3:

> **3.1** *Consider the following 50 m^3 vessels, each containing gas with the given composition:*
>
> | Vessel | A | B |
> |---|---|---|
> | Volume | 50 m^3 | 50 m^3 |
> | Composition | 25% CO_2 | 100% CO_2 |
> | (by volume) | 25% CH_4 | |
> | | 50% H_2 | |
>
> ***A and B are at the same temperature and pressure.***
> *Which one of the following statements is true?*
>
> a) A contains more molecules than B.
> b) B contains more molecules than A.
> c) A and B contain the same number of molecules.
> d) None of the above statements is true.

This test was specifically designed so that no numerical calculations were required in answering the questions (as can be seen in the sample questions above). Despite this, it was interesting to observe during the administration of the test that many of the students tried to use numerical calculations to find the answers. Even though calculators were not permitted, many students covered their question papers with calculations.

The results of the test confirmed that misconceptions were widespread in the class: 38% of the students showed evidence of misconception #1 (tested by one question); 28% showed misconception #2 (this was averaged over five questions); and 27% showed misconception #3 (averaged over two questions).[2] When the same test was administered again after the intervention activities (described in the next section), it revealed a significant increase in understanding.

INTERVENTION ACTIVITIES

We designed a series of intervention activities to address the misconceptions that had been identified during the interviews and the conceptual test. At the same time, we took the opportunity to deal with other related questions, albeit in a less focused manner.

The major objective in designing these activities was to give students a concrete visual or experiential point of reference for their understanding. This approach was based on recommendations in the literature concerning the general use of tangible objects in helping learners develop appropriate mental representations of chemical systems[3-5] as well as more specific recommendations regarding their use in developing the mole concept.[6,7] Where it was not possible to use concrete objects, we used thought experiments instead.

The activities were designed to follow one another. Students performed them in groups of three and were encouraged to discuss their findings with one another and with the tutors. Multiple sets of apparatus were available so that five groups could perform them simultaneously. A class of ninety students could then be handled in six batches over the course of one afternoon. The activities presented here are a refinement of the original set of five activities described by Case and Fraser.[2]

Activity #1

The purpose of this activity is to help students see the difference between the different kinds of moles they will need to work with as chemical engineers (gmol, lbmol, and kmol). They measure out 1 gmol, 1 lbmol, and 1 kmol of water, using a scale, and then are asked a series of questions to help consolidate what they have observed. The activity ends with an inspection of a display of bottles, each containing 1 gmol of a different substance, to provoke thinking about moles, molar mass, density, form, etc.

Activity #2

This activity is aimed at helping students make sense of gas volumes and mixtures of gases. The first task involves a box containing a mixture of squash balls and ping-pong balls, which have approximately the same diameter but significantly different masses. This provides an analogy for a mixture of different gases, such as oxygen and hydrogen, that occupy the same volume but have different masses.

The second task helps them visualize the volume occupied by 1 gmol of any gas at STP using a 22.4-litre Perspex box. They are also asked to calculate the masses of two different gases that would fill this box at STP. This is followed by a third task in which they calculate the mass of air occupying the room where they are working and then are asked what would happen to the mass of air in the room if its composition were different.

Activity #3

This activity is a thought experiment in which the students are asked, first, to calculate the kinetic energy of 1 kmol of each of three different gases, using their molar masses and average velocities. This leads to a discussion of why different gases all occupy the same volume at STP, using the assumption that this is related to their having the same kinetic energy.

The second task here involves determining the volume occupied by the actual molecules (from their molecular diameter) and hence the fractions of both water vapor and liquid water that are empty space. This is to help clarify the difference between liquids and gases.

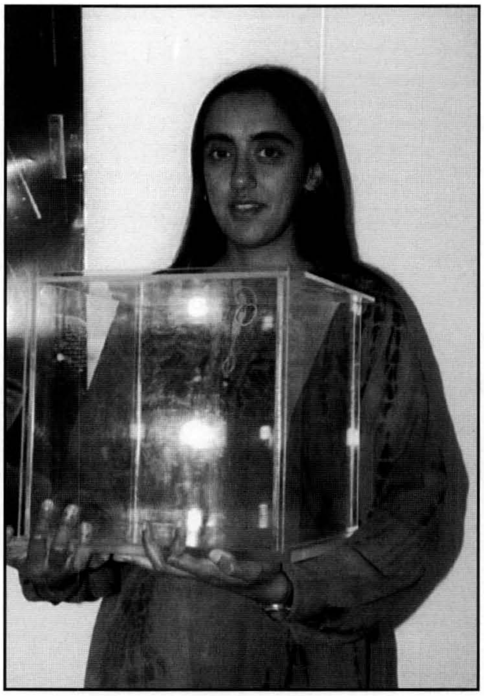
Activity #4

The final activity simulates chemical reactions using nuts and bolts. The concept of moles is further reinforced by getting students to weigh out a large number of each of the "reactants" on the basis of an average mass per nut or bolt (in the same way that coins are "counted" by weight at a bank). One bolt is "reacted" first with one nut, and then with two nuts. The difference between reacting numbers of each "reactant" and masses of each "reactant" is emphasized by the last two tasks in which they weigh out equal masses of nuts and bolts and then "react" them.

EFFECT OF INTERVENTION

When the students were tested again to gauge if their understanding had improved, there was a significant increase in their level of understanding. Figure 1 compares the pre- and post-test scores of all the students. It shows that those who could improve the most had done so, and that the average improvement is half the maximum possible. This figure also shows that there was no difference between the students who were interviewed and those who were not, which indicates that it was the intervention rather than being sensitized to the issues, that made the difference.

Table 1 gives a complete question-by-question analysis of the pre- and post-test results, arranged according to whether the questions covered the misconceptions being directly tackled or not. The shift of students from wrong to right answers,



Course tutor, holding the "mole" box.

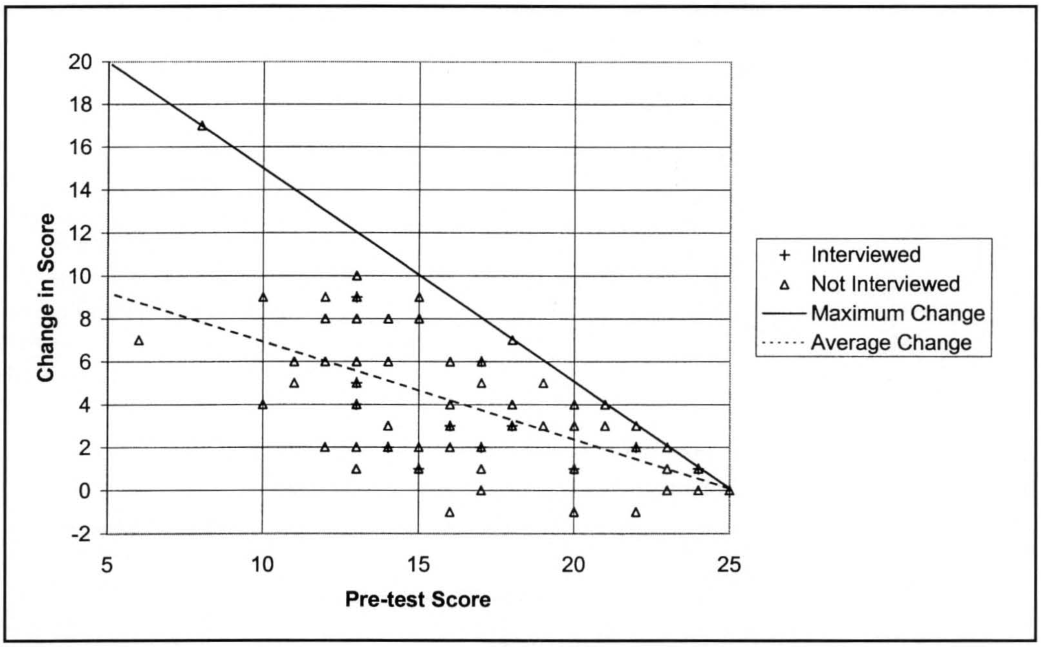


Figure 1.

as well as from right to wrong, is also shown. The shift from right to wrong is taken as a measure of the randomness of answering; this was consistent across the different groups of questions and averaged 6.4% over all the questions.

Table 1 shows clearly that the intervention had a much greater impact on the three misconceptions directly tackled (net shift from wrong to right of 17.1) than on the other issues tackled (net shift of 5.8). This is to be expected, given the clearer focus on them in the design of the intervention.

When the data in Table 1 is analyzed according to the three misconceptions (see Case and Fraser[2] for details of this), misconception #1 dropped from 38% to 22%, misconception #2 from 28% to 9%, and misconception #3 from 27% to 22%. The first two changes (16% and 19%) are significant compared to the randomness of answering (6%), whereas the third one is not (5%). This means that misconceptions #1 and #2 showed significant increases in understanding, whereas misconception #3 did not. This points to the effectiveness of activity #1 in addressing misconceptions #1 and #2.

TABLE 1
Question-by-Question Analysis of Results
("W" to "R" means Wrong to Right: "R" to "W" means Right to Wrong)

Item	Topic	Misc.	Pre-Test %cor.	Post-Test %cor.	Shift		
					W to R	R to W	Net
Misconceptions Tackled in Intervention							
1.2	lbmol	1	64%	76%	19	9	10
1.5	kmol/gmol	2	76%	88%	16	7	9
1.9	Avogadro's number	2	51%	90%	34	3	31
1.10	kmol/gmol gas	2	69%	80%	16	7	9
2.1	moles and molecules (same)	2	65%	91%	22	1	21
2.6	Avogadro's number	2	44%	85%	36	3	33
2.8	moles and gas volume	2	56%	83%	26	5	21
3.1	diff. gases at same conditions	3	63%	71%	15	8	7
3.6	gas mixture composition	3	59%	75%	20	7	13
	Average		*61%*	*82%*	*22.7*	*5.6*	*17.1*
Other Issues Tackled in Intervention							
1.1	kmol		61%	98%	31	2	29
1.3	m mass - kmol		68%	53%	10	22	-12
1.8	molecule and components		68%	75%	10	4	6
2.2	moles and mass (same)		89%	93%	8	5	3
2.3	moles and molecules (diff)		76%	84%	9	3	6
2.4	moles and mass (diff)		83%	85%	12	10	2
2.5	does P affect lbmol		63%	73%	16	8	8
2.7	kmol of diff. substances		66%	68%	12	11	1
2.9	reaction stoichiometry		93%	91%	5	6	-1
3.2	mass of gas mixture/pure gas		61%	78%	15	2	13
3.3	gas mixture composition		70%	61%	5	12	-7
3.4	gas mixture composition		56%	75%	20	5	15
3.5	pure gas cf mixture		74%	90%	18	5	13
	Average		*71%*	*79%*	*13.2*	*7.3*	*5.8*
Not tackled in Intervention							
1.6	unit conv		98%	93%	1	5	-4
1.7	unit conv		75%	83%	10	4	6
Average			*86%*	*88%*	*5.5*	*4.5*	*1.0*
Overall Average			***69%***	***81%***	***16.1***	***6.4***	***9.7***
Error in Pre-Test							
1.4	m mass - lb mol		46%	98%	42	1	

Perhaps even more important than this analysis was feedback over the past three years from those who teach the subsequent mass and energy balance course. They have noted a significant decrease in problems concerning moles.

CONCLUSIONS

What surprised and encouraged us was how enthusiastically all the students engaged in the activities—even the more advanced students, who we thought might find them trivial or boring. It appeared that none of the students had encountered similar activities at school, indicating that their previous experience in learning chemistry had been quite deficient in the use of tangible objects.

Why not try out the mole test on your students? You might be interested in the results. You may also find something in the mole activities that would be useful to try in your class, or use them as a springboard for developing other activities (we found developing them to be an exciting and creative challenge). Full copies of both the conceptual test and the intervention activities may be obtained by contacting the first author at

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