# Order of instruction effects – do they make a difference when teaching senior chemistry with computer based visualizations?

Author

Mukherjee, Michelle M., Fogarty, Ian, Geelan, David R.

Published

2011

Conference Title

Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications (EDMEDIA) 2011

# Order of instruction effects – do they make a difference when teaching senior chemistry with computer based visualizations?

Michelle M. Mukherjee
Queensland University of Technology, Australia
michelle.mukherjee@qut.edu.au

Ian Fogarty
Riverview High School, New Brunswick, Canada
ian.fogarty@nbed.nb.ca

David R. Geelan
The University of Queensland, Australia
d.geelan@uq.edu.au

**Abstract**: This study investigated whether conceptual development is greater if students learning senior chemistry hear teacher explanations and other traditional teaching approaches first then see computer based visualizations or vice versa. Five Canadian chemistry classes, taught by three different teachers, studied the topics of Le Chatelier's Principle and dynamic chemical equilibria using scientific visualizations with the explanation and visualizations in different orders. Conceptual development was measured using a 12 item test based on the Chemistry Concepts Inventory. Data was obtained about the students' abilities, learning styles (auditory, visual or kinesthetic) and sex, and the relationships between these factors and conceptual development due to the teaching sequences were investigated. It was found that teaching sequence is not important in terms of students' conceptual learning gains, across the whole cohort or for any of the three subgroups.

## Introduction

An increasing number of high school Chemistry teachers are using the new forms of scientific visualization made available by widespread computer access – animations and simulations, both interactive and non-interactive – in their classrooms (e.g. Sendlinger et al., 2008, Tuvi-Arad & Blonder, 2010). Preliminary results from an Australian study (Geelan et al., 2010; Geelan & Mukherjee, 2010) suggest that there are advantages for some students' conceptual development in using scientific visualizations, 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 visualizations 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 visualizations in Chemistry classrooms is a positive one and is likely to continue and even accelerate.

While there is beginning to be a research base in Chemistry education around the educational effectiveness of scientific visualizations in teaching, most of these studies tend to be either (a) descriptive projects that focus on students' use of the visualizations 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 et al., 2010; Geelan & Mukherjee, 2010; Özmen, 2008).

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

Given this, it is valuable to collect evidence on the ways in which teachers use visualizations in combination with other teaching strategies. We know that visualizations are at least as effective for learning as other teaching strategies (Geelan, et al., 2010), but if a teacher plans to use both visualizations and more traditional teacher-led explanations, is the order of instruction important? Should the visualization be introduced to students first, followed by explanation, or is the reverse order more effective? Or doesn't it matter? This study is intended to provide evidence that answers these questions. The research question can be stated in the form:

Is it more effective in terms of students' conceptual learning to use a scientific visualization before a teacher-led explanation when teaching a Chemistry concept?

This formulation leads to three hypotheses:

*The null hypothesis: H0*: there is no significant difference in student conceptual learning between the visualization-then-explanation and the explanation-then-visualization sequences

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

*The negative hypothesis: H-:* there is a significant advantage in terms of student conceptual learning for the explanation-then-visualization sequence over the visualization-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 as one another. Further analyses were conducted to see whether the results observed for all students were also observed for male and female students, for students achieving at lower, middle and higher levels academically, and for students with different learning styles (visual, auditory or kinesthetic) (Dunn, Beaudry & Klavas, 2002). We recognize that 'learning styles' are more of a heuristic for thinking about student learning preferences and differences rather than a definitive category system, and that by assigning students to a single category based on their dominant preference we are submerging some genuine complexity, however, we believe there is value in this analysis for teaching purposes.

Geelan et al. (2010) found that in general male students received more benefit from using scientific visualizations than female students, the highest-achieving students received more benefit than lower-achieving students and (somewhat surprisingly) kinesthetic learners received more benefit than either visual or auditory learners. The Canadian data in the present study will be analysed to see whether these general patterns are borne out, and whether order effects are differentially important for these various subgroups within the larger study.

## 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. Three of the five classes were taught by one teacher, Albert. One class was taught by each of two other teachers, Bob and Carl. Prior to instruction, all students completed a 12 item test of their conceptual understanding of the target concepts. 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 comprises 12 multiple-choice items, with four possible answers, and the distractors focus on the common misconceptions as identified in the research literature (e.g., Everhart & Evans, 2006; Özman, 2007).

The visualization 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.

The study design was a revised version of a crossover (Ratkowsky, Evans & Alldredge, 1993) design. All students were taught the concept using both a scientific visualization and a more traditional teacher-led discussion. About half of the participating students (n=76 for the whole study) received the visualization-then-explanation sequence and the other half received the reverse sequence.

Of Albert's three classes, two (n=9 and n=18) received the visualization lesson first, as whole classes, and the explanation lesson second. The third class, (n=17) received the reverse sequence. The approach in Bob's (n=17) and Carl'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 visualization-then-explanation sequence while the other half received the explanation-then-visualization 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. The whole cohort comprised 76 students: 33 male and 43 female. Coincidentally, 33 students (not just the male students) received the lecture-then-visualization teaching sequence and 43 received the visualization-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. All participating students completed a simple learning styles inventory (Dunn, Beaudry & Klavas, 2002) that determined the extent to which they preferred visual, auditory or kinesthetic learning styles. The participating teachers also indicated each student’s sex 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 the whole 5 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 the groups are not different from one another in any systematic way based on their performance on the pretest.

| Group | Teaching Sequence | Pre-test Mean (SD) |
|---|---|---|
| 1 (n=33) | Explanation → Visualization | 4.21 (1.673) |
| 2 (n=43) | Visualization → 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 12 between the pretest and posttest A (after the first session of instruction) – offers an opportunity to explore the question of whether learning with visualizations is more effective than teacher explanations. This first measurement is separate from consideration of order effects, since it simply compares the 33 students whose first exposure to the concepts was a teacher-led explanation with the 43 whose first exposure was the scientific visualization. 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) | Visualization | 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 et al. (2010) 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 – sex, achievement and learning style – 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 – visualizations 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). Differences between the pretest means on a one-way ANOVA for the three learning styles were significantly different at the < .1 level (F(75)=2.61, p=.08) for the learning style groups. Table 3 shows the means and standard deviations for the learning style groups on the pretest.

| Learning Style | Pretest Mean (SD) |
|---|---|
| Visual (n=32) | 4.34 (1.75) |
| Auditory (n=16) | 3.33 (1.54) |
| Kinesthetic (n=28) | 4.54 (1.91) |

*Table 3: Pretest results by learning style*

Tables 4, 5 and 6 show analyses that divide out students who learned first with one or the other teaching strategy, then analyse the results further by sex, achievement and learning style.

| Group | Teaching Experience | | Posttest A minus Pretest |
|---|---|---|---|
| | | | Mean (SD) |
| 1 (n=33) | Explanation | Male (n=16) | 3.56 (2.31) |
| | | Female (n=17) | 1.82 (3.61) |
| 2 (n=43) | Visualization | Male (n=17) | 1.65 (2.60) |
| | | Female (n=26) | 1.96 (2.63) |

*Table 4: Conceptual knowledge gains during first teaching sequence, by sex*

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, visualization, t(41)=-.385, p=.70)

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

*Table 5: 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, visualization, F(42)=1.03, p=.37)

| Group | Teaching Experience | Learning Style | Posttest A minus Pretest Mean (SD) |
|---|---|---|---|
| 1 (n=33) | Explanation | Visual (n=14) | 2.85 (3.16) |
| | | Auditory (n=8) | 3.75 (1.67) |
| | | Kinesthetic (n=11) | 1.64 (3.78) |
| 2 (n=43) | Visualization | Visual (n=18) | 1.50 (2.50) |
| | | Auditory (n=8) | 3.38 (2.88) |
| | | Kinesthetic (n=17) | 1.47 (2.43) |

*Table 6: Conceptual knowledge gains during first teaching sequence, by learning style*

On a one-way ANOVA the learning gains for students with the three different learning styles were not significantly different for either teaching strategy. (explanation, $F(32)=1.11$, $p=.34$, visualization, $F(42)=1.80$, $p=.18$)

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 visualizations 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 Seven 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 → Visualization | 2.48 (2.87) |
| 2 (n=43) | Visualization → Explanation | 2.40 (2.65) |
| Total (n=76) | | 2.43 (2.73) |

*Table 7: 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 8 shows the overall gains by learning style. A one-way ANOVA shows that the differences between the means for these groups is significant at the $p<.05$ level ($F(75)=4.07$, $p=.02$). In this instance it was the auditory learners who made the greatest overall gains.

| Learning Style | Overall gain (post-test B minus pretest) Mean (SD) |
|---|---|
| Visual (n=32) | 1.53 (2.85) |
| Auditory (n=16) | 3.75 (2.65) |
| Kinesthetic (n=28) | 2.71 (2.73) |

*Table 8: Overall gains by learning style*

Table 9 shows the overall learning gains by academic achievement level for students in the two different learning sequences.

| Group | Teaching Experience | Class Rank (1 is lowest, 3 highest) | Overall gain (posttest B minus pretest) Mean (SD) |
|---|---|---|---|
| 1 (n=33) | Explanation-then-visualization | 1 (n=9) | 1.44 (3.00) |
| | | 2 (n=12) | 2.67 (2.43) |
| | | 3 (n=12) | 3.08 (3.20) |
| 2 (n=43) | Visualization-then-explanation | 1 (n=14) | 1.86 (2.35) |
| | | 2 (n=18) | 2.78 (2.71) |
| | | 3 (n=11) | 2.45 (2.65) |

*Table 9: 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 1shows the learning gains for each group of students during each teaching experience.

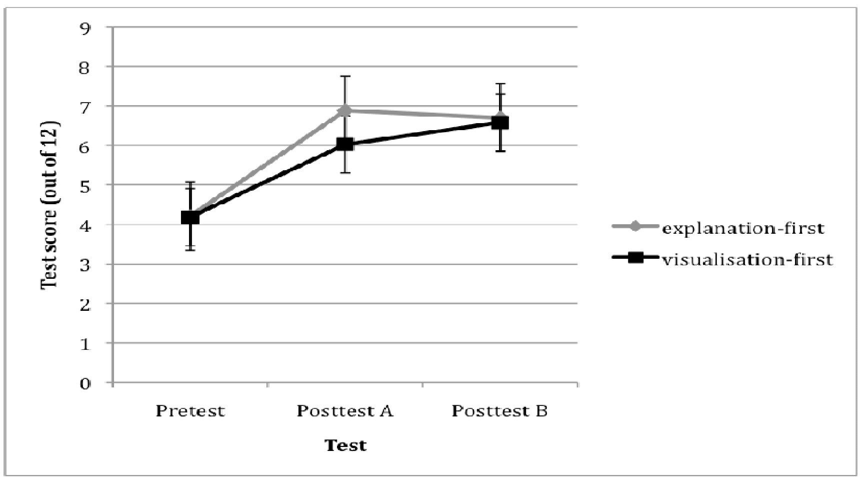


*Figure 1:Learning gains from two learning sequences (error bars show standard error of mean)*

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 visualizations. 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 visualization-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. The data, therefore, support H0, the null hypothesis: there is no evidence that either learning sequence either enhanced or harmed students' learning of the key scientific concepts taught.

This study has a number of limitations. Only the (difficult for many students) concepts 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 type of scientific visualization. The particular visualization 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 visualization – or a set of several chosen visualizations – 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

The results of this study clearly showed that teaching sequence does not matter in terms of whether teachers use verbal explanations and other 'traditional' teaching approaches first or use visualizations first. This finding is robust across both sexes, all learning styles (although auditory learners seemed to benefit more from the whole sequence than did visual or kinesthetic learners) and across levels of academic ability. This finding is helpful for teachers who might be concerned about the order in which they use particular teaching strategies, and frees 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 visualizations.

## References


Dunn, R., Beaudry, J.S. & Klavas, A. (2002). Survey of Research on Learning Styles. *California Journal of Science Education*, 2002(2): 75-94.

Everhart, B.A. & Evans, R. (2006). The efficacy of strategies to reveal and address high school chemistry students' preconceptions. *Studies in Teaching, 2006 Research Digest*, Wake Forest University, pp. 49-54.

Frailich, M., Kesner, M. & Hofstein, A. (2007). The influence of web-based chemistry learning on students' perceptions, attitudes, and achievements. *Research in Science and Technological Education*, 25(2): 179-197.

Geelan, D.R. & Mukherjee, M. M. (2010). Measuring the effectiveness of computer-based scientific visualisations for conceptual development in Australian chemistry classrooms. *Global Learn Asia Pacific 2010*, Penang, Malaysia, May 17-20, 2010.

Geelan, D.R., Mukherjee, M. M., Martin, B. & Mahaffy, P. (2010). Effectiveness of scientific visualizations for supporting conceptual development in high school physics and chemistry. *Annual Conference of the National Association for Research in Science Teaching (NARST)*, Philadelphia, USA, March 20-24, 2010.

Mulford, D. R., & Robinson, W. R. (2002). An inventory for alternate conceptions among first-semester general chemistry students. *Journal of Chemical Education*, 79(6), 739-744.

Özman, H. (2007). The effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning chemical equilibrium. *Asia Pacific Education Review*, 8(3): 413-425.

Özmen, H. (2008). The influence of computer-assisted instruction on students' conceptual understanding of chemical bonding and attitude toward chemistry: A case for Turkey. *Computers & Education*, 51(1): 423-438. DOI:10.1016/j.compedu.2007.06.002

Ratkowsky, D.A., Evans, M.A. & Alldredge, J.R. (1993). *Cross-over experiments: design, analysis and application.* New York: Marcel Dekker.

Sendlinger, S.C., DeCoste, D.J., Dunning, T.H., Dummitt, D.A., Jakobsson, E., Mattson, D.R. & Wiziecki, E.N. (2008). Transforming chemistry education through computational science. *Computing in Science and Engineering*, 10(5): 34-39.

Tuvi-Arad, I & Blonder, R. (2010). Continuous symmetry and chemistry teachers: learning advanced chemistry content through novel visualization tools. *Chemistry Education Research and Practice*, 11, 48-58. DOI: 10.1039/C001046B