Use of Chemistry Demonstrations to Foster Conceptual Understanding and Cooperative Learning among students

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June 23, 2004

Abstract

This study aims to evaluate the effectiveness of chemistry demonstrations in fostering conceptual understanding and cooperative learning among upper secondary school students. The topic of electrochemistry was selected for this study. Two principal evaluation instruments were used: a survey instrument and a content-based conceptual test. Preliminary results indicate that demonstrations in Chemistry are effective in stretching the cognitive spectrum of students, capturing attention, igniting curiosity and promoting functional understanding of various concepts. The demonstration session also provides a context for incorporating cooperative learning elements since the interactive and active environment facilitated by teacher scaffolding provides an inquiry climate and a reflective stance for students to discuss the scientific aspects of each demonstration, both among themselves as well as with the teacher.

Introduction

"Reading about science is interesting, but seeing it in action is fun", *D. Kolb* (Shakhashiri, 1992). Educators have often sought different ways to teach chemistry, and the use of demonstrations is but one of many teaching approaches adopted to enthuse students. Chemistry can also be made more stimulating to students by the use of such visual tools.

Demonstrations

A demonstration is the illustration of a point in a lecture or lesson by means of something other than conventional visual-aid apparatus (Taylor, 1988). One would normally characterize chemistry demonstrations as an experiment that aims to exhibit a particular scientific concept. However, we can extend this definition and divide it into three broad categories, namely (i) visual aids using non-conventional apparatus, (ii) analogue demonstrations, and (iii) real experiments. An example of an unconventional visual aid is the use of teacher and student movements to illustrate

A paper presented at the conference of the International Association for the Study of Cooperation in Education. June 22 - 24, 2004, Singapore.

acid-base and redox chemistry (Lomax, 1994). Lomax's kinetic classroom uses motion to reinforce concepts of chemical transformations.

Analogue demonstrations make use of a phenomenon whose behaviour is similar to that of the scientific concept being discussed. A good example is the use of steel balls on a watch glass to illustrate the close packing of atoms in a metal-like structure (Taylor, 1988). The most common category of chemistry demonstrations is the use of real experiments. Shakashiri provides numerous examples in his four volumes (Shakhashiri 1983, 1985, 1989 & 1992). A popular demonstration is the classic blue-bottle experiment, which is used to show reversible oxidation-reduction reactions involving methylene blue.

The uniqueness of chemistry demonstrations as an instrument to stretch the cognitive spectrum of students lies in the fact that they are effective in capturing attention (Buncick, Betts, & Horgan, 2001), igniting curiosity (Shepardson, Moje, & Kennard-McClelland, 1994) and promoting functional understanding of various scientific concepts (Meyer, Schmidt, Nozawa, & Paneee, 2003).

A number of articles have reported tangible benefits when demonstrations are used in the teaching of science. In a study of an introductory college physics course, Buncick, Betts, and Horgan (2001) mentions that demonstrations encourage inclusivity as it promotes active engagement among students. An increased level of pupil attention and task involvement is also evident in demonstrations employed in a high school setting (Beasley, 1982).

Buncick, Betts, and Horgan (2001) also established that demonstrations do stimulate student engagement since such an approach moves away from a teacher-centered strategy and provides opportunity to elicit student questioning. It could even be a catalyst for student initiated inquiry as well as a learning opportunity since it helps to create mental links between previous and new learning (Meyer, Schmidt, Nozawa, & Paneee, 2003).The authors further add that students can model cognitive strategies by observing the teacher thinking aloud as he conducts the demonstration and how he frames questions that lead to explanations of the underlying concepts. This could challenge students existing understanding and hopefully foster conceptual understanding (Shepardson, Moje, & Kennard-McClelland, 1994).

A traditional chalk-and-talk teaching strategy would probably appeal to students with higher linguistic intelligence and who prefer learning via the auditory mode. Use of demonstrations as a teaching strategy would, however, be useful for students with different learning needs. When combined with traditional methods, it can be especially useful in reaching out to pupils who have higher visual and spatial intelligence but not so high cognitive intelligence. Though there is an abundance of resources on the use of demonstrations to teach chemistry, there still exists only a small research base as regards studies on their effectiveness in promoting cognitive engagement. This suggests that significant research opportunities abound. Even a recent local publication (Tan, Lee, Goh, & Chia, 2002) on science education in Singapore did not include research articles relating to the use of demonstrations in the science classroom. This could indicate a lack of local research base in this area and could therefore be one of the reasons why it may be difficult to justify dedication of teacher time and resources to the use of demonstrations. Moreover, the use of demonstrations as a teaching/learning technique has not been sufficiently investigated in terms of their appropriateness for challenging and developing childrens conceptual understanding (Shepardson, Moje, & Kennard-McClelland, 1994), and thus there is a need for further studies relating to the conceptual understanding of chemistry concepts.

Cooperative Learning

Cooperative learning is an instructional technique whereby students work together in small fixed groups on a structured task (Cooper, 1995). Johnson, Johnson, and Smith (1991), as cited in Towns and Grant (1997) as well as in Bowen (2000), identified five essential components of cooperative learning: (a) positive interdependence among students seeking a common goal, (b) face-to-face interaction among students, (c) individual and group accountability, (d) use of interpersonal skills, and (e) group-processing skills.

Towns and Grant (1997) noted that to learn in a meaningful way, students need to actively process information, and cooperative learning activities can create an environment in which students actively engage in the task by sharing insights, ideas, and representations, giving feedback, and teaching each other. The foregoing ties in well with studies that show that science demonstrations encourage inclusivity since it promotes active engagement among students (Buncick, Betts, & Horgan, 2001) and also increases the level of pupil attention and task involvement (Beasley, 1982). It could prove to be beneficial to incorporate elements of cooperative learning within a demonstration lesson to further improve students understanding of instructional materials. Bare and Andrews (1999), in a study on using demonstrations to illustrate the principles of an ideal gas, reported that they were able to present thought-provoking gas-law problems suitable for cooperative learning activities.

Another possibility for incorporating cooperative learning in a demonstration lesson could be in the form of an assessment technique. Bowen and Phelps (1997) suggested a demonstration-based cooperative testing in a general chemistry classroom to broaden assessment practices. Results show that the use of demonstrations-based assessment can positively affect future performance on standardized tests that emphasize conceptual understanding.

Rationale for selecting Electrochemistry for this study

In the context of the foregoing, the present study aims to evaluate the effectiveness of demonstrations in the teaching of concepts in electrochemistry. An additional objective is to see how elements of cooperative learning can be embedded in the sessions.

The topic of electrochemistry is related to the GCE ordinary level chemistry syllabus that is offered to local students. Butts and Smith (1987), cited in Garnett and Treagust (1992) as well as in Thompson and Soyibo (2002), reported that high school students ranked electrolysis concepts as being the most difficult to understand in the subject of chemistry. In another study of 4344 students in Grade 11 by Okpala and Onocha (1988), cited in Thompson and Soyibo (2002), it was revealed that 50% of the students regarded electrolysis as one of the most difficult concepts to understand. In a report by the University of Cambridge Local Examinations Syndicate on Singapore students performance in the GCE O level Chemistry Examinations (Cambridge Local Examinations Syndicate, 1999), it was mentioned that "ideas relating to electrolysis and electron transfer are not well understood, leading to confused and contradictory statements being made". Also, questions relating to electrochemistry were the least popular among students. The difficulty in understanding abstract concepts in electrochemistry is not unique to local students. As cited in Thompson and Soyibo (2002), evidence (from examination reports) suggests that many high school students in the Anglophone Caribbean also have a poor understanding of electrolysis.

Methodology

(a) Evaluation instruments

Two instruments were designed by the authors to evaluate the effectiveness of chemistry demonstrations in fostering conceptual understanding among students: a survey instrument and a content-based multiple choice questions test. The survey instrument further sought to examine the extent to which cooperative learning elements were fostered in the session. An initial draft of both instruments was constructed and given for validation to two experienced secondary school chemistry teachers and two university chemistry lecturers. Their minor feedback was used to fine tune the format and structure of the instruments.

(i) Survey from

The survey instrument allowed the collection of quantitative and qualitative data. The first part consists of 16 close-ended questions. A selected-response format (Wiersma, 2000) employing a five-point Likert scale (SA strongly agree; A agree; N neutral/not sure; D disagree; and SD strongly disagree) was used. A Likert scale was adopted as it is “a good way of writing close-ended questionnaire items to measure people’s attitudes and opinions with intensity scales” (Nardi, 2003).

Statements were crafted for three subscales: A (educational effectiveness), B (learning environment), and C (nature of demonstrations). This generated a total of 16 statements, five for each of the subscale A and C and six for subscale B. In the second part of the survey form, students were asked to rank (1, 2, and 3; 1 being the best), three demonstrations that they liked best and three demonstrations that they think are the most educational. The primary purpose of this is to look at students views with regard to the demonstrations conducted, and to explore any relationship that may be present between popularity of the demonstration and their perceived educational value.

There is also a feedback field in the survey form to capture general comments from students.

(ii) Multiple choice questions test

The conceptual test on electrochemistry comprised an initial set of 16 multiple-choice questions, with four options (answers) for each item. They were selected from various sources: chemistry textbooks, chemistry workbooks, and past year examination questions, and modified appropriately where necessary. The questions assess comprehension and application levels on Bloom’s taxonomy of educational objectives in the cognitive domain (Thompson & Soyibo, 2002). Esiobu and Soyibo (1995), as cited in Thompson and Soyibo (2002), suggests that for test items to measure students understanding of science concepts, they must test beyond the comprehension level on Bloom’s taxonomy.

After the pilot study, four questions were not used in the actual study since feedback from students showed that these questions were rather difficult to understand or are ambiguous. In addition, the time of 24 minutes for the test was considered rather long. A final set of twelve questions was thus selected to test students’ understanding of electrochemistry concepts.

A duration of 18 minutes was allocated for the 12-item test as it adheres to the time allocation of about 1.5 minutes for each multiple-choice question in the GCE Ordinary level chemistry examination.

(b) Ensemble of demonstrations

A series of demonstrations was assembled to illustrate the electrochemistry concepts that were to be taught. The list of demonstrations is indicated in the Appendix.

(c) Procedure

The demonstration lesson was conducted by one of the researchers (EBAM), and was of 45 minutes duration. Each demonstration was presented in a manner that evokes intrigue and interest. Explanations were infused in the course of the demonstration, and questions were asked to probe student understanding. There was scope for small group discussion to evolve answers to the questions. Judicious apportionment of time allowed the session to be lively whilst ensuring that the necessary concepts were covered in the given time frame.

Table 1: Distribution of Total Scores for School-based Test

Item	Demo Group	Control Group
Mean Subject Grade	3.00	5.00
n	25	25

Table 2: Distribution of Total Scores for Electrochemistry MCQ Test

Item	Demo Group	Control Group
Mean Score (max. 12)	9.56	6.08
SD	1.98	2.16
n	25	25

A posttest only, nonequivalent control group design (Wiersma, 2000), consisting of one experimental group and one control group was utilized as intact classes had to be employed so as not to disrupt the students normal schedule.

The score obtained in a prior school-based test was used to determine the general proficiency level of each group as a pre-test was not administered.

The independent variable in this study was the choice of instructional approach used in teaching chemistry, namely demonstration teaching (DT) or traditional (or non-demonstration) teaching (TT). The experimental group was subjected to treatment by DT while the control group was taught by TT. The control group were also shown the demonstration lesson as an additional enrichment session; this is to ensure that the Hawthorne effect, or novelty effect, does not come into play. 25 students from an all-boys independent secondary school formed the experimental group. They were taught the topic of electrochemistry through demonstration teaching. At the end of the session, the survey instrument and the concept-based test were administered.

The control group, comprising 25 students from the same school, were taught the topic of electrochemistry by the traditional or non-demonstration approach. They then attended the demonstration teaching session on electrochemistry. The concept-based test was administered to the students at the start of the demonstration session while the survey instrument was administered at the end of the demonstration session.

Results

Table 1 shows the distribution of grades for the school-based chemistry test for the control and demo groups.

Table 2 shows the distribution of grades for the MCQ test. Each item on the multiple-choice test is allotted one mark. Hence, the maximum score for the concept-based test is 12.

The results in Table 2 show that students in the demonstration group performed better in the concept-based test than students in the control group, who also fared reasonably well. This is not surprising as the demonstration group has a slightly better proficiency in chemistry as compared to the control group. It would be preferable to see how the results would vary if the academically weaker control group was taught by demonstration teaching. This was not possible in this preliminary study as the choice of groups was decided by the teachers after taking into consideration curriculum constraints and the availability of class groups for this research study.

Table 3: Cronbach Alpha Coefficient for Survey Questionnaire

Group	Number of students	Cronbach Alpha Coefficient for different subscales			Cronbach Alpha Coefficient (for instrument)
		Educational Effectiveness	Learning Environment	Nature of Demonstrations	
Demo Group	25	0.64	0.79	0.75	0.86
Control Group	25	0.79	0.29	0.64	0.76

Table 4: Means for Survey Questionnaire

Group	Number of students	Mean for subscales			Mean for all subscales
		Educational Effectiveness	Learning Environment	Nature of Demonstrations	
Demo Group	25	4.30	4.21	4.36	4.29
Control Group	25	4.12	4.17	4.05	4.11

The reliability of the survey instrument was evaluated by extracting the Cronbach alpha factor (Dalgety, Coll, & Jones, 2003). Its value of above 0.70 reflects good reliability of the overall instrument (Table 3). Analysis of each subscale also showed adequate reliability.

Examination of the means for the various subscales indicate positive responses for the three categories. The mean exceeds 4.00 (Table 4).

Table 5, 6 and 7 show descriptive statistics for the statements in the various subscales of the survey instrument.

It is clear that the demonstration session has evoked positive responses for all the statements. More importantly, the demonstration session has aided conceptual understanding and stimulated further interest in the topic. Students in both groups expressed an interest in wanting to be taught by demonstration teaching.

Responses to the second section of the survey instrument, which looked at the relationship between the demonstrations that students liked best and the demonstrations that students thought were the most educational, offered interesting insights.

In the demonstration group, the most popular demonstration was the electroplating experiment, followed by the orange juice clock/potato clock experiment. This was also the case for the control group. For the demonstration group, students found the electroplating experiment and the demonstration on rechargeable batteries to be the most educational. It is interesting to note that while many felt that these two demonstrations were the most educational, they did not rate these highly as the demonstrations that they enjoyed the most.

The findings for the control group differed in this case. Most students found the orange juice/potato clock as the most educational demonstration, followed by the electroplating experiment. This suggests that for the control group, the most popular demonstration was closely linked with the educational value of the demonstration.

Table 5: Descriptive statistics for subscale A (Educational Effectiveness)

	Item	Min		Max		Mean (SD)	
		Demo	Control	Demo	Control	Demo	Control
1	I was able to understand electrochemistry concepts better.	3.00	3.00	5.00	5.00	4.40(0.58)	4.08(0.64)
2	I am interested in learning more about electrochemistry.	3.00	3.00	5.00	5.00	4.24(0.66)	4.04(0.73)
3	I have learnt about electrochemistry beyond the textbook.	2.00	1.00	5.00	5.00	4.20(0.91)	4.28(0.84)
4	I have a better appreciation of electrochemistry in everyday life.	3.00	3.00	5.00	5.00	4.20(0.65)	4.04(0.61)
5	I found the demonstrations effective in building my existing knowledge on electrochemistry.	3.00	3.00	5.00	5.00	4.48(0.59)	4.16 (0.80)

As the demonstration groups were of slightly higher ability, it seems that the higher ability students are able to distinguish between enjoyment (the most popular demonstration) and what they believe is of higher educational or academic value (the most educational demonstration).

Discussion

Preliminary findings suggest that the use of demonstrations helps to promote conceptual understanding of chemistry. Students in both the demonstration and control groups agree that the demonstration session was educationally effective (mean of more than 4.0 for all groups in this subscale). Most students were able to understand chemistry concepts better. In addition, they believe that the demonstrations were effective in building their existing knowledge on electrochemistry (Statement 5). This finding is important from constructivist considerations since understanding of concepts proceeds better if they are built upon their existing (or prior) knowledge. To what extent their individual understanding has been enhanced as a result is not clear but we expect this would vary and likely to be significant. Further research would be needed to confirm this.

Some qualitative feedback extracted from the written comments on the survey form are presented below.

Demonstration group

Ong C. H.: "I enjoyed the lesson very much and it was one of the most educational lesson I have been through, thank you!"

V. Leong: The lesson was interesting and helped me in my understanding of electrochemistry. Thank you (teachers name)!

Table 6: Descriptive statistics for subscale B (Learning Environment)

	Item	Min		Max		Mean (SD)	
		Demo	Control	Demo	Control	Demo	Control
6	The lesson was enjoyable.	3.00	4.00	5.00	5.00	4.52(0.65)	4.36(0.49)
7	I was more attentive.	3.00	3.00	5.00	5.00	4.32(0.69)	4.36(0.57)
8	The classroom climate was conducive for learning.	2.00	3.00	5.00	5.00	3.64(1.19)	4.04(0.79)
9	The demonstrations allowed me to sharpen my observational skills.	2.00	3.00	5.00	5.00	3.96(0.89)	3.80(0.70)
10	I prefer to be exposed to demonstration teaching as opposed to traditional teaching.	3.00	3.00	5.00	5.00	4.76(0.52)	4.68(0.63)
11	The demonstrations encouraged me to discuss with my classmates the science at work in order to obtain a better understanding.	2.00	2.00	5.00	5.00	4.04(0.89)	3.76(0.72)

Table 7: Descriptive statistics for subscale C (Nature of Demonstrations)

	Item	Min		Max		Mean (SD)	
		Demo	Control	Demo	Control	Demo	Control
12	The demonstrations were interesting.	3.00	3.00	5.00	5.00	4.48(0.59)	4.32(0.63)
13	The demonstrations were educational.	4.00	3.00	5.00	5.00	4.52(0.51)	4.24(0.52)
14	The demonstrations sparked my curiosity in chemistry.	3.00	2.00	5.00	5.00	4.08(0.76)	3.76(0.72)
15	The demonstrations were useful in stretching my understanding of electrochemistry.	3.00	2.00	5.00	5.00	4.08(0.70)	3.88(0.60)
16	The demonstrations were easy to understand.	4.00	1.00	5.00	5.00	4.64(0.49)	4.04(0.89)

Control group

S. Tan: Experiments helped me understand electrochemistry better.

A. B. A. Rahman: I can understand better this way.

Teo, S. K. D: Very educational.

N. B. M. Noor: I understood the topic better.

Furthermore, the demonstration session promotes thinking skills and enables students to think more creatively. Students agree that the demonstration session helped them to learn about electrochemistry beyond the textbook (Statement 3) and allowed them to have a better appreciation of electrochemistry in everyday life (Statement 4). They expressed interest in wanting to learn more about electrochemistry (Statement 2).

The following comments are noteworthy in the context of the foregoing considerations.

Demonstration group

Tan, Y. Z: Much more enjoyable than learning through the textbook, also encourages more thinking.

M. H. Zainal: I prefer lessons like this as it allows students to be more creative and make us think even more.

Control group

Loh, Q. X.: Your lesson is more interesting, making me want to know more about chemistry.

Besides fostering conceptual understanding (Statements 15 and 16), the demonstration session presents a climate suitable for inclusion of cooperative learning elements (Statement 11). The mean value for Statements 15 and 16 exceeds 4.08 for the Demo Group and 3.88 for the Control Group. For Statement 11, the mean value is 4.04 for the Demo Group and 3.76 for the Control Group. The positive environment facilitated by the excitement of the demonstrations and active learning helps to ignite curiosity, generate interest, offer enjoyment and thus provide a platform for effective student peer interaction and cooperation. A typical comment from this group is shown below.

Demonstration group

Cheong, S. H.: I hope to have more of this kind of teaching method. Experiments can help us to understand better as we can interact, ask our friends questions and discuss together.

In the course of conducting the demonstration session, the researcher employed judicious use of questioning to probe student understanding. Scope was presented for students to share insights and have mini discussions in an effort to address these questions. The collaborative work processes engendered as a result do permit strains of cooperative learning elements to emerge. The mean values obtained are significant enough to show that the nature of such cooperative learning elements foster an environment to promote active learning.

It is evident that students prefer the demonstration sessions and welcome its use in the chemistry classroom. All students involved in the study did not disagree when asked if they prefer demonstration teaching to traditional teaching (Statement 10). A number of students felt that in addition to the demonstrations, a hands-on or laboratory session could be carried out as a follow up activity to the demonstration sessions. However, they still believe that even without the hands-on session, the demonstration lessons were much better than their normal (traditional) lessons, as can be seen from the following comments.

Demonstration group

N. Ahmad: Through these demonstrations, I look forward to every Chemistry lesson as it is more interesting than traditional way of teaching. This is good especially when the teacher is also interesting and humorous.

S. H. Teckwani: The class was very, very enjoyable. I hope such kind of demonstration teaching sessions can be carried out more. Furthermore, getting us to do hands on experiments with these (the experiments shown) would also make the lesson even more exciting. Overall, it was excellent!

S. Koordi: I think that we should get a first hand exposure to these experiments. This will make the experiment more interesting as we can see the results more clearly and find out how varying factors affect the results ourselves. But this is a much better lesson indeed than the traditional theoretical teaching.

Control group

Chan, J. H. C: I would like more of this type of lesson.

Limitations of this study

It should be stressed that the findings of this study are preliminary. Due to various constraints, the research design used was not yet optimal.

Since the classes used in this study involved students in Secondary 4 and as they are scheduled to sit for the GCE O level examinations at the end of the year, their schedules are very hectic and the time available for other activities such as participating in a research study was limited. Due to this constraint, the researchers did not have a free hand in the assignment of experimental and control groups to specific classes. The researchers would have preferred assigning classes where students have a lower proficiency in chemistry for the experimental (demonstration) group. However, due to logistical constraints, they were not able to do so. A more rigorous study is being carried out to address these constraints.

Conclusion

Preliminary results from this study show that the use of demonstrations in the teaching of chemistry in the classroom promotes an active learning environment. The demonstrations do foster conceptual understanding and can be used as a vehicle to promote thinking skills among students. It also provides an opportunity for peer interaction as well as the fostering of cooperative learning elements.

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Appendix
List of Demonstrations

1. Electroplating

   Electroplating of copper using dilute copper(II) sulphate and copper(II) sulphate with concentrated sulphuric acid

2. Electrochemical series (ECS)

   Dip magnesium in dilute sulphuric acid

3. Immersion plating

   Dip zinc in copper(II) sulphate and silver nitrate, dip copper in silver nitrate and iron(II) sulphate

4. Producing current with zinc and copper in dilute sulphuric acid

   Use dilute sulphuric acid with zinc and copper as electrodes

5. pH meter with glass electrodes

   Use commercially available pH meter

6. Electrolysis

   Electrolysis of water with dilute sulphuric acid

7. Rechargeable batteries

   Use commercially available rechargeable batteries

8. Cathodic protection for rust

   Dip an iron nail and zinc (connected with a wire)in water

9. Potato clock/Orange juice clock

   Use a potato or orange juice (and two different electrodes) to generate a current to power a clock