

# Does teaching sequence matter when teaching high school chemistry with scientific visualisations?

By Ian Fogarty, David Geelan and Michelle Mukherjee

**Five Canadian high school Chemistry classes in one school, taught by three different teachers, studied the concepts of dynamic chemical equilibria and Le Chatelier's Principle. Some students received traditional teacher-led explanations of the concept first and used an interactive scientific visualisation second, while others worked with the visualisation first and received the teacher-led explanation second. Students completed a test of their conceptual understanding of the relevant concepts prior to instruction, after the first instructional session and at the end of instruction. Data on students' academic achievement (highest, middle or lowest third of the class on the mid-term exam) and gender were also collected to explore the relationship between these factors, conceptual development and instructional sequencing. Results show, within this context at least, that teaching sequence is *not* important in terms of students' conceptual learning gains.**

## INTRODUCTION

An increasing number of high school Chemistry teachers are using the new forms of scientific visualisation made available by widespread computer access – animations and simulations, both interactive and non-interactive – in their classrooms (e.g. Sendlinger et al., 2008, Tuví-Arad & Blonder, 2010). Results from an Australian study (Geelan, 2012; Geelan, Mukherjee & Martin, 2012; Geelan & Mukherjee, 2011) suggest that there are advantages for students' conceptual development in using scientific visualisations, but that these advantages are quite small in terms of effect size. There is a significant body of other research, however, that suggests that the use of scientific visualisations enhances students' enjoyment of, and engagement with Chemistry learning (e.g. Frailich, Kesner & Hofstein, 2007; Özmen, 2008). Given these combined findings, it appears that the trend toward increasing use of scientific visualisations in Chemistry classrooms is a positive one and is likely to continue and even accelerate.

Whilst we can see the beginnings of a research base in Chemistry education around the educational effectiveness of scientific visualisations in teaching, most of these studies tend to be either (a) descriptive projects that focus on students' use of the visualisations and their subjective experience, (b) semi-quantitative studies that focus on students' self-reported attitude, enjoyment and engagement rather than on achievement and conceptual development. A few recent studies have focused more directly on student learning outcomes (Frailich, Kesner & Hofstein, 2007; Geelan, Mukherjee & Martin, 2012; Geelan & Mukherjee, 2011; Özmen, 2008).

Even these studies, however, tend to focus on the visualisation as a single teaching intervention or experience, often reporting quantitative data comparing the achievement or learning of students learning with visualisations with that of students taught using more 'traditional' Chemistry teaching strategies such as lecturing or class discussion. It is clear that scientific visualisations will never entirely replace these other forms of Chemistry pedagogy, and nor should

they. Visualisations are merely a new and shiny tool in an already very well-stocked toolbox of teaching strategies and student activities used by effective Chemistry teachers. If the educational use of scientific visualisations is compared metaphorically to a wood saw, it will do a great job of sawing wood but a very poor job of hammering nails. Teaching tools ought to be used to do the things they do well.

Given this, it is valuable to collect evidence on the ways in which teachers use visualisations in combination with other teaching strategies. We know that visualisations are at least as effective for learning as other teaching strategies (Geelan, 2012), but if a teacher plans to use both visualisations *and* more traditional teacher-led explanations, is the order of instruction important? Should the visualisation be introduced to students first, followed by explanation, or is the reverse order more effective? Or doesn't it matter? This study is an initial and limited attempt to provide evidence that answers these questions.

Our concerns are essentially those of classroom teachers in this project: what works in the classroom? The first author of this paper is a practicing classroom teacher, and the other two authors have also worked as teachers in high school chemistry classrooms. While there are some recent attempts (e.g., Kyza, Erduran & Tiberghien, 2009; Ling, 2011; Yore & Hand, 2010) at systematizing approaches to the use of scientific visualisations in teaching, there does not yet seem to be a strong theoretical case for any particular ways of combining visualisations with other teaching approaches in sequences. For the moment, this paper attempts to capture some empirical evidence that addresses the question in the title: 'Does teaching sequence matter?'

The research question can be stated in the form:

*Is it more effective in terms of students' conceptual learning to use a scientific visualisation before a teacher-led explanation when teaching a Chemistry concept or to reverse this sequence?*

This formulation leads to three hypotheses:

*The null hypothesis:  $H_0$ :* there is no significant difference in student conceptual learning between the visualisation-then-explanation and the explanation-then-visualisation sequences

*The positive hypothesis:  $H_+$ :* there is a significant advantage in terms of student conceptual learning for the visualisation-then-explanation sequence over the explanation-then-visualisation sequence

*The negative hypothesis:  $H_-$ :* there is a significant advantage in terms of student conceptual learning for the explanation-then-visualisation sequence over the visualisation-then-explanation sequence

These hypotheses were tested using quantitative evidence from a brief test of conceptual understanding of the target concept, described in more detail below.

Of course, students are not all the same. Further analyses were conducted to see whether the results observed for all students were also observed for male and female students and for students achieving at lower, middle and higher levels academically.

## METHOD

Five classes of Chemistry students in a Canadian high school studied the concepts of dynamic chemical equilibria and Le Chatelier's Principle during late 2009. It is worth noting here that Le Chatelier's Principle correctly predicts most but not all situations, and needs to be taught with care. Some teachers prefer to avoid it entirely and teach students to analyze equilibria in other ways, but it appears in syllabus documents in many jurisdictions.

Three of the five classes were taught by one teacher, James. (All names used in this paper are pseudonyms. All participants in the study were informed about the research project and their consent obtained.) One class was taught by each of two other teachers, Peter and Malcolm. The three teachers were close colleagues in the school with comparable levels of teaching skill and experience, such that the teaching approaches used during the teacher explanations sequences were highly comparable. All students in all five classes also learned in the same way with the computer-based visualisations: one student working on one computer, without interacting with either a teacher or other students. This means that, despite the relatively small numbers in each of the classes, the data from the five classes were sufficiently comparable that combining them for the quantitative analysis was appropriate.

Prior to instruction, all students completed a twelve item test of their conceptual understanding of the target concepts. Students completed the test in ten minutes with time to spare. The test was based on the Chemistry Concept Inventory (Mulford & Robinson, 2002) and was designed to distinguish the extent to which students have developed the 'correct' scientific concept in relation to a topic, rather than any of a number of possible 'misconceptions'. The test comprised twelve multiple-choice items, with four possible answers for each item, and the distractors focused on the common misconceptions as identified in the research literature (e.g. Everhart & Evans, 2006; Özman, 2007).

The study design was a revised version of a crossover (Ratkovsky, Evans & Alldredge, 1993) design. All students were taught the concept over two thirty

minute periods, using a scientific visualisation and a more traditional teacher-led discussion. That is, students were taught for twenty-five minutes using one approach, then completed a post-test, then (on another day) taught for a further twenty-five minutes using the other approach and again post-tested. About half of the participating students ( $n=76$  for the whole study) received the visualisation-then-explanation sequence and the other half received the reverse sequence.

The visualisation used was one developed by McGraw Hill publishers and available online at: <http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/lechv17.swf>. It consists of a central site with links to a number of different equilibrium situations, in the liquid and gas phases. Each situation is explained by a recorded narration and illustrated using Adobe Flash animations. The animations work across a number of levels of representation, from the symbolic (chemical equations) through the macroscopic (colour changes and other indications of chemical activity), to the molecular/sub-microscopic scale. Students were encouraged at the beginning of the session to use the student controls, to pause and replay. The visualisation contains multiple representations of the same example including a macroscopic, microscopic, symbolic and graph perspectives. All students were finished with the visualisation after twenty-five minutes.

For the 'explanation' sessions, the teachers directed the explanation, and the approach was similar to lecturing, although students were asked questions and given opportunities to ask questions. The teachers were encouraged to 'teach the topic as you usually would, if you were not using a visualisation', and (quite typically for senior chemistry classrooms) this approach was largely a combination of lecturing and whole-class discussion.

Of James' three classes, two ( $n=9$  and  $n=18$ ) received the visualisation lesson first, as whole classes, and the explanation lesson second. The third class, ( $n=17$ ) received the reverse sequence. The approach in Peter's ( $n=17$ ) and Malcolm's ( $n=15$ ) classes was different: each class was split approximately in half, the halves matched for gender balance, and half of each class received the visualisation-then-explanation sequence while the other half received the explanation-then-visualisation sequence. In each of the five classes, the whole teaching sequence occurred across two class periods, with one 'treatment' in the first class and the other in the second.

Each group received the same time allotments for each phase. On Day 1, all students completed the pretest in a ten minute time frame. The instructional period was twenty-five minutes long for both the traditional lecture/discussion style and the visualisation style. The teacher finished the lecture at the twenty-five minute mark and all students had finished the visualisation in the time frame. Finally, the students were given post-test A over twenty minutes. On Day 2, the groups were given the reverse treatment for twenty-five minutes followed by twenty minutes for post-test B.

There were seventy-six students in the whole cohort. Thirty-three were male and forty-three female. Coincidentally, thirty-three students (not just the male students) received the lecture-then-visualisation teaching sequence and forty-three received the visualisation-then-lecture sequence.

All students completed the same test that was used as the pretest twice more, once after their first teaching experience and once after their second (at the

end of the teaching sequence). This approach was intended to explore the 'order effect' for learning of the concepts. The repeated use of the same test may have led to some student disenchantment with the test, which may have affected results, but this was probably not a large factor. Some memory effects for particular questions may also have occurred, however these would have been the same for all students in all teaching sequences, and since the **differences** in learning gains are being measured, should not adversely affect the findings. Any sensitization of the students to particular concepts through having answered the questions, would likewise be the same for all students in either sequence, since all students completed the test prior to any teaching.

The participating teachers also indicated each student's gender and his/her grade on the midterm examination in Chemistry (a proxy for academic achievement in Chemistry more generally) on an anonymized class list to enable finer-grained analyses by these variables to be conducted.

## RESULTS AND DISCUSSION

An initial question to be addressed is the comparability of the two groups of students created from across all five classes, based on their teaching sequence. Table 1 shows the number of students each group and the mean and standard deviation for their scores on the pre-test. The difference of means on a two-tailed independent samples t-test was not significant ( $t(74)=.062, p=.95$ ), so, based on their performance on the pretest, the groups are not different from one another in any systematic way.

Group	Teaching Sequence	Pre-test Mean (SD)
1 (n=33)	Explanation → Visualisation	4.21 (1.673)
2 (n=43)	Visualisation → Explanation	4.19 (1.930)
Total (n=76)		4.20 (1.811)

Table 1: Pretest scores for all students.

A comparison of the students' conceptual learning – expressed as the increase in correct questions out of twelve between the pretest and posttest A (after the first session of instruction) – offers an opportunity to explore the question of whether learning with visualisations is more effective than teacher explanations. This first measurement is separate from consideration of order effects, since it simply compares the thirty-three students whose first exposure to the concepts was a teacher-led explanation with the forty-three whose first exposure was the scientific visualisation. Table 2 shows the results of this comparison.

Group	Teaching Experience	Posttest A minus Pretest Mean (SD)
1 (n=33)	Explanation	2.67 (3.129)
2 (n=43)	Visualisation	1.84 (2.591)
Total (n=76)		2.20 (2.847)

Table 2: Conceptual knowledge gains during first teaching sequence, all students.

The mean gains look different by inspection, but the standard deviations are large, and on a two-tailed t-test the difference between the means was shown

not to be significant ( $t(74)=1.26, p=.21$ ). This result reflects that of the Geelan & Mukherjee (2011) study, which found no significant differences between the two treatments in a more formal crossover study design.

Before leaving the first teaching sequence we will touch briefly on the other variables collected – gender and academic achievement – to see whether a finer-grained look at the data will show differences for these groups. The question is whether a particular type of teaching – visualisations or teacher explanations – is more effective for any particular group of students. On the pretest, scores for male and female students were statistically not different ( $t(74)=-.065, p=.95$ ) on a two-tailed t-test, and on a one-way ANOVA, the means on the pretests of the three achievement groups (ranked by performance on the midterm exam) were not significantly different ( $F(75)=.783, p=.46$ ).

Tables 3 and 4 show analyses that divide out students who learned first with one or the other teaching strategy, then analyse the results further by gender and achievement.

Group	Teaching Sequence		Pre-test Mean (SD)
1 (n=33)	Explanation	Male (n=16)	3.56 (2.31)
		Female (n=17)	1.82 (3.61)
2 (n=43)	Visualisation	Male (n=17)	1.65 (2.60)
		Female (n=26)	1.96 (2.63)

Table 3: Conceptual knowledge gains during first teaching sequence, by gender.

On a two-tailed t-test the learning gains for male and female students were not significantly different for either teaching strategy. (explanation,  $t(31)=1.64, p=.11$ , visualisation,  $t(41)=-.385, p=.70$ )

Group	Teaching Experience		Posttest A minus Pretest Mean (SD)
1 (n=33)	Explanation	Class Rank (1 is lowest, 3 highest)	
		1	1.78 (2.49)
		2	3.33 (3.42)
2 (n=43)	Visualisation	3	2.67 (3.34)
		1	1.07 (2.30)
		2	2.39 (2.68)
		3	1.91 (2.77)

Table 4: Conceptual knowledge gains during first teaching sequence, by academic achievement (score on Chemistry midterm, divided into highest, middle and lowest third of the class).

On a one-way ANOVA, the learning gains for students at the three levels of academic achievement were not significantly different for either teaching strategy. (explanation,  $F(32)=.62, p=.54$ , visualisation,  $F(42)=1.03, p=.37$ )

In a sense all of the results and discussion so far, while of some interest for teaching, have been preamble to the main thrust of this paper: the discussion of 'order effects'. That is to say, is it important for students' development of scientific concepts whether teachers use scientific visualisations in their teaching before or after giving verbal explanations? Or does order not matter?

The simplest measure is the overall learning gain, from the pretest to the final post-instruction test after both learning experiences. Table Five shows these results. The difference between the means of these groups is not statistically significant ( $t(74)=1.41, p=.89$ ).

Group	Teaching Sequence	Overall gain (post-test B minus pretest)
		Mean (SD)
1 (n=33)	Explanation → Visualisation	2.48 (2.87)
2 (n=43)	Visualisation → Explanation	2.40 (2.65)
Total (n=76)		2.43 (2.73)

Table 5: Overall gain scores for all students.

It seems clear, then, that for the whole student group, teaching sequence does not matter in terms of overall conceptual learning gains. This may come as a relief to classroom teachers, since the order of activities may well be influenced by school-based factors such as access to computer facilities, and teachers are unlikely to have complete freedom to order the instruction in any particular way.

Does this finding hold up for the different subgroups? The difference between the means of the overall learning gains for male ( $n=33, M=2.70, SD=2.35$ ) and female ( $n=43, M=2.23, SD=3.00$ ) students was not significant ( $t(74)=.73, p=.47$ ).

Table Six shows the overall learning gains by academic achievement level for students in the two different learning sequences.

Group	Teaching Experience	Posttest A minus Pretest
	Class Rank (1 is lowest, 3 highest)	Mean (SD)
1 (n=33)	Explanation-then-visualisation	1 (n=9) 1.44 (3.00)
		2 (n=12) 2.67 (2.43)
		3 (n=12) 3.08 (3.20)
2 (n=43)	Visualisation-then-explanation	1 (n=14) 1.86 (2.35)
		2 (n=18) 2.78 (2.71)
		3 (n=11) 2.45 (2.65)

Table 6: Overall conceptual knowledge gains during overall teaching sequence, by academic achievement (score on Chemistry midterm, divided into highest, middle and lowest third of the class).

Figure One shows the learning gains for each group of students during each teaching experience.

The two groups begin at the same point on the pretest. Learning gains are steeper for the explanation-first group on their first exposure to the concept, and there is a small 'negative learning' effect from posttest A to posttest B for this group. It seems improbable that negative learning is actually taking place, although it is possible some students may have been confused by the visualisations. It is also plausible to suggest that they may have expended less effort when doing the same test for the third time. Students in the visualisation-first group experienced lower gains on their first exposure but made up ground on the second (explanation) learning experience. The overall gains for the two groups were very similar, bearing out the statistical analyses above. That is to say, the null hypothesis – no significant difference – was supported.

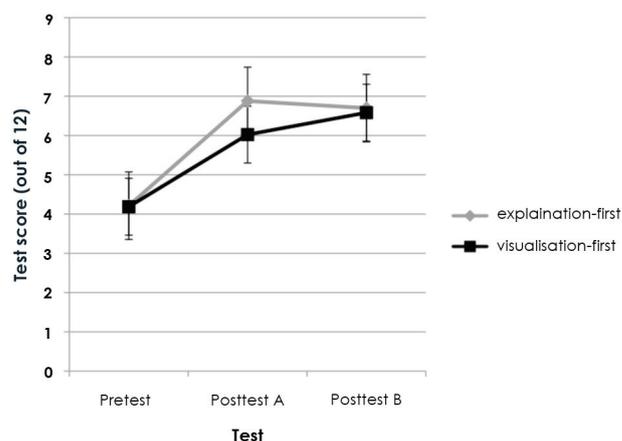


Figure 1: Learning gains from two learning sequences (error bars show standard error of mean).

This study has a number of limitations. The sample size was quite small, and in particular, when the results are separated by gender or academic achievement levels, some of the cells are so small that no meaningful statistical analysis can be conducted. While we believe there is value in reporting studies of this kind, much larger studies with large enough groups for credible statistical analyses would yield results in which much more confidence could be placed. We wish to make it clear that our claims must be as modest as our participant numbers.

Only the concepts – difficult for many students (Banerjee, 1991; Gorodetsky & Gussarsky, 1986; Quilez-Pardo & Solaz-Portoles, 1995) – of dynamic chemical equilibria and Le Chatelier's Principle were studied. While it is plausible that these findings might be generalizable to other Chemistry concepts, there is considerable scope for further research of this kind relating to other concepts, and it will be difficult to make broad generalizations about the issue until more evidence is available.

Similarly, all students in this study used one particular scientific visualisation. The particular visualisation is an animation rather than a simulation, and it is not highly interactive: it is more like a series of short narrated animated video clips hyperlinked together in a single site than a truly interactive simulation of the relevant processes and phenomena. It is possible that the results observed in this study may have been different if a different visualisation – or a set of several chosen visualisations – had been used in the study. Again, further research is required in order to build (or challenge) confidence in the tentative findings reported.

Students were also at one particular school in one particular Canadian province with its particular syllabus and mix of student abilities and characteristics, and with particular teachers. Further national and international research in a variety of contexts is required to support or challenge these findings.

## CONCLUSION

Overall, the results of this study are clear: in the very limited contexts explored in this small study, teaching sequence did not matter in terms of whether teachers used verbal explanations and other 'traditional' teaching approaches first or visualisations first. This finding was robust across both genders and across levels of academic ability. This finding may be helpful for teachers who might be concerned about the order in which they use particular teaching strategies, and may help free teachers to organize instruction based on issues such as

maintaining student interest and engagement, as well as the inherent constraints of teaching in busy schools with sometimes-limited access to computers. There is, of course, considerable scope for more and larger studies addressing this and other issues in relation to the educational use of scientific visualisations.

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