Conceptual change using demonstration in EM and EMI

The effect of classroom demonstrations based on conceptual change instruction on students' understanding of electromagnetism and electromagnetic induction

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Abstract:

The main purpose of this study was to investigate the effectiveness of classroom demonstrations based on conceptual change instruction on Junior College year 2 students' understanding of electromagnetism and electromagnetic induction. Based on conceptual change theory, a pedagogical approach called "PORE" was proposed for instruction using demonstrations. PORE comprises four stages: predict, observe, resolve and extent. Results showed that presenting classroom demonstration using "PORE" is more effective than traditional teaching methods.

The cognitive conflict level test (CCLT) developed by Lee et al. (2003) was used to determine the cognitive conflict experienced by students for each demonstration. Data from the CCLT can provide a useful dimension for evaluating the effectiveness of a demonstration for instruction.

Qualitative analysis of students' written conceptual reasoning in this study contributed to the understanding of common conceptual difficulties faced by Junior College students in the learning of electromagnetism (EM) and electromagnetic induction (EMI). Students' difficulties in transferring Newton's laws to the context of EM and EMI found in this study suggested a need to integrate mechanics early in the teaching of EM and EMI.

The effect of classroom demonstrations based on conceptual change instruction on students' understanding of electromagnetism and electromagnetic induction

1. Introduction:

Backgroud: Is classroom demonstration an entertainment or educational tool?

Classroom demonstration has been a common science instructional tool since the seventeenth century. But surprisingly there are still differences in opinion about its usefulness as an educational tool. Some educators, such as Beall (1996), criticised the use of demonstrations as time-consuming and merely for entertainment (as cited in Walton, 2002). While other educators (Schilling, 1959; Freier, 1981; Hilton, 1981; Shmaefsky, 2005; Black, 2005) have long advocated the use of classroom demonstration for its benefits in generating interest and promoting conceptual understanding in science.

Rationale of the study on classroom demonstrations

In Singapore, Junior Colleges have implemented the new curriculum (H1, H2 Syllabus) since 2006. Curriculum time was shortened in line with the Singapore Ministry of Education's direction of "Teach Less Learn More". For H2 syllabus, practical periods are mainly used for the teaching of School based Science Practical Assessment (SPA), leaving little time for conducting experiments that help students acquire conceptual understanding in physics. For H1 syllabus, no curriculum time is allocated for practical.

In my college, Physics teachers felt that physics demonstrations will help to improve students' conceptual understanding and interest. However, the pedagogical approach adopted by most teachers for showing demonstrations is the traditional teacher-centered approach. As the use of demonstrations is more time consuming and curriculum time in the new syllabus is shorter, the main focus in this study is to find out how to use classroom demonstration not only as an entertaining but also an effective educational tool.

Significance of the study

Through the study we will get a better understanding on how to use a conceptual change approach to enhance the effectiveness of classroom demonstrations. The learning gain from applying conceptual change theory can be transferred to other non-demonstration aspects of teaching such as the use of ICT simulations. The study will explore the feasibility of measuring the cognitive conflict experience by students during a demonstration and used this information to evaluate the demonstration's effectiveness for teaching and learning. Furthermore, through the study we will gain some insights into the conceptions of Singapore Junior College students in the field of electromagnetism and electromagnetic induction.

Research questions

The study seeks to investigate the following questions:

1. Is the use of classroom demonstrations based on conceptual change instruction more effective than traditional teaching in enhancing students' conceptual understanding in electromagnetism and electromagnetic induction?

2. Are the demonstrations developed in this study able to elicit cognitive conflict amongst students?

3. What common conceptual difficulties or misconceptions do Singapore junior college year 2 students in this study have in the topic of electromagnetism and electromagnetic induction?

2. Review of the literature

Effectiveness of demonstration in enhancing conceptual understanding

The effects of demonstrations on conceptual understanding reported by various research studies were not universally positive. A number of studies (Theng, 2005; Roth, McRobbie, Lucas, & Boutonne, 1997; Halloun & Hestenes, 1985) showed that demonstrations do not help students to understand the phenomena that are being demonstrated. Halloun and Hestenes (1985) cast doubt on the effectiveness of typical classroom physics demonstrations in altering mistaken physics beliefs unless the demonstrations are performed in a context that elicits and helps to resolve conflicts between common sense and specific scientific concepts.

These studies highlighted several problems that need to be considered if demonstrations were to achieve its intended purpose of helping students understand scientific concepts:

- Students existing non-scientific beliefs are highly resistant to change.
- Demonstrations presented in a traditional manner with the transmission perspective of teaching and learning do not lead to conceptual change.
- Demonstrations could potentially cause more confusion rather than clarification of understanding if students are not provided with opportunities to openly discuss and check the suitability of their observations, interpretation and explanations of the concepts.

On the other hand, many research studies have successfully used demonstrations to foster conceptual understanding. Two main features amongst these studies appeared to have positive influence on the effectiveness of classroom demonstrations:

- *Firstly, the demonstrations were designed to directly address known non-scientific conceptions.*

Studies such as Sokoloff and Thornton (1997), Reddish, Saul and Steinberg (1997), Fagen (2003) and McDermott (1990, 2001) which used demonstrations that directly addressed known student misconceptions produced positive gain in conceptual understanding.

Secondly, the demonstrations were used to elicit cognitive conflict.

Many studies (Sokoloff & Thornton, 1997; Reddish et al., 1997; Crouch, Fagen, Callan, & Mazur, 2004; Fagen, 2003; Hynd, Alvermann, & Qian, 1997; Yavuz, 2005) tried to generate some form of cognitive conflict by requiring students to predict and explain the outcome of the demonstrations before showing the demonstrations. A meta-analysis of science studies in conceptual change (Guzzetti, Snyder, Glass, & Gamas, 1993) has documented the effectiveness, at least in the short term, of strategies believed to produce cognitive conflict.

The need to elicit cognitive conflict is well known to be an important component of the conceptual change theory and this likely explains why all the researchers in these studies try to incorporate strategies to elicit cognitive conflict in their instructional technique. However, these studies have assumed that the demonstrations have caused cognitive conflict and did not assess whether students really experienced cognitive conflict. Thus, there is a possibility of a gap existing between what the researchers expected students to experience and what the students really experienced.

In my present study, I will use a pen and paper instrument called Cognitive Conflict Level Test (CCLT) developed by Lee et al. (2003) to determine if students have really experience cognitive conflict during the demonstrations.

Conceptual change theory

In conceptual change theory, learning is viewed as a process where the learners realign, reorganise and replace existing conceptual structure in order to understand new knowledge. Learning Science is viewed as promoting conceptual change from students' informal ideas to those of the scientific community. At the heart of conceptual change theory is the constructivist view of learning that knowledge cannot be transmitted from one knower to another but must be actively constructed by the learner.

There are two types of conceptual change, known as assimilation and accommodation. When the new conception does not cause dissatisfaction, the new conception will be assimilated alongside the old conception by the learner. When the new conception causes dissatisfaction, then the learner will appraise the new conception against the existing old conception. If the old conception is more sensible conceptual may not occur. If the new conception makes more sense to the learner, accommodation will occur.

Hynd et al. (1997) have shown that conceptual change proceeds in a piecemeal, saw-toothed fashion and documented that restructuring of knowledge may lead to new nonscientific conceptions. Conceptual change is not a quick or simple process and students spend some time in an unstable conceptual state, oscillating between their original conception and the target scientific conception (Grayson, 2004).

Classical view of conceptual change:

Duit and Treagust (2003) did a review of the research in conceptual change in the past 3 decades and found that the best known conceptual change model in science education proposed by Posner, Strike, Hewson and Gertzog (1982), Hewson and Hewson (1984, 1988, 1996), Strike and Posner (1985, 1992) believed that conceptual conflict is needed to initiate conceptual change:

> If the learner was dissatisfied with his/her prior conception and an available replacement conception was intelligible, plausible and/or fruitful, accommodation of the new conception may follow. (Duit & Treagust, 2003)

Comtempory multi-perspective view of conceptual change:

The classical view of conceptual change holds the individual constructivist perspective and consider learning largely as an individual activity where the learner actively discover and build knowledge for himself.

More recent view of conceptual change advocated viewing the process of learning science from both the individual constructivism and social constructivism perspectives. (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Social constructivism suggests that learners need to be encultured into the practices of Science through social interactions and the support of more experienced members such as teachers. But for this to occur, according to individual constructivism perspective, learners need to actively engage themselves in personal meaning making and construction of knowledge.

Cognitive conflict

Lee and Kwon (2001) developed the cognitive conflict process model to explain the cognitive conflict that occurs when a student is confronted with an anomalous situation that is incompatible with his or her perception in learning science (as cited in Lee et. al, 2003, p.586). This model has three stages : preliminary, conflict and resolution. The preliminary stage represents a process in which a student who has belief in a preexisting conception accepts an anomalous situation as genuine. In the second stage, cognitive conflict occurs when a learner

> recognizes an anomalous situation,
>
> expresses interest or anxiety about resolving the cognitive conflict, and

engages in cognitive reappraisal of the situation.

In the final stage, learners would resolve or dismiss the cognitive conflict.

Based on the cognitive conflict process model, Lee et al. (2003) developed the pen and paper instrument Cognitive Conflict Level Test (CCLT) for measuring secondary students' cognitive levels as they learned science. The results of their study indicated that the instrument is a valid and reliable tool for measuring cognitive conflict levels.

Misconceptions in Electromagnetism (EM) and Electromagnetic Induction (EMI)

Unlike in mechanics, alternative conceptions in the domain of EM and EMI have not been investigated in great detail (McDermott & Reddish, 1999). The conceptual difficulties in EM and EMI found in the literature is synthesized and summarised in Table 3.1.

Table 3.1 : Summary of sources conceptual difficulties in EM and EMI

Sources of conceptual difficulties	**Description of misconception**	**Evidence from research paper**
Difficulties in transfer of Newton's laws	Difficulty in transferring Newton's third law	Maloney, O'Kuma, Hieggeike and Heuvelen (2001) Galili (1995)
	Difficulty in transferring Newton's second law	Bagno and Eylon (1997) Itza-Ortiz, Rebello and Zollman (2004).
Inappropriate analogies with E field and charges	A charge in a magnetic field will always experience a force	Maloney et al. (2001) Itza-Oritz et al. (2004) Saglam and Millar (2006)
	Magnetic force acts in the direction of the magnetic field	Maloney (1985) Maloney et al. (2001) Saglam and Millar (2006)
"Flow" interpretation	Misinterpretation of	Saglam and Millar (2006)

of field lines	magnetic field lines as flow lines	Maloney et al. (2001)
Difficulties interpreting Faraday's Law	Relating presence of induced current to flux	Mauk and Hingley (2005) Saarelainen, Laaksonen and Hirvonen (2007) Maloney et al. (2001)
	Relating magnitude of induced current to change of flux	Maloney (1985) Maloney et al. (2001)
Difficulties interpreting Lenz's Law	Relating direction of induced current to "resisting magnetic field"	Mauk and Hingley (2005) Bagno and Eylon (1997)

3. Methodology

In this section, the methodology for the study will be described for the following 3 areas:

A. Effectiveness of Conceptual change instruction with demonstration

B. Effectiveness of demonstrations in eliciting cognitive conflict

C. Students' learning difficulties in EM and EMI

A. Effectiveness of Conceptual change instruction with demonstration

Experimental Design

A within-subjects (or repeated-measures) experimental design was used to compare two treatment conditions for one single sample of students (Gravetter & Forzano, 2003). Each student participated in both treatment conditions and the design aimed to look for difference between the two treatment conditions within the same group of students.

Sample

The sample consisted of two JC2 H2 Physics classes (class 1 and class 2). The total number of participants was 45 (22 from class 1 and 23 from class 2).

Treatment Conditions

The two treatment conditions are:

i. Demo (PORE) Treatment

Students were given the Demonstrations Observations and Explanation Worksheet (DOEW) (see Appendix I - Sample Demonstrations D3 & D5).

PORE

The pedagogical approach for PORE is a based on conceptual change theory. There are 4 stages :

a. **P**redict

- A concept question based on a demonstration is presented. Demonstration is designed to directly address known alternative conception. Students predict and explain the outcome of the demonstration individually.

b. **O**bserve

- Students observe the outcome of the demonstrations. Cognitive conflict will be elicited if students predicted the outcome wrongly. Students are confronted to explain their thinking to help them see the errors in their alternate conceptions. According to Posner's conceptual change model, for conceptual change to happen it is necessary for students to be dissatisfied with their prior conceptions.

c. **R**esolve

- Students engaged in collaborative group discussion to construct meaningful understanding of the scientific explanation. According to Posner's conceptual change model, students will undergo conceptual change provided the scientific explanation is intelligible and plausible to them.

d. **E**xtend

- The purpose is to illustrate the usefulness of the scientific concepts in explaining problems of different contexts. According to Posner's conceptual change model, conceptual change is more likely to occur if the scientific explanation is fruitful to students.

Traditional treatment

Students were taught using traditional teacher-centered approach. Students were given a question similar to the demonstrations. They were given some time in class to solve the question individually. After that, the teacher revealed the answer of the question and explained the physics involved. Students were allowed to ask the teacher questions to clarify doubts. Students' work was collected back by the teacher.

Development of demonstrations

8 demonstrations (D1 to D8) were developed in this study. 4 demonstrations (D1 to D4) were on electromagnetism (EM) and 4 demonstrations (D5 to D8) were on electromagnetic induction (EMI). The demonstrations were developed to directly address and elicit known misconceptions/difficulties in electromagnetism reported in physics educational research. Table 4A.1 summarises the demonstrations and the misconceptions that it intends to address.

Table 4A.1 Demonstrations and related misconceptions in EM / EMI

Demo	**Physics Field**	**Demo Title**	**Misconception to be elicited**
D1	EM	Rod on rail (Magnetic force on current in B field)	Inappropriate analogies with E field: Eg. Force acts along field lines
D2	EM	Magnetic force on a moving charge in B field	Inappropriate analogies with E field and charges Eg. Force acts along field lines
D3	EM	Interaction of wire and magnet (Newton's 3rd Law in EM context)	Difficulties transferring Newton’s 3rd law to EM phenomena
D4	EM	Turning effect of a coil in a B field	Misinterpretation of magnetic field lines as representing “flow” lines
D5	EMI	Rotating aluminum can (Newton's 3rd Law in EMI context)	Difficulties transferring Newton’s 3rd law to EMI phenomena
D6	EMI	Magnet falling through an aluminum tube	Difficulties in interpreting Faraday’s law and Lenz’s law
D7	EMI	Magnet falling through a solenoid	Difficulties in interpreting Faraday’s law : Incorrectly relating induced emf to flux or change of flux rather than rate of change of flux. Difficulties in interpreting Lenz’s law.
D8	EMI	Magnet swinging pass a solenoid	Difficulties in interpreting Faraday’s law : Incorrectly relating induced emf to flux or change of flux rather than rate of change of flux. Difficulties in interpreting Lenz’s law.

Counterbalancing

As the duration of the study was long (2 months), counterbalancing was used to reduce order effects and time-related threats to the internal validity of the experiment.

The sample was divided into two halves, class 1 and class 2. Both halves would receive both treatment conditions but in alternate order. Counterbalancing would ensure that each class receive demo (PORE) treatment in both EM and EMI areas.

Table 4A.2 shows how the counterbalancing was carried out in the study.

Table 4A.2 Counterbalance of treatment conditions

Demo	**Physics Field**	**Class 1 (22 students)**	**Class 2 (23 students)**
D1	EM	Demo (PORE) treatment	Traditional treatment
D2	EM	Traditional treatment	Demo (PORE) treatment
D3	EM	Traditional treatment	Demo (PORE) treatment
D4	EM	Demo (PORE) treatment	Traditional treatment
D5	EMI	Demo (PORE) treatment	Traditional treatment
D6	EMI	Traditional treatment	Demo (PORE) treatment
D7	EMI	Demo (PORE) treatment	Traditional treatment
D8	EMI	Traditional treatment	Demo (PORE) treatment

<u>Instrument</u>

A **conceptual understanding test (CUT)** consisting of 8 open ended questions similar in context to the 8 demonstrations was designed to evaluate students' ability to provide the correct outcome and explanation. **(Appendix II – Sample Q3 & Q5).**   CUT was administered once at the end of instruction on all 8 demonstrations.

Limitations of the experimental design

- Participant attrition

The original sample size was 48 but 3 students did not participate fully in the entire study as they were absent from school when some of the activities for the study was implemented. Hence the final sample size is only 45 students.

- External Validity

The study is only conducted on a small sample of 45 students from two H2 JC2 Physics classes. Therefore results should not be generalised to a large general student population.

- Long time delay before measurement of effectiveness

The study lasted about 2 months. The CUT to evaluate the effectiveness of the two treatment conditions was administered once at the end of the study. The effect of the conceptual change instruction may not be lasting. Any difference in effect between the two treatments for the first few demonstrations may be reduced due to the long time delay.

B. Measuring students' cognitive conflict elicited by the demonstrations

During the demonstration instruction using the PORE teaching approach, students were first required to predict and explain the outcome of a conceptual question. After which, the demonstration was performed to confront students prior conception and to elicit cognitive conflict. Immediately after observing the demonstration, students were told to complete the Cognitive Conflict Level Test (CCLT) developed by Lee et al. (2003). The administration of the CCLT was done before the resolve stage to measure the level of cognitive conflict experience by each student due to seeing the outcome of the demonstrations.

Instrument

The CCLT is a pen and paper instrument consisting of 12 items on a 5-point Likert scale (0 = 'not at all true' to 4 = 'very true'). CCLT identifies 4 components of cognitive conflict : recognition of anomalous situation, interests, anxiety and cognitive reappraisal of the cognitive situation. There are 3 items measuring each of the 4 components, making a total of 12 items for the CCLT as shown in the Table 4B.1.

Table 4B.1. CCLT test items

CCLT Test Items	Components of Cognitive conflict Measured
1. When I saw the result, I had doubts about the reasons.	Recognition of anomalous situation
2. When I saw the result, I was surprised by it.	
3. As the result is different from my expectation, I find the demonstration strange.	
4. The result of the demonstration is interesting.	Interest
5. Since I saw the result, I have been curious about it.	
6. The result of the demonstration attracts my attention.	
7. The result of the demonstration confuses me.	Anxiety
8. Since I cannot solve the problem, I am uncomfortable.	
9. As I cannot understand the reason for the result, I feel uneasy.	
10. I would like to find out further whether my idea is incorrect.	Cognitive reappraisal of the cognitive situation.
11. I need to think about the reason for the result a little longer.	
12. I need to find a proper explanation for the result.	

Lee et al. (2003) has reported CCLT to be a valid and reliable instrument for measuring students' cognitive conflict. The researchers reported the content validity coefficient of CCLT among 6 experts ranging from 0.85 to 0.97 and the Cronbach alpha coefficient reliability coefficient for CCLT of over 0.86.

For the present study, Cronbach alpha coefficient for the CCLT was found to be over 0.86. Table 4B.2 below summarises the Cronbach alpha coefficient for the present study by each demonstrations.

Table 4B.2 Cronbach alpha coefficient for CCLT by demonstrations

Demo	Cronbach alpha coefficient for CCLT
D1	0.891
D2	0.942
D3	0.924
D4	0.86
D5	0.936
D6	0.947
D7	0.916
D8	0.948

C Students' learning difficulties in EM and EMI

Students' written explanations in the conceptual understanding test **(CUT)** were analysed and coded to identify common misconceptions in the fields of EM and EMI for JC students. The percentage of students exhibiting similar difficulties will be counted to provide an indication of common misconceptions that need to be addressed in the teaching of EM and EMI.

4. Findings and Discussion

In this section, the results and findings for the following 3 areas will be analysed and discussed:

A. Effectiveness of Conceptual change instruction using demonstration
B. Effectiveness of demonstrations in eliciting cognitive conflict
C. Difficulties in EM and EMI

A. Effectiveness of Conceptual change instruction using demonstration

The conceptual understanding test (CUT) for EM and EMI was analysed for the correctness of the prediction and explanation. Each question in the CUT corresponds to a demonstration used during instruction and serves to assess students' understanding of the underlying physics concepts illustrated in the demonstration.

The table below summarises the underlying physics domains of the demonstrations, the question in the CUT linked to the demonstration and the classes undergoing demo (PORE) treatment for each demonstration.

Physics Domain	Demonstration	CUT Question	Demo (PORE) treatment	Traditional treatment
EM	D1	Q1	**Class 1**	Class 2
EM	D2	Q2	Class 2	**Class 1**
EM	D3	Q3	Class 2	**Class 1**
EM	D4	Q4	**Class 1**	Class 2
EMI	D5	Q5	**Class 1**	Class 2
EMI	D6	Q6	Class 2	**Class 1**
EMI	D7	Q7	**Class 1**	Class 2

EMI	D8	Q8	Class 2	**Class 1**

The data were analysed to determine if the demo (PORE) instructional method is more effective than the tradition teaching method for ;

- the overall EM and EMI domains,
- in the EM domain only and
- in the EMI domain only.

1 tailed repeated measures t-Test was used to evaluate if the Demo (PORE) instruction is more effective than traditional teaching. A p value of < 0.05 is considered statistically significant.

The Cohen's effect size is computed as described in Graventer and Wallnau (2008) to evaluate the treatment effect of DEMO (PORE) :

$$d = \frac{\text{sample mean difference}}{\text{sample standard deviation}}$$

Cohen's suggested criteria for evaluating the size of the treatment effect are :

	Evaluation of treatment effect
d between 0.2 to 0.5	Small effect
d between 0.5 to 0.8	Medium effect
d more than 0.8	Large effect

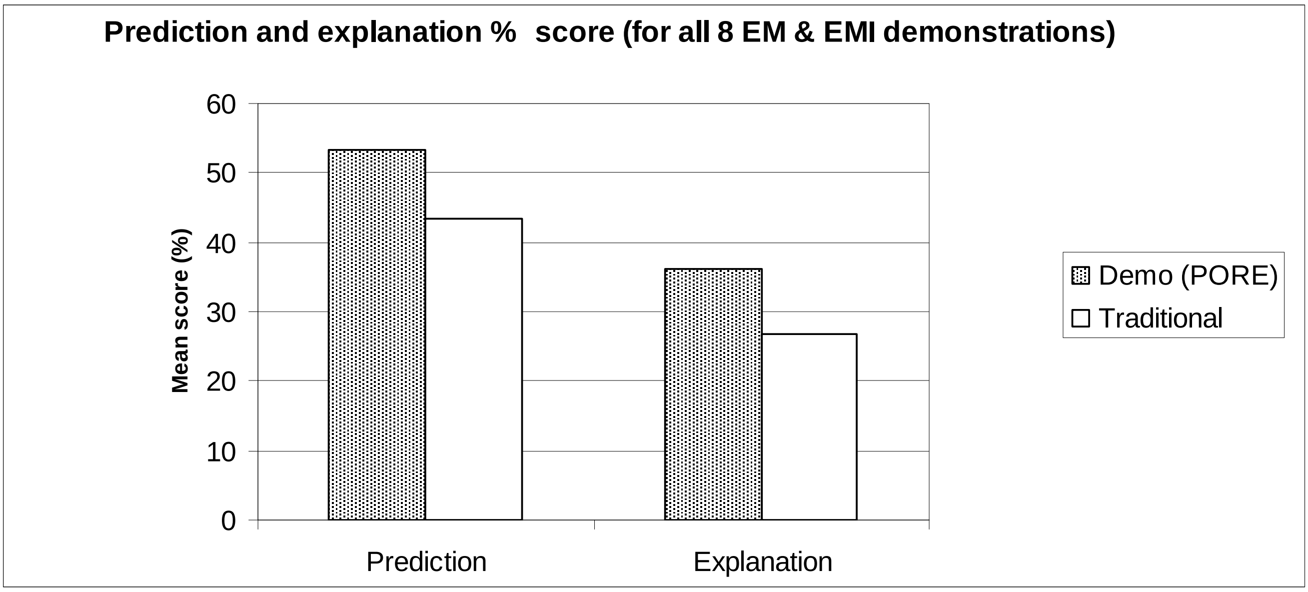
<u>Analysis of overall performance in CUT (for combined EM and EMI domains)</u>

Table 5A.1 and Fig 5A.1 show the overall prediction and explanation mean % score for all 8 demonstrations. Each student is given a $X_{overall}$ score and $Y_{overall}$ score for questions instructed using demo (PORE) and traditional methods respectively. For class 1, $X_{overall}$ score is computed based on Q1,4,5,7 and $Y_{overall}$ score is based on Q2,3,6,8. Whereas, for class 2, $X_{overall}$ score is computed based on Q2,3,6,8 and $Y_{overall}$ is based on Q1,4,5,7.

Table 5A.1 Prediction and explanation mean % score (for all 8 EM and EMI demonstrations)

	Sample size	Demo (PORE) treatment Mean Overall Score (%)	Traditional treatment Mean Overall Score (%)	Mean Difference overall score (%)	Standard deviation	Significance (1-tailed repeated-measures t Test)	Cohen's Effect size
	N	$X_{overall}$	$Y_{overall}$	$D_{overall}$ (D = X – Y)	$SD_{overall}$	$p_{overall}$	$d_{overall}$
Prediction	45	53.3	43.3	9.4	38.2	0.05	0.25
Explanation	45	36.1	26.7	9.4	34.2	0.036	0.28

Fig 5A.1 Comparison of prediction and explanation % score (for all 8 EM and EMI demonstrations) between demonstration (PORE) treatment and traditional treatment.



Overall, the analysis of the CUT showed that students performed better for questions taught using the demo (PORE) for both prediction of outcomes and explanation of the underlying physics.

For prediction of outcome, instruction using the demo (PORE) teaching method is more effective than traditional teaching method by a mean difference = 9.4% with SD = 38.2%. The treatment effect was statistically significant, $t(44) = 1.66$, $p = 0.05$, Cohern's treatment effect size $d = 0.25$. There is a small treatment effect according to Cohen's suggested criteria.

For explanation of underlying physics, instruction using the demo (PORE) teaching method is more effective than traditional teaching method by a mean difference = 9.4% with SD = 34.2%. The treatment effect was statistically significant, $t(44) = 1.85$, $p = 0.036$, Cohern's treatment effect size $d = 0.28$. There is a small treatment effect according to Cohen's suggested criteria.

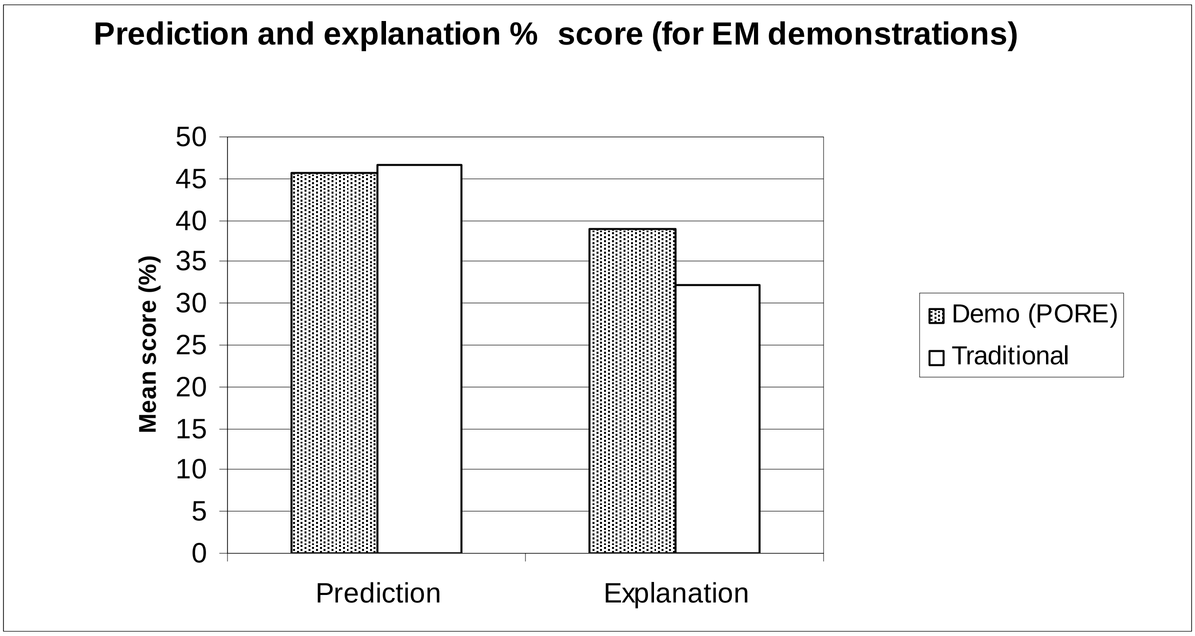
Analysis of performance in CUT (for EM domain)

Table 5A.2 and Fig 5A.2 show the prediction and explanation mean % score for EM demonstrations (D1 to D4). Each student is given a X_{EM} score and Y_{EM} score for questions instructed using demo (PORE) and traditional methods respectively. For class 1, X_{EM} score is computed based on Q1,4 and Y_{EM} score is based on Q2,3. Whereas, for class 2, X_{EM} score is computed based on Q2,3 and Y_{EM} is based on Q1,4.

Table 5A.2 : Prediction and explanation % score (for EM demonstrations)

	Sample size	Demo (PORE) treatment Mean Score (%)	Traditional treatment Mean Score (%)	Mean Difference in treatments score (%)	Standard deviation	Significance (1-tailed repeated-measures t Test)	Cohen's Effect size
	N	X_{EM}	Y_{EM}	D_{EM} (D = X – Y)	SD_{EM}	p_{EM}	d_{EM}
Prediction	45	45.6	46.7	-1.1	48.3	0.44	-0.02
Explanation	45	38.9	32.2	6.7	50.7	0.19	0.13

Fig 5A.2 Comparison of prediction and explanation % score (for EM demonstrations) between demonstration (PORE) treatment and traditional treatment.



In the domain of electromagnetism (EM), the analysis of the CUT showed similar performance for questions taught using the demo (PORE) for both prediction of outcomes and explanation of the underlying physics. A likely reason could be due to the long time lag between instructions and the final assessment of CUT. The teaching of EM demonstrations D1 to D4 took place from 3 Mar 2008 to 9 Apr 2008 while the CUT was administered on 12 May 2008. The long time delay of about a month could have affected students' ability to recall the demonstrations and reduced the effect of instructions.

For prediction of outcome, instruction using the demo (PORE) teaching method is as effective as traditional teaching method with a mean difference = -1.1% with SD = 48.3%. The treatment effect was not statistically significant, t(44) = -0.154, p = 0.44, Cohern's treatment effect size d = -0.02. There is no treatment effect according to Cohen's suggested criteria.

For explanation of underlying physics, instruction using the demo (PORE) teaching method is more effective than traditional teaching method by a mean difference = 6.7% with SD = 50.7%. The treatment effect was not statistically significant, t(44) = 0.882, p = 0.19, Cohern's treatment effect size d = 0.13. There is no treatment effect according to Cohen's suggested criteria.

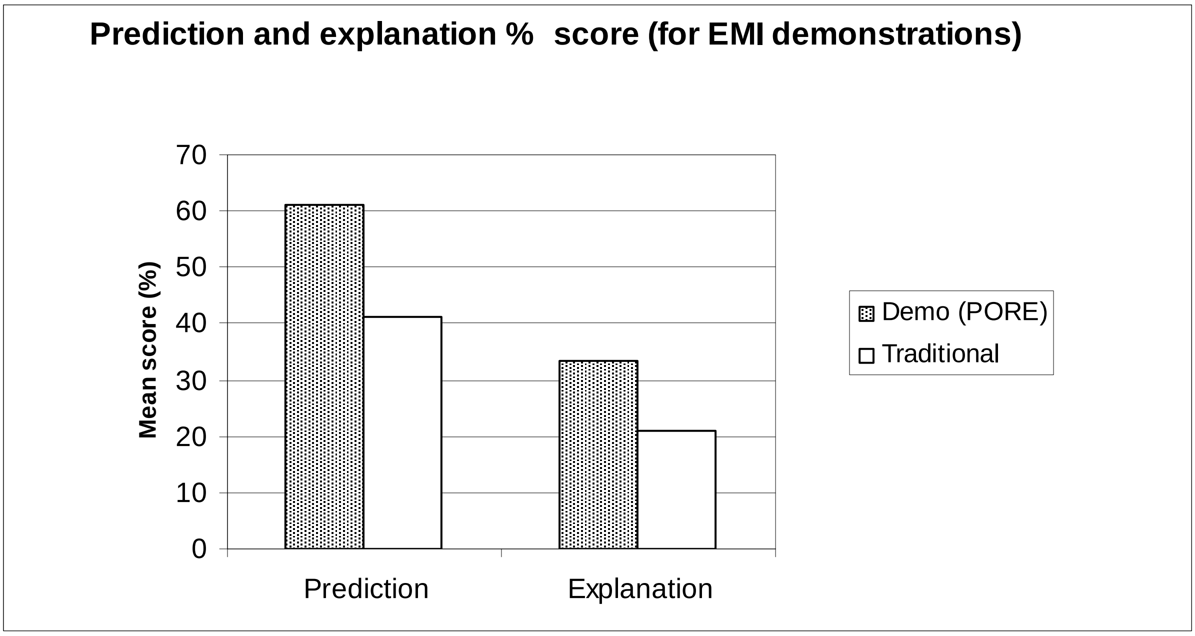
Analysis of performance in CUT (for EMI domain)

Table 5A.3 and Fig 5A.3 show the prediction and explanation mean % score for EMI demonstrations (D5 to D8). Each student is given a X_{EMI} score and Y_{EMI} score for questions instructed using demo (PORE) and traditional methods respectively. For class 1, X_{EMI} score is computed based on Q5,7 and Y_{EMI} score is based on Q6,8. Whereas, for class 2, X_{EMI} score is computed based on Q6,8 and Y_{EMI} is based on Q5,7.

Table 5A.3 : Prediction and explanation % score (for EMI demonstrations)

	Sample size	Demo (PORE) treatment Mean Score (%)	Traditional treatment Mean Score (%)	Mean Difference in treatments score (%)	Standard deviation	Significance (1-tailed repeated-measures t Test)	Cohen's Effect size
	N	X_{EMI}	Y_{EMI}	D_{EMI} (D = X – Y)	SD_{EMI}	p_{EMI}	d_{EMI}
Prediction	45	61.1	41.1	20.0	48.1	0.004	0.42
Explanation	45	33.3	21.1	12.2	42.8	0.031	0.29

Fig 5A.3 Comparison of prediction and explanation % score (for EMI demonstrations) between demonstration (PORE) treatment and traditional treatment.



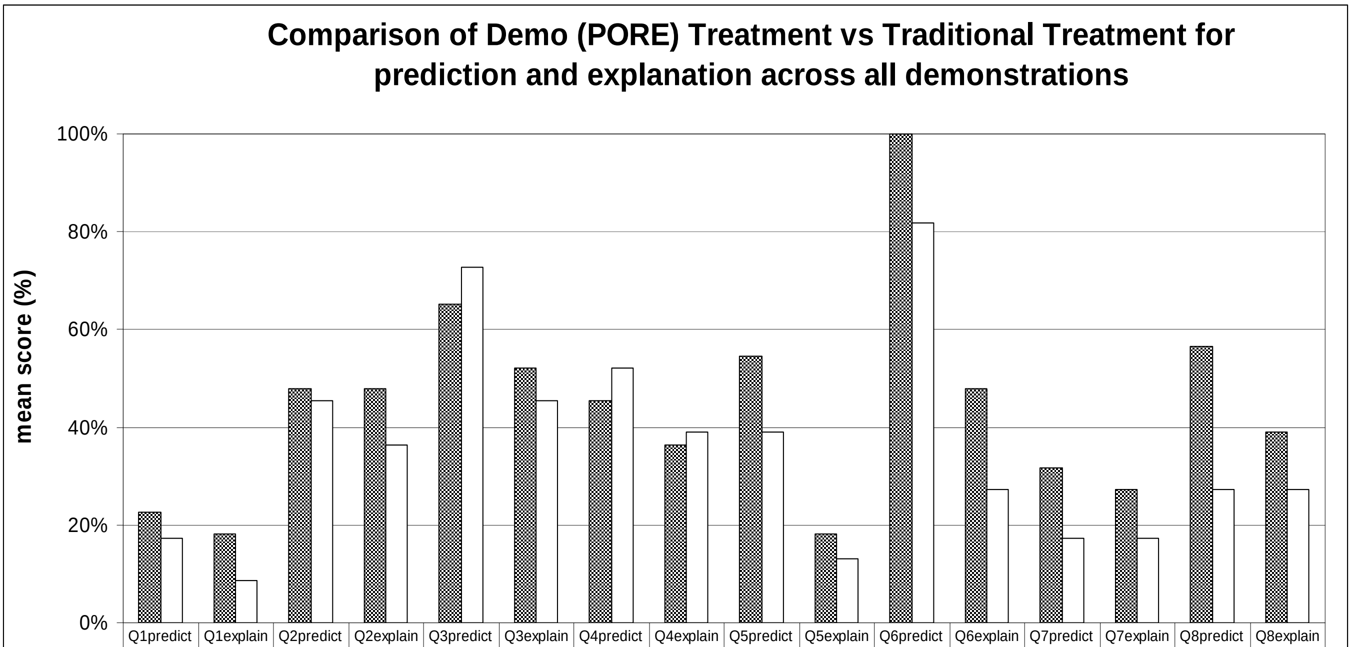
For the domain of electromagnetic induction (EMI), the analysis of the CUT showed that students performed much better for questions taught using the demo (PORE) for both prediction of outcomes and explanation of the underlying physics.

For prediction of outcome, instruction using the demo (PORE) teaching method is more effective than traditional teaching method by a mean difference = 20.0% with SD = 48.1%. The treatment effect was statistically significant, $t(44) = 2.787$, $p = 0.004$, Cohern's treatment effect size $d = 0.42$. There is a small treatment effect according to Cohen's suggested criteria.

For explanation of underlying physics, instruction using the demo (PORE) teaching method is more effective than traditional teaching method by a mean difference = 12.2% with SD = 42.8%. The treatment effect was statistically significant, $t(44) = 1.914$, $p = 0.031$, Cohern's treatment effect size $d = 0.29$. There is a small treatment effect according to Cohen's suggested criteria.

<u>Comparison of Demo (PORE) and Traditional treatment across demonstrations</u>

Fig 5A.4 below shows a comparison of the mean score (%) of prediction and explanation for Demo (PORE) and Traditional treatment by demonstrations.



	Q1predict	Q1explain	Q2predict	Q2explain	Q3predict	Q3explain	Q4predict	Q4explain	Q5predict	Q5explain	Q6predict	Q6explain	Q7predict	Q7explain	Q8predict	Q8explain
Demo (PORE)	22.7%	18.2%	47.8%	47.8%	65.2%	52.2%	45.5%	36.4%	54.5%	18.2%	100.0%	47.8%	31.8%	27.3%	56.5%	39.1%
Traditional	17.4%	8.7%	45.5%	36.4%	72.7%	45.5%	52.2%	39.1%	39.1%	13.0%	81.8%	27.3%	17.4%	17.4%	27.3%	27.3%

B. Effectiveness of demonstrations in eliciting cognitive conflict

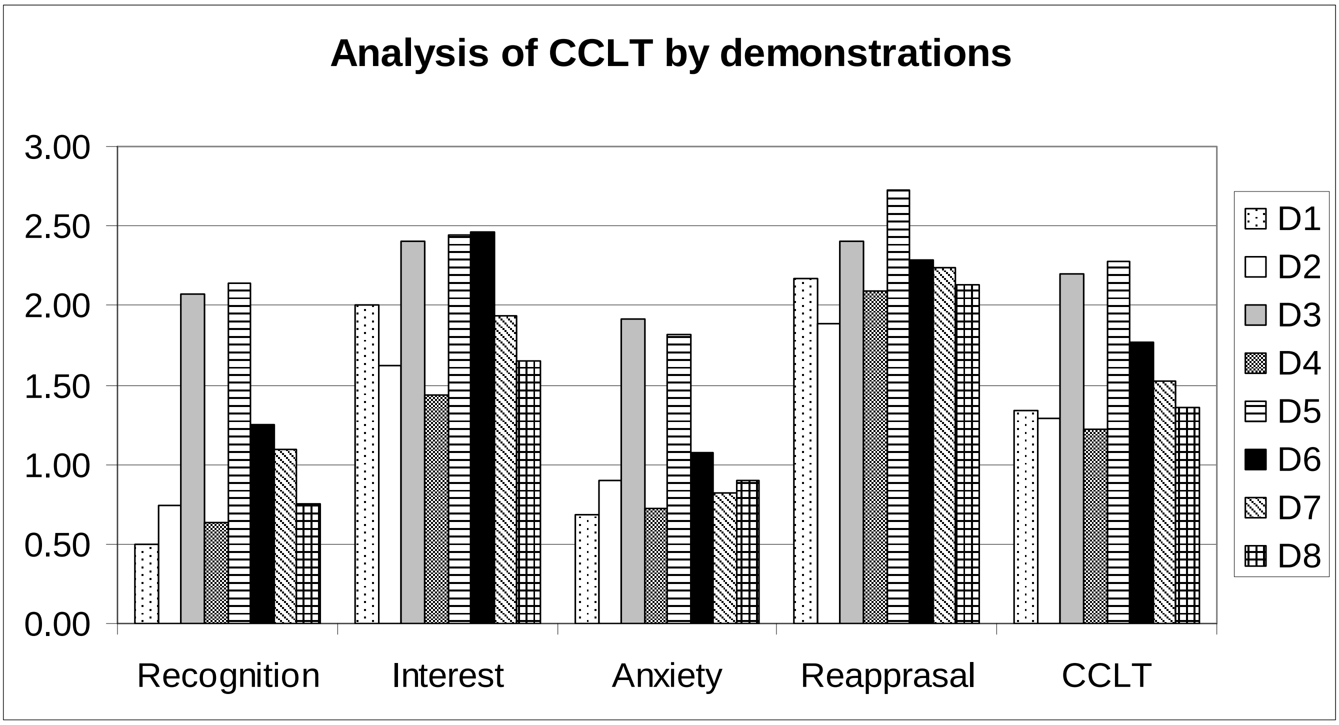
Students' responses to the cognitive conflict level test (CCLT) was analysed for each demonstrations to determine the effectiveness of the demonstration in eliciting cognitive conflict in students. Table 5B.1 and Fig 5B.1 summarises the 4 subfactors and total CCLT by each demonstrations. Note the Likert scale used in CCLT is from 0 = 'not at all true' to 4 = 'very true'.

Table 5B.1 CCLT Analysis by demonstrations

				Subfactors of CCLT				**Total**
Class	**Demo**	**Physics Field**	**Demo Title**	**Recognition**	**Interest**	**Anxiety**	**Reapprasal**	**CCLT**
Class 1	D1	EM	Rod on rail (Magnetic force on current in B field)	0.50	2.00	0.68	2.17	1.34
Class 2	D2	EM	Magnetic force on a moving charge in B field	0.74	1.62	0.90	1.88	1.29
Class 2	**D3**	EM	Interaction of wire and magnet (Newton's 3rd Law in EM context)	**2.07**	**2.41**	**1.91**	**2.41**	**2.20**
Class 1	D4	EM	Turning effect of a coil in a B field	0.64	1.44	0.73	2.09	1.22
Class 1	**D5**	EMI	Rotating aluminum can (Newton's 3rd Law in EMI context)	**2.14**	**2.44**	**1.82**	**2.73**	**2.28**
Class 2	D6	EMI	Magnet falling through an aluminum tube	1.25	2.46	1.07	2.29	1.77
Class 1	D7	EMI	Magnet falling through a solenoid	1.09	1.94	0.82	2.24	1.52
Class 2	D8	EMI	Magnet swinging pass a solenoid	0.75	1.65	0.90	2.13	1.36
			EM Overall (demo D1 to D4)	**0.99**	**1.87**	**1.06**	**2.14**	**1.51**

EMI Overall (demo D5 to D8)	**1.31**	**2.12**	**1.15**	**2.35**	**1.73**
Overall (demo D1 to D8)	**1.15**	**2.00**	**1.10**	**2.24**	**1.62**

Fig 5B.1 Analysis of CCLT by demonstrations



It is interesting to note that the two demonstrations with highest CCLT level are D3 and D5 which are both designed to elicit difficulties in translating Newton's 3rd law in electromagnetism and electromagnetic induction. The high CCLT score for these two demonstrations clearly suggested that students were surprised by the outcomes of the demonstrations.

Overall, students found the demonstrations interesting (overall interest subfactor = 2.00) and is keen to find out the reasons for the outcomes of the demonstrations (overall reappraisal factor = 2.24). The other 2 subfactors on recognition of a discrepant event and anxiety were felt less strongly accept for demonstrations D3 and D5.

It appeared that demonstrations D3 and D5 were most effective amongst the 8 demonstration in eliciting cognitive conflict as seen from the generally higher scores in total CCLT and the 4 subfactors.

C. Difficulties in EM and EMI

Student common difficulties and wrong reasoning as shown in their answer in the EM & EMI Conceptual Understanding Test (**CUT**) are analysed. A detail discussion of all questions in the CUT is beyond the scope of this paper. The analysis presented below will focus on students' difficulty in transferring Newton's 3rd law to EM and EMI. Tables 5C.3 and 5C.5 show the breakdown of student explanations in the **CUT** for Q3 and Q5. Percentages are percentages of students who gave that reasoning in their answers. Note the percentages of acceptable and unacceptable explanations do not total to 100% because student answers frequently fell into more than one reasoning category. Also the categories include the most frequent reasoning, not all observed reasoning.

Analysis of Q3

Table 5C.3 : Interaction of wire and magnet (Newton's 3rd Law in EM context)

	Demonstration treatment Class 2 (23 students)	**Traditional treatment Class 1 (22 students)**	**Overall Class 1 & 2 (45 students)**
Correct prediction of outcome	65.2%	72.7%	68.9%
Acceptable explanation	52.2%	45.5%	48.9%
Unacceptable explanations			
Wrong reasoning / Difficulties :			
Difficulty transferring Newton 3rd Law	21.7%	22.7%	22.2%

to EM context			
Confuse EM with EMI.	17.4%	18.2%	17.8%
No explanation	0%	4.3%	2.2%

Q3 shows a horseshoe magnet suspended from a spring balance. A wire is situated between the poles of the magnet. Question ask students to compare the readings on the spring balance when there is no current in the wire, when a current flows in one direction in the wire and when the current flows in the opposite direction in the wire. To get the correct answer students need to deduce the magnetic force acting on the wire when a current flows. Apply Newton's 3rd between the wire and the magnet to deduce the changes in the reading of the spring balance.

21.7% of class 2 (demonstration treatment) and 22.7% of class 1 (traditional treatment) did not transfer Newton's 3rd law to the EM interaction between the current in the wire and the horseshoe magnet. Students showed a wrong conception that the direction of the force acting on the wire is the same as the direction of the force acting on the magnet. For instance, one student wrote:

"With a current in the wire in the direction of YX, using FLHR, there will be an upward force acting on the wire, and thus the bar magnet" (student id 104)

Other students applied Fleming's left hand rule to deduce the direction of the magnetic force but wrongly reasoned that the magnetic force acts on the horseshoe magnet or on the spring instead of on the wire. The following is an example of such wrong reasoning :

"Using Fleming's left hand rule, when a current is passed from Y to X, there will be an upward force produced. This force would result in the horseshoe magnet being pushed upwards" (student id 106)

17.4% of class 2 (demonstration treatment) and 18.2% of class 1 (traditional treatment) have confused EM with EMI concepts and inappropriately utilised EMI concepts such as Flemings RHR and Lenz's law. It is possible that the discussion of application of Newton's 3rd law during instruction has led some students to confuse "action and reaction" in Newton's 3rd law with the term "oppose" stated in Lenz's law.

Analysis of Q5

Table 5C.5 : Rotating aluminum disc (Newton's 3rd law in EMI context)

	Demonstration treatment Class 1 (22 students)	**Traditional treatment Class 2 (23 students)**	**Overall Class 1 & 2 (45 students)**
Correct prediction of outcome	54.5%	39.1%	46.7%
Acceptable explanation	18.2%	13.0%	15.6%
Unacceptable explanations			
Wrong reasoning / Difficulties :			
Difficulty transferring Newton 3rd Law to EMI context	9.1%	21.7%	15.6%
Difficulty in interpreting Lenz's law	54.5%	56.5%	55.6%
No explanation	4.5%	8.7%	6.7%

Q5 shows an aluminum disc that is free to spin about the vertical axis passing through its centern. The question what will happen to the disc when a horseshoe magnet rotates clockwise above it. To get the correct answer students need to apply Lenz's law to deduce that the magnet experience an anticlockwise torque against its motion. Apply Newton's 3rd between the magnet and the disc to reason that a clockwise torque will cause the disc to rotate clockwise.

The need to use both Lenz's law and Newton's 3rd law to explain this question drew up a multitude of incorrect reasoning which clearly showed students' lack of understanding and ability to distinguish these two fundamental physics ideas.

9.1% of class 1 (demonstration treatment) and 21.7% of class 2 (traditional treatment) have difficulty applying Newton's 3rd law to the EMI interaction between the magnet and the disc. Students showed a wrong conception that the direction of the force (or torque) opposing the magnet's motion is also acting in the same direction on the disc. For instance, one student wrote:

"The current produces a opposite magnetic field which opposes the movement of the magnet. By Newton's third law, the force exerted on the magnet, causing it to spin the other direction will also be exerted back onto the disc. Thus it spins anticlockwise." (student id 215)

Such argument showed students failing to apply the idea that reaction is "equal but opposite in direction" to the action.

54.5% of class 1 (demonstration treatment) and 56.5% of class 2 (traditional treatment) have a fuzzy idea on "oppose" in Lenz's law. Some students thought that oppose means the induced emf or current is opposite to the clockwise rotation of the magnet and gave wrong argument such as :

"Using Lenz's law, the induced emf will be in a direction to oppose the change and flowing in the anticlockwise direction" (student id 107)

Many students tend to treat "oppose" intuitively as that the disc will rotate in opposite direction to oppose the motion of the magnet. For example, a student wrote:

"eddy current would be induced in the aluminium disc to oppose motion of the magnet. The disc would thus spin in an opposite direction." (student id 218)

5. Conclusion and recommendations

The main objective of this study was to determine if the use of classroom demonstration base on conceptual change instruction is more effective than traditional teaching in enhancing students' conceptual understanding in electromagnetism and electromagnetic induction.

Based on statistical analyses results given in section 5, it indicated that the proposed conceptual change instruction approach "PORE" is more effective than traditional teaching in terms of students' ability to recall the correct prediction and explanation for the underlying physics in EM and EM1 phenomena.

If only EMI demonstrations were considered, the statistical analyses results provided even greater evidence that conceptual change instruction approach "PORE" is more effective than traditional teaching in helping students' recall the correct outcome and explaining the physics related to the demonstrations.

However, if only EM demonstrations were considered, there was no statistical significance between "PORE" and traditional teaching. A possible reason was the long time lag of a month between the EM demonstrations and the conceptual understanding test (CUT). This could indicate that once off conceptual change instruction may not be long lasting as students' prior conception are very resistant to change and students may revert back to their prior conception.

In this study, the demonstrations were developed to address known misconceptions in EM and EMI. A conceptual question based on the demonstration was designed to get students to predict and explain the outcome of the demonstration so as to get students to think and make a personal intellectual commitment on the presented demonstration. Students who held alternative conceptions in their thinking would be confronted through the demonstration. The purpose was to generate cognitive conflict amongst students who may have inappropriate alternate conceptions. According to Posner's conceptual change model, for conceptual change to happen it is necessary for students to be dissatisfied with their prior conceptions.

In this study, unlike others reviewed in the literature, it was not assumed that students will experience cognitive conflict so long as they see a demonstration. The CCLT was used to determine if students really experienced high cognitive conflict through viewing the demonstrations. Two demonstrations D3 and D5 stood out by producing the highest CCLT level which indicated students had experienced high cognitive conflict during the presentation of these two demonstrations. For D3 and D5, analysis of the CCLT showed students scoring high level in all the 4 components related to cognitive conflict, namely recognition of anomalous situation, interests, anxiety and cognitive reappraisal of the cognitive situation. Both D3 and D5 were designed to elicit difficulties in translating Newton's 3rd law in electromagnetism and electromagnetic induction. The high CCLT score for these two demonstrations clearly suggested that the students were surprised by the outcomes of the demonstrations. It also suggested that students had not made connections between Newton's 3rd law and electromagnetism and electromagnetic induction before the instruction. In the CUT, students were able to predict the outcomes for D3 and D5 relatively better than the other demonstrations accept for D6 and D8. For the "PORE" treatment class, 65% and 55% students predicted D3 and D5 correctly; 100% and 57% predicted D6 and D8 correctly; less than 48% predicted the other demonstrations correctly (see results presented in Fig 5A.4). D6 appeared to be too easy for students even during the instruction. D8 was the last demonstration in the study and students probably would have a fresher impression of the demonstration.

In terms of ability to explain the underlying physics, D3 was the most well answered demonstrations with 52% "PORE" treatment students able to provide acceptable explanations. However, only 18% of "PORE" treatment students were able to explain the outcome for D5, which was one the two lowest amongst all the demonstrations. D5 appeared to be conceptually more difficult for students to understand than D3. In the analysis of misconceptions shown by students for Q5 in the CUT, a high percentage of 54.5% students showed difficulty interpreting Lenz's law. It is highly possible that the interplay of Lenz's law and Newton's 3rd law posed great conceptual difficulties and may have even led to new misconceptions for students.

Recommendations and Implications

Based on the results of the study, the following are recommended:

- Demonstration based on the proposed conceptual change approach "PORE" is more effective than traditional teaching in helping students change their prior conception to acceptable scientific conception.
- The study can be improved by administering a conceptual understanding test after instruction of EM demonstrations rather than at the end of the entire study.
- CCLT can be used as a tool to evaluate the ability of a demonstration in eliciting cognitive conflict. Such information will be useful in making improvements to a demonstration and in the selection of demonstrations to be used for instruction. Using demonstration in class involves more time, hence using effective demonstration is an important consideration for instruction.
- Analysis of the CUT showed students have largely similar conceptual difficulties to those reported in the literature. Teachers should be aware of common students' misconceptions to be more effective in helping students make changes to the acceptable scientific conceptions.
- In the teaching of EM and EMI, there is a need to :
    - help students integrate EM and EMI with mechanics early in the instruction

- to illustrate the difference between Newton's 3rd law and Lenz's law
- clarify similarities and differences of EM & EMI with E field & g field

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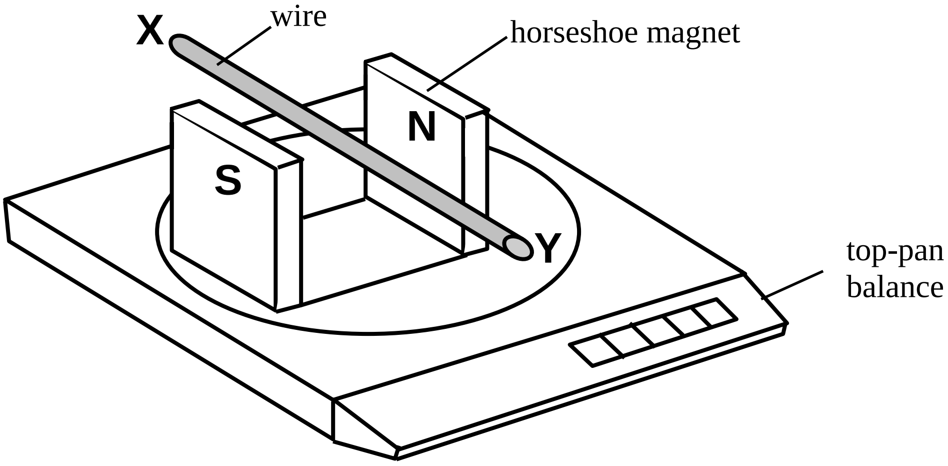
Appendix I

Demonstration Observation and Explanation Worksheet (DOEW)

Question D3

A horseshoe magnet rests on a top-pan balance with a wire situated between the poles of the magnet.



With no current in the wire, the reading on the balance is $\mathbf{W_o}$.

With a current in the wire in the direction XY, the reading on the balance is $\mathbf{W_1}$.

With a current in the wire in the direction YX, the reading on the balance is $\mathbf{W_2}$.

Rank the readings $\mathbf{W_o}$, $\mathbf{W_1}$ and $\mathbf{W_2}$ from greatest to smallest.

(A) $W_1 = W_2 > W_o$
(B) $W_0 > W_1 > W_2$
(C) $W_1 = W_o = W_2$
(D) $W_2 > W_o > W_1$
(E) $W_1 > W_o > W_2$

Section A : Prediction

What is your prediction? ____________________

What are your reasons?

Appendix I

Demonstration Observation and Explanation Worksheet (DOEW)

Question D5

An empty aluminum can floats in a beaker of water. A magnet attached to the end of a stick is lowered into the aluminum can as shown in Fig 1.1.

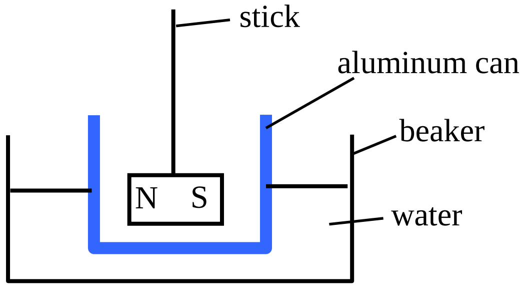


Fig 1.1 (side view)

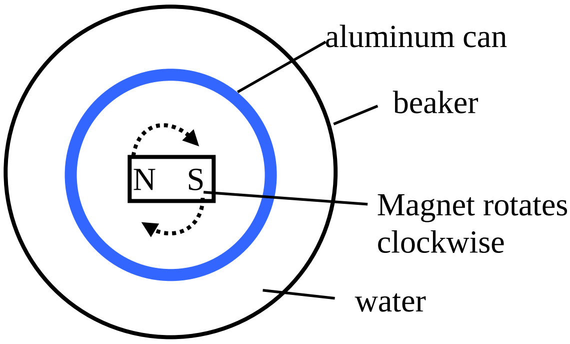


Fig 1.2 (top view)

When the magnet is rotated clockwise as viewed from the top (see Fig 1.2) without touching the aluminum can, the aluminum can will

- **(A)** remain stationary.
- **(B)** rotate clockwise
- **(C)** rotate anticlockwise.
- **(D)** oscillate back and forth.

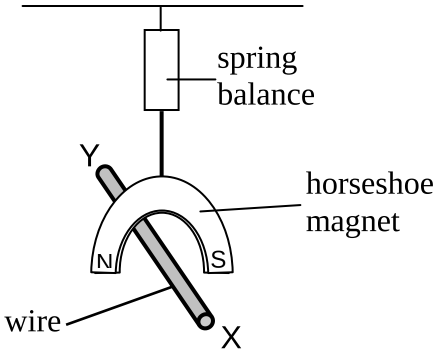
Section A : Prediction

What is your prediction? ____________________

What are your reasons?

Conceptual Understanding Test (CUT) **Appendix II**

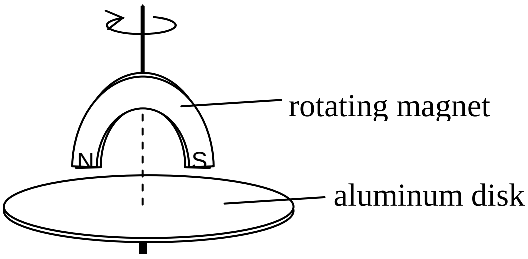
Q3. A horseshoe magnet is suspended from a spring balance. A wire XY is situated between the poles of the magnet. With no current in the wire, the reading on the spring balance is $\mathbf{T_o}$. With a current in the wire in the direction XY, the reading on the spring balance is $\mathbf{T_1}$. With a current in the wire in the direction YX, the reading on the spring balance is $\mathbf{T_2}$. Rank the readings $\mathbf{T_o}$, $\mathbf{T_1}$ and $\mathbf{T_2}$ from greatest to smallest. [5]



Answer : ....

Explain your answer briefly.

Q5. An aluminum disk is free to spin about the vertical axis passing through its center. Suspended above the disk is a horseshoe magnet. The horseshoe magnet rotates about a vertical axis in a clockwise direction (as viewed from the top). What will happen to the disk as viewed from the top? [5]



Answer : ....

Explain your answer briefly.
