Preparing the Mind of the Learner – Part 2

Paper

Ghassan Sirhan[a] **and *Norman Reid**[b]

a) *The Centre for Teaching and Learning, Al-Quds University, Al-Quds (East Jerusalem), Palestine, PO Box 20002*
e-mail:sirhangh@yahoo.com
b) *The Centre for Science Education, University of Glasgow, Glasgow, Scotland, G12 8QQ*
e-mail: N.Reid@mis.gla.ac.uk

The effectiveness of pre-lectures has already been described in this journal.[1] This paper completes the story by describing the effect of new teaching materials for first year undergraduates, which were designed to mimic the pre-lecture. It is shown that these materials are able to enhance the performance of the less well-qualified students so that their performance in formal examinations does not differ from that of their more qualified colleagues.

Introduction

In 1968, Ausubel[2] made the comment: "*If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.*" In a previous paper,[1] it was noted that this bold assertion was supported by several studies (Johnstone and Su,[3] Johnstone [4, 5]). In particular, a study that looked at pre-lectures has described in some detail the effects of pre-learning.[1]

A pre-lecture can be described as an activity carried out before a block of lectures, designed to ensure that the essential background knowledge is established and is accessible so that new learning can be built up on a sound foundation. A decision in the University of Glasgow to develop a new introductory course in chemistry provided an opportunity to introduce pre-lectures. These were subsequently discontinued. The effects of the pre-lectures have already been described in detail.[1] and later the opportunity arose to develop teaching materials that sought to mimic pre-lectures in many ways. The effect of the use of these materials is described here.

Students will come to lectures with a wide variety of background knowledge. In some cases, previous learning in chemistry may have led to an incomplete or incorrect grasp of concepts. For other students, ideas once known and understood may not have been used for many months, making it difficult to retrieve them from long-term memory. In order to allow effective learning, it is important to ensure that the background knowledge and understanding is not only present but stored in such a way that it is accessible and understood correctly. This is the basis for the idea of the pre-lecture.

The General Chemistry course

In 1993-94, a new course was introduced at the University of Glasgow. Previously, students studying chemistry at level 1 (of a Scottish four year degree) all followed the same course. With increasing numbers (typically between 600-800 every year over the past few years) and more diverse entry qualifications, two chemistry classes were formed. The mainstream class (Chemistry-1) continued to operate, while the smaller class (General Chemistry) was offered a course with a slight reduction of content. General Chemistry was aimed to meet the needs of students with a wide range of entry qualifications in chemistry. Success in either course allowed students to proceed on to Chemistry at level 2.

Students take three subjects in the first year and both classes, therefore, took about a third of the time-commitment of a first year student. The level of both courses was appropriate for students who had obtained a pass in Chemistry at Higher Grade in the Scottish Certificate of Education. However, the entry qualifications of the students in General Chemistry ranged from those who have passed Chemistry at the Scottish Higher Grade (occasionally, with a pass at the Scottish Certificate of Sixth Year Studies as well) to those who had indicated no formal chemistry qualification at all, their entry to the university being based on qualifications in other subjects. Surveys of students showed low levels of commitment and motivation because the majority were taking the course merely to fulfil Faculty requirements.

Pre-lectures operated for the first two years (1993-94, 1994-95) of the General Chemistry course. A pre-lecture can take many forms (see, for example, Kristine[6]). In the General Chemistry course, pre-lectures took the following form. Working in an ordinary lecture theatre, it involved a short multiple-choice test that sought to check on

necessary background knowledge. The students marked this for themselves. The results provided them with some evidence about the level of their background knowledge and understanding. They were invited to see themselves as 'needing help' or 'willing to offer help'; the latter group assisted the former to complete various tasks, working in pairs or trios.

In this way, support was available for the students in need of help to understand the background knowledge that would enable them to make sense of the lecture course to follow. Those able to offer help assisted in this process of teaching, and, by the very act of teaching others, they themselves were assisted in ensuring that ideas were grasped clearly and correctly. The lecturer, supported by demonstrators, was on hand to offer assistance as required.

After two years the pre-lectures, as described here, were discontinued but, as has already been shown,[1] the pre-lectures of this form had the effect of supporting selectively the less well qualified students so that final performance did not relate to entry qualification. Many other alternative explanations were explored but none was shown to account for this effect.

Performance and entry qualifications

Usually, performance in formal assessments reflects the quality of entry qualifications. This typical pattern can be illustrated (see Table 1) by looking at the Chemistry-1 class (the mainstream class). Students enter with qualifications at Higher Grade or Higher Grade along with the Certificate of Sixth Year Studies (CSYS).

Taking any of the five years, it is easily seen that performance in examinations (either in January or in June) relates very closely to entry qualification. The Chemistry-1 class never has had pre-lectures as described for the General Chemistry Class. It has already been demonstrated that the presence of pre-lectures with the General Chemistry class (1993-94 and 1994-95) removed this relationship between examination performance and entry qualification while, on the removal of the pre-lectures (1995-96, 1996-97, 1997-98), the relationship was re-established.1

The Chemorganisers

In session 1998-99, the opportunity arose to develop and test teaching materials that sought to copy the pre-lecture idea. These materials were called 'Chemorganisers'. The materials were designed to provide bridges between what the learner already knows and what is to be learned. They were designed to help the learner organise and retrieve material that had already been learned. They also sought to teach by filling the gaps and clearing areas of misconception.

The Chemorganisers were based particularly on ideas developed by Ausubel[2] in 1968 (preparing the mind for learning) and Johnstone[7] in 1993 (the information processing model with its overall insight into learning). The Chemorganisers were designed to fulfil three broad aims:

1) Enhancing the preparation of the mind for new learning by:
   (a) assisting students to recall important background information.
   (b) helping students to organise and relate new information to their previous knowledge.
   (c) clearing up misconceptions.
   (d) filling gaps.

2) Easing the load on the working memory space by:
   (a) presenting material in such a way as to minimise demands on working memory space.
   (b) teaching students how to break down complex areas into manageable amounts.
   (c) enabling students to see interconnections so that knowledge can be 'chunked'.[8]

Table 1: Chemistry-1 Students' Performance with Entry Qualifications

Entry Qualification	Pass Grade	Average Mark for sessions									
		94/95		95/96		96/97		97/98		98/99	
		Jan	June	Jan	June	Jan	June	Jan	June	Jan	June
Certificate of Sixth Year Studies (CSYS)	A	77	77	81	82	84	81	87	89	90	85
	B	55	55	69	70	72	73	76	76	84	76
	C	38	40	59	64	65	60	68	66	68	62
	D	28	33	45	54	56	50	64	59	60	53
Scottish Higher Grade (H)	A	50	53	63	66	68	65	72	71	76	68
	B	31	38	48	54	51	51	59	55	63	55
	C	23	28	51	56	54	55	58	52	55	46

3 Changing attitudes towards learning by:
(a) giving students the opportunity to reinforce understanding and increase their confidence.
(b) enhancing motivation by providing students with summaries, related diagrams, and tables to be used for examination revision.
(c) encouraging students to become aware of their own learning processes, and as far as possible, to be in control of them.

Some sixty Chemorganisers were developed, covering those topics that had been found previously (by means of scrutiny of examination scripts as well as extensive use of questionnaires) to be causing difficulties for students. Although apparently very different from pre-lectures, their underlying aim was to mimic pre-lectures in preparing the minds of learners.

Each Chemorganiser was designed to fit on to one A4 page in landscape orientation, making it easier for the students to see all the parts of the presentation at one time. The style, language and terminology were made consistent with the way individual lecturers presented the topics. Extensive use of variable typescript formats and shading was introduced to aid ease-of-use and to emphasise key points.

Each Chemorganiser started by introducing the topic or presenting the problem, followed by a list of the background information that the student would need (entitled: "Before You Start"). The topic was explained, often using an example, a general strategy was outlined and students were given opportunities to try out their skills, with answers provided. Although each Chemorganiser covered a single topic or idea, links between Chemorganisers were provided so that students could move from one to another logically or could move back to a previous one to clarify underlying ideas.

Each Chemorganiser was constructed with a clear single focus in mind. The aim was to reduce demands on "Working Memory Space" by minimising unnecessary 'noise'.[9] They also aimed to develop an idea and then allow students to apply it in an unthreatening way to build confidence and provide useful feedback. The format of the Chemorganisers is shown in Figure 1 with a complete example being shown in the Appendix. In the set of Chemorganisers, many covered very basic background knowledge, including mathematical knowledge, with ten in inorganic, twelve in physical, and twelve in organic chemistry. Five dealt with the mole and four with acids, bases and pH, all known areas of difficulty.

The Chemorganisers in use

The Chemorganisers were used by the General Chemistry students in two main ways:
Twelve of the Chemorganisers (mainly those with fundamental mathematical emphases such as logarithms) were used at the beginning of the academic year 1998/99. These twelve were used on three occasions, the classes being optional for students. At the beginning of each class, the appropriate Chemorganiser sheets were distributed by the staff member who asked the students to look at each sheet. A discussion session was then started by explaining the theoretical background behind each problem, 'Before you start', and then the worked example was worked through step by step. When students were satisfied that they understood the process, they were asked to try on their own (or with a partner) to solve the self-assessment question(s). In many ways, this use of the Chemorganisers directly reflects the way the former pre-lectures operated. The atmosphere was

Figure 1: The Chemorganisers

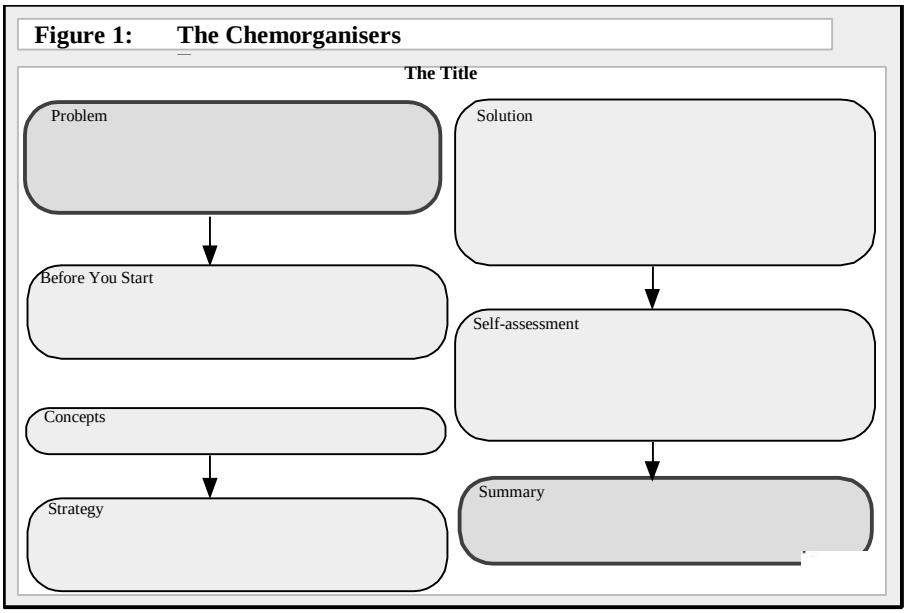

Table 2: Results of Statistical Analysis of General Chemistry Students' Examination Performances Based on Chemistry Entry Qualifications

Year	N	Exam	Average Marks			t-test	Mann-Whitney test
			Class	Upper	Lower		
1993/94	110	January	53.3	54.4	51.3	not sig.	not sig.
		June	47.3	47.4	46.3	not sig.	not sig.
1994/95	180	January	48.7	49.5	49.3	not sig.	not sig.
		June	48.6	48.8	48.6	not sig.	not sig.
1995/96	169	January	41.0	44.3	37.1	sig. at 0.1%	sig. at 1%
		June	45.2	49.4	40.3	sig. at 0.1%	sig. at 1%
1996/97	163	January	45.8	50.3	42.0	sig. at 1%	sig. at 1%
		June	43.4	46.1	41.9	not sig.	not sig.
1997/98	229	January	45.1	46.8	43.9	not sig.	not sig.
		June	43.2	46.6	38.7	sig. at 0.1%	sig. at 0.1%
1998/99	192	January	47.4	48.6	46.7	not sig.	not sig.
		June	49.4	50.9	48.6	not sig.	not sig.

unthreatening, involved no assessment and allowed students to be involved in cooperative learning.

The other Chemorganisers (the majority) were distributed at the beginning of the appropriate blocks of lectures. These contained relevant themes from inorganic, physical, and organic chemistry. They were offered to students throughout the course, but there was no pressure on students to take them, to use them, or to use them in a specific way.

Numerous observations were made throughout the course by means of questionnaires, sample interviews as well as informal communications with students during problem solving and laboratory sessions. These all indicated that the Chemorganisers were being used and were appreciated. However, in this paper, only the possible relationship between the use of the Chemorganisers and the performance in formal examinations is discussed in detail.

Examination performance

Students sit formal examinations in January and June as well as undertaking class tests at various stages throughout the year. The performance in the formal examinations is considered here. The General Chemistry class cannot be divided up into groups according to exact entry qualification because the diversity of entry qualification would make the groups too small for comparison purposes in any one year-group. Instead, following the analysis described previously,[1] the General Chemistry class was divided up into two groups.

Group 1: those with an upper level of qualification in chemistry (a pass at Scottish Higher Grade at "C" or better)

Group 2: those with a lower entry qualification in chemistry (less than a Scottish Higher Grade pass at "C").

The pattern of examination results is shown in Table 2. To check if the difference in performance between the upper and lower groups is statistically significant, two statistical tests were employed. The t-test assumes an approximation to normal distribution while the Mann-Whitney makes no such assumption. Both tests were employed since the actual mark distributions only roughly approximated to a normal distribution. However, the conclusions from both tests are identical. This shows that, in the first two years (when there were pre-lectures), there are no statistically significant differences between the two groups while, in the next three years (when such pre-lectures did not operate), the performance of the two groups was frequently different. In the final year when Chemorganisers were in use, the significant differences again disappeared.

Another way of looking at the data is to explore the *differences* in average performance between the two groups. This is shown in Table 3. This shows even more clearly that, in the middle three years when the pre-lectures were NOT operating, the differences in performance between the two groups are significant. The first two years (with pre-lectures) and the final year (with Chemorganisers) show no significant differences.

Finally, it is possible to explore subgroups by bringing together numbers from several years (to make comparisons possible). This is shown is Table 4. An inspection of the data again illustrates the way the pre-lectures (the first two years) and

Table 3: General Chemistry Main Groups Performances (Upper and Lower)

Year	Number of pre-lectures	% of Students		January			June			Average differences between Upper and Lower in January and June Exams
				Average Marks		Differences	Average Marks		Differences	
		Upper	Lower	Upper	Lower	Upper - Lower	Upper	Lower	Upper - Lower	
93/94	8	50.9	42.7	54.4	51.3	3.1	47.4	46.3	1.1	2.1
94/95	6	50.0	40.0	49.5	49.3	0.2	48.8	48.7	0.2	0.2
95/96	0	50.9	40.8	44.3	37.1	7.2*	49.4	40.3	9.2*	8.2*
96/97	0	43.2	48.4	50.3	47.0	8.3*	46.1	41.9	4.2	6.3¶
97/98	0	52	41.4	46.8	43.9	2.9	46.6	38.7	7.9*	5.4#
98/99	0	39.6	56.8	48.6	46.7	1.9	50.9	48.6	2.3	2.1

* These differences are significantly different (t-test, two-tailed, unrelated): $p<0.001$

¶ These differences are significantly different (t-test, two-tailed, unrelated): $p<0.01$

\# These differences are significantly different (t-test, two-tailed, unrelated): $p<0.05$

the Chemorganisers (the last year) bring about a different pattern of examination results when compared to the middle three years. The pattern of performance for the students who had entered with a Standard Grade pass is particularly interesting. These are students who had passed at Standard Grade (at about age 15-16) and had not taken Chemistry at the Higher Grade. It is clear that the pre-lectures and the Chemorganisers were working extremely effectively in 're-awakening' the chemistry of two years before and, perhaps, filling some of the gaps between what they had learned and what was needed to make sense of the university course. In this way, they were able to perform just as well as their better qualified peers in the examinations.

Conclusions

It is frequently an observation that curriculum interventions can affect most learners, with the favoured groups (usually the more able) gaining most. In this case, the less well qualified gained most. It can be argued that the better qualified had less need for the mind preparation that was offered through the Chemorganisers and, therefore, derived less benefit. Other observations did not suggest that any particular segment of the class was not using the Chemorganisers. Nonetheless, the observation of the less favoured group benefiting specifically from a curriculum intervention is unusual.

The importance of the idea of preparing the mind of the learner was first laid down by Ausubel.[2] Later, Johnstone[9] developed a predictive model in the specific context of science education. In applying this, it is clear that, in the idea of preparing the mind of the learner, there is a fundamental principle which can be turned into a practical reality: this brings benefits to those who are disadvantaged by their lack of previous experience of chemistry. The pre-lecture can be used in any course in Higher Education while the set of Chemorganisers may prove to be a useful resource to assist the hard-pressed university teacher when faced with classes where the background experience may be inadequate as a basis for success.

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Table 4: General Chemistry Sub-Groups' Performances

(a) The first two years (The presence of pre-lectures)

Group	1993/9			1994/9				Two years			
	N	January	June	N	January	June		N	January	June	Average
Higher	52	53.5	47.2	85	48.4	49.2		137	50.3	48.4	49.4
Standard	21	55.2	50.2	23	50.8	49.3		44	52.9	49.7	51.3
Alternative	16	50.3	42.7	28	50.5	50.7		44	50.4	47.3	48.9
None	10	44.5	44.1	21	46.1	45.2		31	45.6	44.9	45.2

(b) The intermediate three years (No pre-lectures)

Group	1995/9			1996/9			1997/9			Three years			
	N	January	June	N	January	June	N	January	June	N	January	June	Average
Higher	77	44.4	49.6	58	49.4	45.0	109	46.6	47.1	244	46.6	47.4	47.0
Standard	19	36.2	38.1	25	42.9	41.2	26	35.7	30.5	70	38.4	36.4	37.4
Alternative	22	37.6	42.0	23	41.0	40.0	18	49.8	42.2	63	43.1	41.4	42.3
None	13	31.4	39.7	17	42.3	47.3	26	44.5	41.2	56	40.8	42.9	41.9

(c) The last year (Introducing the Chemorganisers)

Group	1998/9					One year			
	N	January	June			N	January	June	Average
Higher	73	48.8	51.0			73	48.8	51.0	49.9
Standard	22	50.7	51.3			22	50.7	51.3	51.0
Alternative	37	43.3	48.6			37	43.3	48.6	46.0
None	19	45.0	50.8			19	45.0	50.8	47.9

Groups:

Higher:	The Higher Grade of the Scottish Qualifications Authority
Standard:	The Standard Grade of the Scottish Qualifications Authority
Alternative:	Qualifications based on SCOTVEC modules or Wider Access courses
None:	No formal chemistry qualification at all

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Chemorganiser

The Mole and solutions

Problem
How many mL of 2 M H_2SO_4 will be required to neutralise 25 mL of 1 M NaOH?

Before you start

* The millilitre (mL) is one thousandth of a litre: 1000 mL = 1 litre
  If a solution contains 1 mole of dissolved material per litre it is said to be **Molar** solution and the symbol used is **M**. Thus a 2 M solution contains 2 moles per litre.
* Neutralisation is complete when all the H^+(aq) of an acid have joined with exactly the same number of OH^-(aq) of an alkali:
  $2\ H^+(aq) + 2\ OH^-(aq) \longrightarrow 2\ H_2O(l)$
* The reaction of a strong acid with strong alkali (base) gives new material called a **salt**:
  H_2SO_4 + 2 NaOH ⟶ Na_2SO_4 + $2\ H_2O$
  acid — alkali (base) — a **salt** — water

Concepts
Strong acid, strong alkali (base), concentration, mole, neutralisation, salt, molar solution, molarity, neutralisation point

Strategy
(1) Imagine the alkali in a beaker: How many moles of OH^- in the beaker?
Number of moles OH^- = Volume (in litres) x Molarity x Number of OH^- in the formula
(2) Imagine the acid in a beaker: How many moles of H^+ in the beaker?
Number of moles H^+ = Volume (in litres) x Molarity x Number of H^+ in the formula
(3) When an acid neutralises an alkali. The number of H^+ = the number of OH^-

Solution
(1) Number of moles OH^- = Volume in litres x Molarity x Number of OH^- in the formula
= 25 ÷ 1000 L x 1 x 1 (i.e. 1 OH^- in NaOH)
= 0.025 moles OH^-

(2) Number of moles H^+ = Volume in litres x Molarity x Number of H^+ in the formula
Suppose that the volume of the acid is **V**
= (**V** ÷ 1000 L) x 2 x 2 (i.e. 2 H^+ in H_2SO_4)
= (0.004 **V**) Litres

(3) The number of H^+ = the number of OH^-
0.004 **V** = 0.025
V = 0.025 ÷ 0.004 = 0.00625 Litres = 6.25 mL

Thus: 6.25 mL volume of H_2SO_4 is needed.

Self-assessment

(a) What is the molarity of $Ca(OH)_2$ when 100 mL of it can be exactly neutralised by 12.5 mL of 0.50 M HCl ?
(b) 100 mL of 0.20 M HCl are placed in a flask. How many millilitres of 0.40 M NaOH are required to bring the solution to the neutralisation point

Summary

* Number of Moles OH^- = Volume (L) x Molarity (mol L^{-1}) x Number of OH^-
* Number of Moles H^+ = Volume (L) x Molarity (mol L^{-1}) x Number of H^+
* In our problem above:

  At neutralisation point,
  Number of moles OH^- (alkali) = Number of moles H^+ (acid)
  Therefore, V x M x number of OH^- = V x M x Number of H^+

  Or, $V_1 \times M_1 \times P_1$ (alkali) = $V_2 \times M_2 \times P_2$ (acid)
  [P stands for ***power*** (H^+ or OH^- per formula)]

Answers: (a) 0.031 M, (b) 50 mL