Journal of Science and Mathematics
Education in Southeast Asia
2009, Vol. 32 No. 1, 62-84

PEOR – Engaging Students in Demonstrations

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Demonstrations are a core part of science teaching. In 1980 a three-part assessment method using demonstrating was proposed. Known as DOE this consisted of demonstration, observation and explanation. DOE quickly evolved into POE: predict, observe, explain. In the light of experiences with POE and insights from constructivist theory we set out in this paper a learning-focused refinement of POE, namely PEOR: predict, explain, observe, react. We offer a theoretical justification for the value of PEOR and argue that it is more than a simple update of the earlier protocol. PEOR can be used with any age of students. We illustrate its use in practice with initial teacher education students working on the topic of forces and fields. The demonstration we describe is called 'floating magnets'. PEOR enabled the teacher to clarify students' current conceptions about the topic. We found that these surfaced naturally and served as an important start in the process of clarifying ideas about the broader course content. When using PEORs with student teachers, we also noted that students' affective and cognitive engagement in the activity was considerably greater than that shown during a traditional demonstration.

Key words: Demonstration; Engagement; Constructivism; Cognition, Affect, PEOR; Field; Force

Introduction

Demonstrations are part of mainstream science teaching. Over the years there have been many articles in the literature about demonstrations, sharing novel pedagogic and scientific ideas. This paper describes the basis for, and some uses of, a constructivist-informed demonstration approach that we call PEOR: predict, explain, observe, rethink/reinforce (Scaife, 1994, 2008).

PEOR is a learning-focused refinement of a protocol known as POE: predict, observe explain. POE evolved from an assessment tool known as DOE: demonstration, observation, explanation. DOE was devised by Champagne, Klopfer and Anderson (1980) at a time when constructivist-informed teaching approaches such as Nuffield Science, the Learning in Science Project (LISP) and the Children's Learning in Science (CLIS) project materials were first starting to appear. DOE was a significant step in a learner-centred direction. It was not, however, a teaching strategy. Champagne et al. stated their purposes in using DOE as being, 'to describe the preinstructional knowledge of mechanics, mathematical skills, and reasoning skills of a sample of college physics students' (p. 1074), and to explore the influence of these variables on subsequent learning in mechanics. DOE was an assessment tool. Students were to observe demonstrations and then write about their observations. Students' responses became data about 'preinstructional knowledge'.

Champagne et al. (1980) commented that some of their DOE questions asked students to make a prediction. Gunstone and White (1981) built on this idea and made prediction a core part of what they called the predict-observe-explain (POE) protocol. POE had much in common with DOE: they were both assessment tools rather than teaching strategies; they required students to write about their observations and they involved students working mainly individually. Commenting on the data generated from POE assessment Gunstone and White noted that many students did not explain their predictions and neither did they manage to resolve differences between their predictions and their observations.

The constructivist claim that learning is highly influenced by current knowledge led in the 1980s to a great deal of fruitful work eliciting students' prior ideas in science. Naturally this prompted the question: What are the implications for teaching? Discussing this question in 1985, Champagne, Gunstone and Klopfer again referred to DOE but somewhat surprisingly it was still regarded as an assessment instrument rather than a teaching approach. By 1992 White and Gunstone had extended the scope of POE: students were asked to, 'predict the outcome of some event, and must justify their prediction; then they describe what they see happen; and finally they must reconcile any conflict between prediction and observation' (White and Gunstone, 1992, p.44). The emphasis in this account remains on assessment of students' written responses: 'The POE task is another measure of ability to apply knowledge' (ibid., p.45). However there is a final section in the chapter on POE, less than one page long, entitled 'Using POEs in teaching'. Here White and Gunstone mention the use of discussion as part of POE. As far as we can tell from the literature this represents the first recorded shift away from POE as assessment and towards thinking of it as a teaching strategy.

Perhaps the most valuable aspect of POE in teaching is the way it transformed the pedagogic impact of demonstrations by integrating student predictions. Instead of students watching the teacher do a demonstration and then writing it up in idealised form (Wellington, 1981), in POE they were asked to make predictions about what would happen; they then saw what did happen and were expected to try to construct an explanation for what they had observed. Asking people to predict something, especially when they can hear or see other peoples' predictions and they know they won't have to wait long to 'see who's right' is a powerful psychological strategy. It makes use of what Dennett (1991) argues is the universal human quality of 'epistemic hunger', that is, curiosity and desire for explanatory stories. Curiosity can be inferred from the behaviour of many animals, notably cats, but human curiosity has a dimension that may be unique to us. Once we express our curiosity through prediction we become 'stakeholders' in what happens. We care about the outcome: we become *engaged* in what's going on. Engagement has 'gold standard' in teaching: without it the prospect of fruitful learning is poor; with engagement the door to learning is open. This is what makes prediction so valuable in demonstrations and what made POE such an important step forward.

Why propose a refinement of POE? Firstly, the science teaching community has had more than a decade's experience in using POE and practices have moved on. Secondly, since POE was originally devised, constructivist ideas have blossomed. An internet search on the term 'constructivism' now yields well over a million hits. In view of this it would be surprising if it were not possible to look at the use of prediction in science demonstrations in a new theoretical light. Key ideas from constructivism are discussed in the following section.

Ideas from Constructivism

The following is a brief summary of points that are compatible with constructivism and that provide a basis for the components of the refinement of POE that we call PEOR: predict, explain, observe, rethink or reinforce.

For further reading on constructivism in education see, for example, von Glasersfeld (1995), Scaife (2007, 2008), Steffe and Gale (1995).

1. Engagement is necessary for learning. Learning occurs from action: physical or mental. The 'object' of mental action is set by where we fix our attention. The direction of our attention is influenced by interest, novelty, curiosity and peer behaviour, all of which contribute to engagement. Engagement grabs the attention and focuses mental action.
2. Self value is efficacious for learning. This includes belief in the value of one's own ideas, belief that others value one's ideas, and belief in the possibility for growth in one's knowledge.
3. Languaging – turning thoughts into spoken or written words – is conducive to learning, because it involves creating and committing oneself to a position and hearing or seeing oneself express it (Dennett, 1991).
4. Peer interaction has high salience. What I think others think of me, what I feel about others, what I think of the ideas they are expressing: all of these may be highly influential on my thinking and acting. Peer interactions are qualitatively different from student-teacher interaction; in particular, differences between oneself and one's peers may be harder to ignore than differences from the teacher.
5. If they are to be meaningful, patterns, relationships, laws, generalisations, abstractions and symbolic representations emerge from prior 'concrete' perceptions that are reflected on. Languaging with others about observed events, such as science demonstrations, provides both perceptual material and a context for reflection.
6. Incoherence is undesirable. In general it is addressed or avoided rather than tolerated. The 'stake-holder' effect – caring about the outcome - makes it more likely that incoherence will be addressed rather than avoided ('Why did *that* happen?'). Post-observation discussion with peers and teacher adds to the likelihood that incoherence will be addressed.

What have We Learnt from Experience of Using POE in Teaching?

1. Students may guess or may avoid making a prediction.
2. There is a risk of behavioural patterns emerging, e.g. students may learn to look for a non-obvious prediction because that is the nature of this 'game'.
3. Right and wrong can dominate, instead of thinking and understanding.
4. Students may adopt habitual roles: I'm nearly always right, or nearly always wrong, so it's not worth trying.
5. The implications of the observations may be clear to the teacher but not to some of the students – and the teacher may miss this fact.
6. 'Explain' may be the teacher explaining – a reversion to transmission teaching with the emphasis on the right answer, leaving some learners' ideas about the science topic unchanged (though they might learn what they are *supposed* to say).
7. If the focus is on the right answer but the demonstration doesn't give the right answer, learners' confidence in the status of science and scientific knowledge may be undermined.

PEOR

PEOR is an attempt to build on the experience of POE in the light of developing ideas from constructivism about learning. In this section we look at arguments for each of the four parts of PEOR.

Predict

As mentioned above prediction tends to evoke engagement and a sense of a stake in what happens. In addition constructivism has taught us that learners' initial ideas are the platforms from which they construct new knowledge. In our view the teacher's task is to guide and nudge learners from where they are now towards understandings that fit better with the science community. It is therefore useful for the teacher to learn where the students are starting from, so as to be able to target her/his teaching interventions where they are needed. Students' predictions provide the teacher with this 'diagnostic' information – provided the students express their views about the demonstration rather than trying to guess the right answer to please the teacher. 'Right answerism' (Holt, 1964) is a major hurdle to be overcome, as Dreyfuss and Jungwirth (1989) found: students whom they observed readily used the word 'photosynthesis' in response to teachers' questions - despite having little or no coherent understanding of plant nutrition. If the emphasis in class is on expressing and considering ideas, students' sense of self worth is likely to grow and their energy may shift away from closing in on the right answer or switching off their thinking. The teacher may be able to connect directly with some of the students' predictions by testing them in the demonstration, thereby providing further affirmation that the predictions are taken seriously.

In summary, used in this way *P engages learners and informs the teacher.*

Explain

We don't want students to guess or opt out of taking part. Our experience is that learners of all ages have personal theories about why things happen and about what they expect to happen. Expecting them to explain their thinking behind their predictions encourages them to engage with the demonstration, especially if they know not only that this will be expected but that they may be called to account. We want to encourage tentative, imaginative thinking, rather than right answerism, so the premium in the E phase is on the process of thinking, not on the conclusions. A student who says, 'I think after you burn iron wool it will turn into a powder and be really light,' is not right but at this stage that isn't the issue. What matters is that (i) the student is engaged and (ii) the teacher has an insight into the student's thinking. To illustrate the importance of the second point consider a student's prediction that ammeters connected on either side of a bulb in a circuit will show similar readings. This is correct. The teacher knows that any slight difference will arise from the calibration of the meters. But now let's ask the student to explain her/his reasoning: 'It's because the meters aren't sensitive enough to show the current used up by the bulb.' This changes matters! The Explain phase has revealed to the teacher that the student holds the common non-scientific conception that current gets used up by bulbs. Inclusion of the Explain phase in PEOR provides the teacher with diagnostic information about the students' ideas and takes seriously Piaget's recommendation that if one wants to find out about people's thinking one should not be content with eliciting their judgments but should seek their *justifications* for their judgments. Informed by diagnostic information from the E-phase, the teacher is in a position to make decisions about what questions to ask and what guidance to give during the following parts of the activity.

The safest classroom context, psychologically speaking, for trying out ideas is discussion with one or two peers, rather than answering to the teacher in front of the class. Because of this, E is initially carried out in small groups, after which the views of one or two groups may be elicited by the teacher for the class to hear. By circulating during the group discussion, the teacher may be able to select groups with divergent views for reporting back to the class.

In summary, *E encourages thinking about the science and informs the teacher about the students' pre-teaching conceptions.*

Observe

The trap for the teacher in the observation phase is that what is obvious to the teacher may not be so to students. One of us recalls using digital ammeters in a demonstration leading towards the idea of conservation of current in a series circuit. The meter readings were 453mA and 452mA, which from the teacher's viewpoint was consistent with Kirchhoff's current law. It later emerged, however, that for some students this was confirmation that current does indeed get 'used up' in circuits! A teacher in the New Zealand based Learning in Science Project commented, 'They focus on things I would never dream of looking at, even' (Osborne and Freyberg, 1985, p15). We could amend this in the context of demonstrations to 'They *see* things.....'. To help avoid this trap in PEOR the teacher can ask lots of attention-orienting, or Socratic questions. We usually specify that these are for discussion by students with their immediate neighbours, which is both safe and non-disruptive to the flow of the demonstration. As earlier, the questions target thinking, in this case about concrete observations and their implications. Observation offers the opportunity for concrete perceptual experiences as opposed to abstractions. Why is this significant in learning? Here we can draw on the constructivist insight that *plausibility* from the learner's perspective is highly significant. Teachers are all too well aware that they can provide what seem to be cast iron arguments in support of a scientific position yet some learners just don't 'get it', because it doesn't make sense to them. For instance, to many people, adults as well as children, plants *must* take in food through their roots and electricity *must* get used up in circuits. Science demonstrations can have a high impact in terms of plausibility because of a common human propensity: we tend to believe what we see first hand. For example, if a teacher only tells students that when iron wool is burnt to a powder the powder is heavier than the iron wool, many will be unpersuaded. If they *see* the scales tipping for themselves, some will pause for thought.

In summary, *O provides concrete, plausible perceptual experiences.*

React and Revisit: Rethink or Reinforce

By the end of the observing some students will have found that their predictions fitted with what they observed and others will have experienced a misfit. The R part of PEOR asks students to react to the observation by revisiting their predictions and explanations and discussing in small groups how they feel about them now: would they like to stick with them or update them? This process is intended to help students to rethink their ideas about science or, if their ideas fitted, to reinforce them and to use them to peer teach others. The R part makes use of the insight that languaging is a process of creative commitment to a belief position and that a peer group is a testing ground for the belief.

In summary, *R gives learners the opportunity to test, change or reinforce new ideas.*

In the account above we have stressed issues related to learning; for instance: small group discussion for safe languaging of tentative ideas and for addressing differences, prediction for learner engagement, explanation to promote high-level thinking as opposed to guessing, peer teaching to reinforce some ideas and challenge others. For us this practical and theoretical focus on *learning* is what makes PEOR a pedagogic step forward from POE.

When making use of PEOR there is a strong argument for using slightly novel or unusual demonstrations so that the students' experience is 'authentic'. The use of novelty brings with it the elements of surprise and curiosity and at the same time it challenges students to apply their ideas to new situations. If the PEOR presented is a traditional classroom demonstration or one commonly found in books the exercise may prove to be an anticlimax and one that will not motivate students to participate. In comparing POE with PEOR, one can argue that a PEOR sequence has a learning focus that is nourished by curiosity. This curiosity stimulates engagement throughout the whole sequence and hence students are active participants throughout the exercise. In our experience PEOR can be used fruitfully with learners of any age and level. In the second part of this paper we illustrate the use of PEOR in the context of initial teacher education.

Field Theory and Floating Magnets' Experiment

As part of our current research, PEORs were used with undergraduate science student teachers participating in a course on 'Field Theory'. At the start of this course, students would benefit from knowing about non-contact forces, 'action at a distance' effects and Newton's second and third laws of motion as these are considered to be basic building blocks of this theory. In the first lesson of the course, students were encouraged to discuss these ideas using the 'floating magnets' experiment. This experiment involves dropping a ring magnet onto another ring magnet placed at the bottom of a retort stand set up as shown in Figure 1. Students are asked to predict and explain the subsequent motion of the second ring magnet as it approaches the first magnet. When magnets approach each other, their like poles face each other as shown in Figure 2.

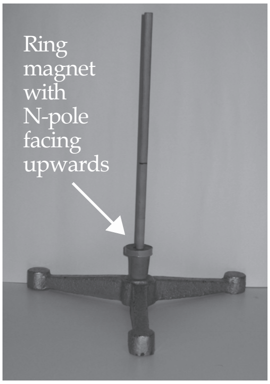

Figure 1. Initial position of the first ring magnet.

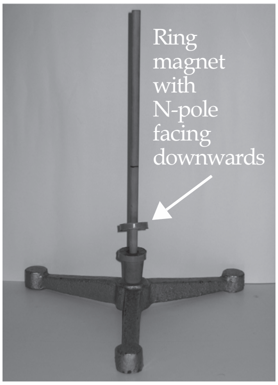

Figure 2. Final position of second ring magnet after it is dropped.

It is useful for the teacher to decide what he or she would consider a good prediction and explanation for the level of the class being taught. This is known as the 'target response'. The target response for the class in the above example is shown in the appendix.

The analysis of the students' responses to this PEOR indicated how well students grasped these ideas from their past course work and what conceptual understanding students hold about them. It also served to diagnose the type of support needed when students participate in the course on 'Field Theory'. Last but not least the students' affective reaction to giving predictions and explanations in physics lessons was monitored and investigated.

Context of Study

The PEOR exercise was conducted with a group of twenty-five B.Ed. students studying at a University in Malta. The group was made up of sixteen women and nine men. The average age of the students in this group was 18 years as most of them had just left sixth form. The group also included two mature students each about 25 years old. In their B.Ed. course these students opted for a specialisation in science. PEOR was featured in a unit on 'Field Theory'. The unit consisted of seven, two-hour sessions and included an overview of gravitational, electric, and magnetic fields. The level of the course content corresponds to work covered at advanced matriculation level. Before introducing PEOR, students discussed forces and this led to classifying contact and non-contact forces.

Analysis of Students' Responses to PEOR - Demonstration 1

When using students quotes to illustrate affective reactions, pseudonyms have been used.

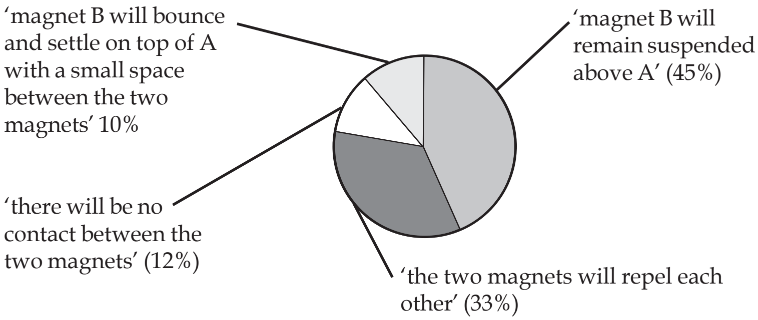

Figure 3. Students' predictions.

Prediction Phase

The main predictions given by the students can be summarised in two statements: (i) 'magnet B will remain suspended above A' and (ii) 'the two magnets will repel each other'. Other predictions that were less frequently stated were the possibility that 'magnet B will bounce and settle on top of A with a small space between the two magnets' and that 'there will be no contact between the two magnets'. Some students made predictions that included more than one of the above statements. The percentages presented in Figure 3 refer to the number of times a statement surfaced in relation to the total number of statements presented. This will apply to all percentage calculations reported here.

Although the 'floating magnets' experiment was not one commonly found in schools the students could apply their background knowledge on magnetism to this specific case. The first prediction seems to follow from the students' experiences when handling magnets in school.

Explanation Phase

The two main explanations put forward here were 'the magnets will repel each other as same poles are facing each other' and 'the fields are repelling each other'. In this phase some students simply applied the fact that 'like poles repel' to explain the subsequent motion of the magnets while others preferred to consider fields in their explanation. These latter ideas were rather hazy, as these statements indicate: 'the fields are repelling each other' and 'the field in between is zero'. A number of students used statements that considered ideas such as: electric field, gravitational PE, and charges and forces that repel each other, to explain the prediction. These were vague explanations and were gathered under the title 'others' (Figure 4).

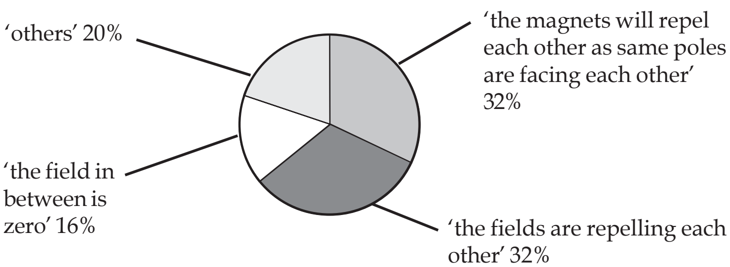

Figure 4. Students' responses for 1st explanation.

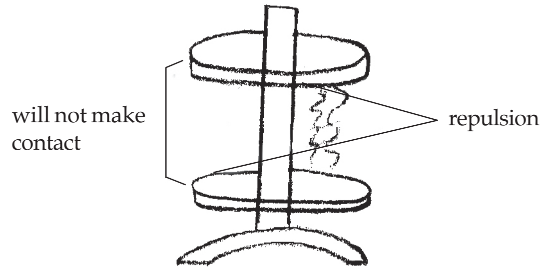

Figure 5. Student's diagram showing repulsion of magnets.

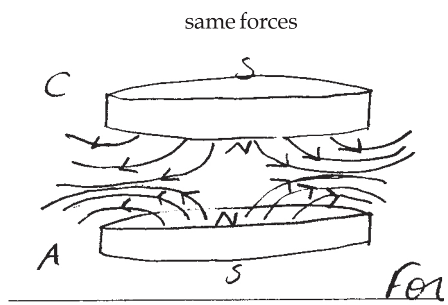

Figure 6. Student's diagram showing magnetic fields.

In the space for the diagram, three students left this empty, while ten redrew the diagram with the second magnet in its final position and labelled the region where repulsion occurred (e.g. Figure 5). The remaining twelve opted to draw the magnetic field around the magnets (e.g. Figure 6).

Observation Phase

In these observations, most students gave detailed descriptions. They mentioned the fact that the falling magnet oscillated up and down before settling and some stated how the distance between the magnets changed. Others gave a rough estimate of this distance once the motion stopped. This part of the exercise did not seem to pose a real challenge to the students.

Reinforce/Rethink Phase

The main ideas that surfaced in the rethinking/reinforcement process were that most students had 'not predicted that magnet B would hit magnet A and then move away from it' or that 'the magnets would bounce up and down'. Once students noted this, they tried to rethink their position and explain the observation using unbalanced forces. A typical statement was 'In my prediction I did not mention that there will be bouncing. I think that the bouncing makes sense until the forces between the magnets cancel each other out' (Dora). This rethinking shows development in understanding but we judge it to be incomplete at this level of study as the students did not specify the types of forces acting on each magnet.

Demonstration 2: A Second Cycle of PEOR

After the four phases of demonstration 1, students were taken through a second PEOR cycle. This time, a third magnet was dropped onto the first two magnets.

Prediction Phase

A number of students included in their prediction that 'there will be bouncing between the magnets until equilibrium is reached', while others stated that 'the third magnet will remain suspended above the second magnet'. A few mentioned that 'repulsion occurs between the magnets' (Figure 7).

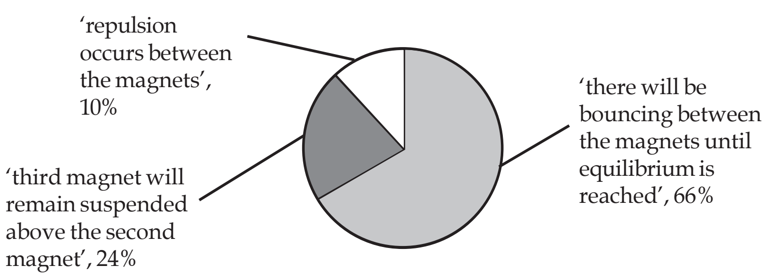

Figure 7. Students' responses for 2nd prediction.

Explanation Phase

In this case, 12 of 25 students stated that two types of forces acted on the magnets. Reference was made to the magnetic force of repulsion and the gravitational force.

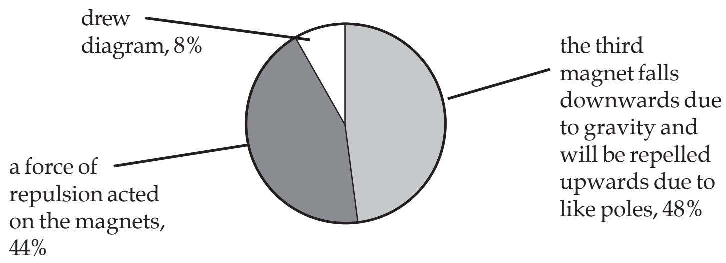

Figure 8. Students' responses for 2nd explanation.

The combined effect of these two forces was also discussed by the students. As in demonstration 1 these forces were not always linked to a particular body hence the explanations presented were vague. Eleven students focused on the magnetic force that resulted between the poles of the magnets, while the remaining two students opted to use a diagram to explain how these forces act.

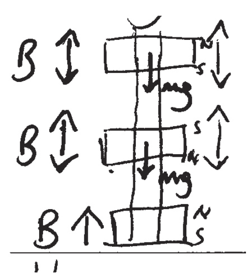

Figure 9. Students' diagram showing repulsion of magnets.

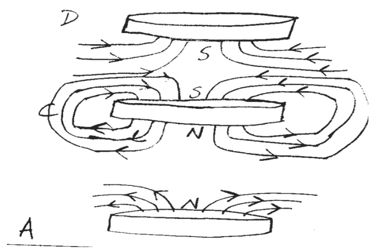

Figure 10. Students' diagram showing magnetic fields.

The diagrams drawn by 15 students were again a reproduction of the set up, this time with three magnets instead of two [e.g. Figure 9]. The labelling indicated the poles, the region where different forces occurred and the final distances between the magnets. The remaining ten students again opted to make use of fields to explain the resulting action of the magnets [e.g. Figure 10].

Observation Phase

In these observations, most students gave adequately detailed descriptions.

Reinforce/Rethink Phase

Students found it difficult to give a full description of this more complex three body system. Eight students just left out the answer to this question, possibly indicating either apathy towards what they saw as 'déjà vu' (first Rethinking phase) or that it proved too baffling to tackle. Ten of 25 students gave descriptive statements with no apparent rethinking. The remaining seven students tried to explain how the size of the resultant force on each of the magnets varied as magnet C fell down. They did not find this easy, as this typical response indicates: 'the second magnet has an array of forces acting on it, the first magnet is pushing it downwards along with gravity, so the second magnet moves downwards until an equilibrium is reached for equal separation' (Rona).

Diagnostic Analysis of Student Responses

In this section some frequently occurring students' responses from the field data will be analysed for their physics content.

1. In the first explanation phase, most students mentioned the repulsive non-contact force resulting from approaching 'like' poles, but did not include the gravitational force acting on the magnet as it moved down the rod. Hence students did not consider the resultant force acting on the magnet as one made up of magnetic and gravitational forces and provided an incomplete argument.
2. A feature that surfaced in the students' responses to the first prediction, explanation and observation was that although non-contact forces were mentioned, students did not state on which bodies the forces were acting. When the forces acting on a particular body are not specified, one cannot apply Newton's third law of motion to deduce the resultant force acting on the body, nor Newton's second law to indicate the type of motion the body would exhibit. This omission provided a source of vagueness when trying to determine the type of motion the falling magnet will follow. This latter fact links with a reflection made by Poon (2006) on Newton's third law when he stated that "Overall, it seems that, for the student, the term 'interaction' in a two-body process is just a vague reference to the aggregate of all the whole-body motions and the whole-body forces that are hypothesized for the given event" (p.244). This seems to be the case for many of the explanations offered by our participants.
3. In most phases, when describing the motion of magnets, no indication of a position and time were given when a particular type of motion such as deceleration would occur. This resulted in the description for the motion of the falling magnet being hazy. Ignoring these two physical quantities contributes to the vagueness of the answers given and to argumentation that would be considered inadequate if it were given at the end of this study module.
4. The response required for the second explanation is more complex than the first as it involves three bodies and the forces acting on them. In this explanation, one typical response was: 'The third magnet falls downwards due to gravity and will be repelled upwards due to like poles'. In this response, the students included the gravitational force and hence could consider a resultant force. As the students' focus was mainly on the falling magnet, an incomplete picture of the situation was given, as Newton's laws were applied only to this body.
5. Again, in the second explanation no reference is made to a particular

region or time frame when repulsion or attraction would occur. The conclusion about the resulting distances holds only for the end of the motion i.e. one point in time and one position of the fall. Again ignoring these two physical quantities gives rise to lack of clarity in the arguments presented.

At the start of the lesson prior to the PEOR activities, contact/non-contact forces were discussed and examples of such forces were elicited. The idea of 'action at a distance' was also discussed during this introduction. Students knew about non-contact forces but few of them had heard of the 'action at a distance' effect. From their responses it appeared that they understood the meaning of this phrase only in specific contexts such as the gravitational attraction between the earth and the moon. We anticipated that as the students were presented with these ideas at the start of the lesson they might make use of them in the first PEOR session. The PEOR session was intended to provide a means of getting students to think about non-contact forces, the 'action at a distance' effect of forces and application of Newton's 2^{nd} and 3^{rd} laws of motion to explain the resultant motion of a body in an unusual setting.

The fact that the term 'action at a distance' was never referred to by students in the PEOR sessions, especially in their explanations, suggests that they found it difficult to apply the term to an unusual context. The exercise indicated that students were not used to referring to such a term when explaining non-contact forces and the majority seemed to think that explaining non-contact forces using just the concept of 'force' was enough. This latter fact led to responses that omitted considering the body on which the force is acting and hence produced problems when considering the type of motion a body would exhibit.

It seems that to date, these students' ideas of 'non-contact forces', 'action at a distance' and Newton's third law are disjointed and superficial. The fact that non-contact forces and 'action at a distance' effects were milestones in field theory and that Newton's laws are essential for the study of bodies in fields implies that these need to be well understood if students are to grasp well the evolution of ideas in this area.

Affective Responses to PEORs

As our student participants were completely new to PEOR we anticipated that they would feel apprehensive about predicting the outcome of an experiment and then explaining why they thought that this outcome would result. To monitor the affective impact of the PEOR sessions, the verbal and non-verbal cues that surfaced in the class during the exercise were closely observed. In the event our concern turned out to be ungrounded as most students took to PEORs with no apparent difficulty. With some relief we recorded in our autobiographical log dated 14/03/07 - 'As opposed to past experiences there was no air of apprehension or insecurity in the classroom when the students were presented with PEORs'.

We generated feedback about the students' affective reactions to this exercise through three main sources – 1) an audio recording of the lesson containing the PEORs, (2) group interviews and (3) participant reflection sheets about PEORs. The impression we formed from listening back to an audio recording of the PEOR session was that the students were deeply engaged in the activity. The PEOR session took about ½ an hour of the 2hr lesson and during this time the students' behaviour was either one of (1) productive reflection - here students were either actively engaged in writing their responses and in brief moments of consultation with peers or (2) classroom discourse - here students were actively engaged in arguments about what they wrote and why they did so.

The feedback obtained from the group interviews and the participant reflection sheets was also positive: nearly all the students commented that 'they learned a lot from PEORs and they enjoyed doing them'. The two aspects of PEORs that recurred in students' feedback were (1) the predicting and (2) the sharing of ideas in class discussion. These issues surfaced in all of the group interviews and in seventeen of the twenty-five students' reflection sheets. The following comments represent what many students said about these two aspects: ". . . the prediction part helped me a lot to reflect and think before I reach a conclusion. Being given the chance to think and express one's thoughts is a very important learning process" [Dora]; "… sharing our observations made us confront our ideas with ideas others had and while trying to prove our points we learned things from one another" [Dave].

Other comments that add to the account of participants' feelings were "… predicting what would happen, was a bit uncomfortable, this is because we had to write it down on the sheet knowing that they are going to be seen individually by the lecturer." [Tina] and "… in the group everyone was allowed to give in their ideas freely. Even when I made a mistake the tutor let me express my ideas and challenged the others to think on what I was saying, so as to come up with a better explanation" [Jane]

Conclusions - Some Pedagogic Insights

Two main points of pedagogy emerged for us from the use of PEORs reported above. The first is that the students' disjointed knowledge structure and the lack of linkage between non-contact forces, 'action at a distance' and Newton's second and third law needed to be addressed with some form of bridging processes. Two measures were included to address this. These were: (1) The sequence of PEORs was extended by dropping a fourth and a fifth magnet. In each case, spoken predictions, explanations, observations and rethinking/reinforcements were made. As a final step, students were asked to predict what would be observed had the top magnet been pushed down slightly. (2) Presenting students with a variety of different contexts where their ideas can be applied.

The second conclusion relates to the students' and the teacher's affective responses to PEOR. We would argue that the affective impact of a pedagogic strategy is as important an educational consideration as its coherence in terms of the rationality of the discipline. This is because while the rationality of the approach may be valued by teachers it may go unnoticed by many students. The affective impact, on the other hand, is the key to engagement, which in turn opens the door to learning. Our PEOR experience indicates that avoiding unnecessary emphasis on right and wrong answers encourages learning. When one is working with students and student teachers this dimension needs to be worked at and brought out so that they come to construct a climate of trust in which uncertainties and gaps in understanding can be expressed and opened up to the influence of new ideas. This was aptly described by a student who said in one of the reflection sheets – "I was never ridiculed or demoralised but rather encouraged to move on" [Jane]. Such a positive climate needs to be part of the learning environment as it is from this that meaningful learning grows.

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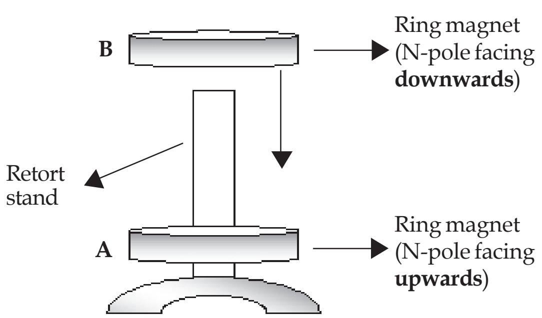
Appendix

Target Responses

A 'target response' is a response that a teacher would be pleased to receive from a student; it would indicate that the student's understanding, at the level of teaching concerned, is good.

Demonstration 1

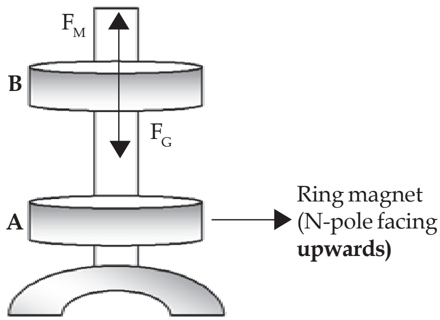
The set up presented shows a retort stand and a ring magnet with the N-pole facing upwards.



Predict what you think will happen if a second ring magnet is introduced at B and released with the N-pole facing downwards.

Magnet B will fall towards magnet A and as it approaches A, magnet B will slow down and stop momentarily. B will then start to oscillate up and down until it stops and settles down a short distance above A.

Explain the above prediction.



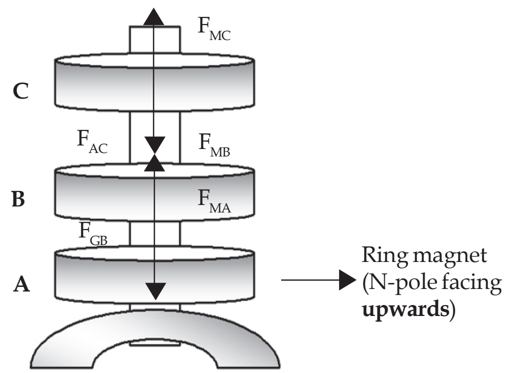
When the magnet is released it will accelerate downwards because of the pull of gravity F_G. As it approaches A it slows down because another force comes into play i.e. the magnetic force of repulsion which increases as B approaches A. This magnetic force F_M will eventually be equal but opposite to F_G and cause B to stop accelerating. As magnet B continues approaching A, $F_G < F_M$ and a resultant net upward force will accelerate the magnet B upwards. Magnet B will then move up and down, as an unbalanced force is produced from the resultant of F_G & F_M. This force acts on B but varies in size and direction. The amplitude of B's oscillations diminishes with time because of the frictional force that results between the rod and the magnet. B will eventually settle down at a distance away from A where $F_G = F_M$.

Demonstration 2

Predict what you think will happen if a third ring magnet is introduced above B and released with the S-pole facing downwards.

When the magnet C is released it will accelerate downwards. As magnet C approaches B it will slow down at the same time pushing magnet B slightly downwards. Both magnets B and C will then oscillate up and down until eventually they come to rest. B will now be closer to A than it was before. The distance BC will be greater than AB.

Explain the above prediction.



Magnet C will accelerate downwards towards magnet B as the gravitational force F_{CG} acts on it. As it approaches B, magnet C will exert a force of repulsion F_{MB} on B and push it downwards. At the same time magnet B exerts an upward force of repulsion F_{MC} on C so that this slows down. B is also repelled upwards by A with the magnetic force F_{MA} and hence it is slowed down and stops moving downwards. Besides these forces that interact on B and C there are the gravitational forces that constantly act downwards. The system of unbalanced forces that results will cause C and B to oscillate up and down until the resultant force acting on each becomes and remains zero. When this happens, B and C stop moving. B is now closer to A than it was before C was introduced, because C exerts a downward force on B.