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# Peer instruction: a case study for an introductory magnetism course

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**Abstract**

Peer instruction (PI) has been introduced as a collaborative learning strategy for the introductory physics course for engineering students at Ghent University and in this paper results for the magnetism part are reported. Using the magnetism concept inventory, a test instrument comparable to the better known force concept inventory, the positive impact of PI has been demonstrated by comparing two similar student populations and measuring the Hake gain factor. Special attention has been paid to the enhancement of the traditional lecture demonstrations by PI and a number of worked out examples are given. The framework of Vygotsky's zone of proximal development is offered as a pedagogical explanation for the effectiveness of PI.

## 1. Introducing peer instruction

Over the last decade many attempts have been made at improving the effectiveness of the introductory physics course at university level. While in most cases extensive use has been made of the technological advancements made possible by the general introduction of the computer, one of the more successful innovations is the 'low tech'—hence low cost—peer instruction (PI) technique. Originally conceived and promoted for physics by Mazur at Harvard University [1, 2], the use of PI has since been successfully extended to chemistry, astronomy and biology [3]. In the space of a few years, PI has established itself as an important interactive teaching style, inducing collaborative learning, and is perfectly suited for any classroom setting, including the large classrooms often found at university level introductory science courses.

An effective use of PI requires that students read the appropriate assigned material before the lecture. Lecturing then consists of short 10–15 min explanations by the lecturer, followed by some well prepared questions. These questions intend to assess the understanding of the basic concepts. Students have to come up with an answer within the specified time of a few minutes. The answers are polled and, if sufficiently divergent, students are given an opportunity to discuss their reasoning with dissenting neighbours and to eventually change their minds. Ideally a consensus should be reached by some 90% of the students. This peer-to-peer interaction requires active involvement of the students, thereby greatly enhancing the quality of their learning. It is quite essential that the lecturer can walk through the classroom while observing the students and listening to the arguments, occasionally steering the discussion in the right direction. To get some appreciation of the distribution of the answers the lecturer can simply ask for a show of hands or use a flashcard system. This works for classes of almost any size as the exact number of correct answers is not really important. If the number of initially correct answers is too high PI becomes rather pointless as students get bored or sidetracked; if it is too low the question was probably too tough to begin with. One quickly gets a feeling for the 'right degree of complexity' to obtain optimal interaction. At Ghent University we mostly use the simple (anonymous) show of hands, occasionally complemented by a pre-printed (non-anonymous) paper form. The paper form tends to take more time and some students consider it intrusive; we used it mainly to collect data for evaluating the effectiveness of PI.

Asking the right questions is crucial for PI. Eric Mazur coined the term *ConcepTest* specifically for this kind of problem. A good number of appropriate ones covering the traditional introductory physics course are available in [1] and many more can be found on Harvard's 'Galileo' website [3].

Evaluating the impact of any educational innovation is notoriously difficult. Traditional examinations do not provide an adequate test for the impact of PI. As Mazur has already remarked, before using PI, his students were perfectly able to solve rather intricate examination problems using 'the right formulae'. The real problem is to recognize whether students grasp the core concepts. Multiple choice tests such as the force concept inventory (FCI) [4] and the mechanics baseline test (MBT) [5] have been shown in large scale experiments to be well adapted to measure this specific aspect for introductory mechanics courses [6]. As PI aims specifically at improving the student's basic understanding of physical phenomena, the FCI test can be and has been used to evaluate the success of PI in the field of mechanics. For electricity and magnetism, similar instruments have been developed by Maloney *et al* [7]: the electricity concept inventory (ECI) and the magnetism concept inventory (MCI). Although these tests have as yet failed to gain the widespread acceptance enjoyed by the FCI and MBT they have nevertheless proven to be useful for our purpose.

## 2. PI at Ghent University: the context

Recently a unique opportunity for testing the efficiency of PI presented itself at Ghent University. Due to a curriculum change in the Faculty of Engineering, an identical course of magnetism had to be taught to two very similar student populations: approximately 200 second semester engineering students (group I) and 200 third semester engineering students (group II). Both populations had an identical physics background and similar mathematical skills. While there were two different lecturers, both used the same course text, the same overhead transparencies and the same demonstration materials. Both had been teaching this course for several years in the traditional way. The physics department decided to continue traditional teaching for group I but to introduce PI for group II and to compare the performance of both groups using a pre-test and post-test based on the MCI. Due to Faculty of Engineering regulations, participation in this test could not be made compulsory and in the end 150 students from group I took both the pre-test and post-test part, as well as 130 from group II.

While most results reported in this paper have been obtained with the aforementioned specific student groups, the PI format has since been used with many more groups. In our experience, some groups do not readily accept this 'unfamiliar' format and find it far more convenient to simply sit down and listen (or not) to traditional lecturing. Giving a small credit for participating did not markedly affect the students' general attitude towards PI. We therefore endeavour to convince the students that PI really benefits them. During the first few lectures we only use 'easy' ConcepTest questions, gradually progressing to some more difficult ones.

These questions are similar to the ones found in [1, 3]; we will therefore not elaborate on them and instead focus on PI-enhanced lecture demonstrations which we consider to be a crucial aspect of our lecturing. We found these demonstrations excellent occasions to win over the students for PI. Prior to the formal introduction of PI, lecture demonstrations had already been supported by concept-type questions, but few students—usually the same ones throughout the semester—actively participated. Because the demonstrations themselves have not changed with the introduction of PI they provide a reliable point of comparison. Moreover, with the assistance of PI even quite intricate experiments become pedagogically feasible as will be borne out by one of the examples. We should also point out that no description of the lecture demonstrations is made available beforehand.

## 3. PI-enhanced lecture demonstrations: some examples

### 3.1. Introduction to the Lorentz force

*The context.* Students are familiar with static electric and magnetic fields and with electric forces on charged particles. They have not yet been introduced to the Lorentz force. The lecture starts with the following demonstration. In a cylindrical glass container (diameter 10 cm, height 3 cm) filled with diluted sulfuric acid two electrodes (height 2 cm, diameter respectively 1 and 10 cm) are concentrically arranged. A thin slice of cork floats freely on top of the sulfuric acid. The container is placed on top of a pole piece of a powerful electromagnet and a DC power supply (12 V, 10 A) can be connected to the electrodes.

*Comments.* Students should know that the $E$-field is radially symmetrical while the $B$-lines are for all practical purposes perpendicular to the surface of the liquid. The geometry of the field lines is revealed by asking short PI format questions. The answers confirm the familiarity of most students with these concepts.

The following experiments are subsequently performed.

- A current $I_E$ is established between the electrodes. The electrolytic action is clearly visible as bubbles ($H_2$ gas) appear at the anode. The cork may be slightly disturbed by these bubbles and generally tends to stick to the cathode. The direction of the current is reversed a few times to establish this more clearly.
- The current $I_E$ is switched off and the electromagnet is switched on, creating a $B$-field. The magnitude of $B$ can be varied by changing $I_B$ but even at maximum amplitude the cork appears to be undisturbed.
- Finally $I_E$ and $I_B$ are switched on simultaneously. The cork starts moving in circles, slowly at first, then picking up speed. The final speed clearly depends on both $I_B$ and $I_E$. The rotational sense of the cork reverses when either $I_E$ or $I_B$ is reversed.

Without any further explanation students are asked the following questions.

- Why would the cork move when the electric field is switched on?
  Students are familiar with electrolysis and we expect them to find out that both positive $H^+$ and negative $SO_4^{2-}$ ions move radially, whereby collisions with the much heavier negative ions push the cork towards the anode.
- What brings about the circular path of the cork?
  We expect the students to observe that electric and magnetic fields are simultaneously required for any (circular) motion to occur. Having established that the path of the cork actually reflects the path of the negative ions, they should now work out that charged particles move perpendicularly to a $B$-field, but only when they are already in motion. As our students are familiar with the use of the cross product, they will hopefully come up with the suggestion

$$\bar{F} \propto \bar{E} \times \bar{B}$$

or even better

$$\bar{F} \propto \bar{v} \times \bar{B}.$$

*Comments.* Without the assistance of PI, few students can adequately explain this demonstration. With the step-by-step approach and the benefit of PI, most of them get a good grasp of the Lorentz force principle and subsequently use it effortlessly. Perhaps even more important: examples such as this convince the more insecure students that they really can understand such physical phenomena, and that PI helps them to do so.

### 3.2. The falling magnet

*The context.* Students have studied permanent magnets. They are shown two cylindrical objects of roughly 2 cm diameter and 1 cm height. These cylinders look and feel identical, except that one is painted white and the other green. The lecturer takes a 3 m long copper tube into which the cylinders can comfortably slide. The tube is held vertically and the white cylinder is dropped from the top. As expected, it falls (almost) freely and emerges at the bottom end with reasonably high speed after about 1 s. However, when the green cylinder is dropped it takes a spectacular 12 s to travel the length of the tube and it hits the floor at much lower speed. To allow students in the front rows to watch the cylinders' motion and verify that no trickery is involved the copper tube has a 0.5 cm wide slit over the whole length. In this way students are able to observe that the motion of the green cylinder is quite complicated: it visibly speeds up and then slows down several times while at the same time tumbling and spinning around.

*Comments.* The white cylinder is manufactured in plain steel while the green one is a permanent magnet, in our case a strong Nd–Fe–B magnet[3]. As the magnet falls, eddy currents are produced throughout the conducting copper tube and by Lenz's law this slows down the magnet until it comes almost to a standstill and gravity takes over again. When in pre-PI times students were urged to offer an explanation, 'magnetism' was mentioned, but certainly not unanimously, although as the lecture was about magnetism this should have been fairly straightforward. With PI, agreement on 'magnetism' as the cause is quickly reached. When students subsequently form discussion groups in order to determine the exact physical mechanism, many come up with the right answer. This contrasts sharply with non-PI students who almost never find the eddy current mechanism on their own.

The impact of PI has been measured directly by giving the following examination question: 'You have two similar looking small objects and you are told that one of them is a permanent magnet while the other is non-magnetic. Identify the magnet without using any metering instruments. You may ask for one more object to help you out'. Without PI some 50% of the answers are acceptable, and this number rises to 85% with PI.

As an added bonus, the fact that some students stick to physically spoken weird explanations (e.g. 'special magnetic' copper) for such a simple experiment is taken as an opportunity to discuss 'hands on' what constitutes experimental proof and good science, and how pseudo-scientific explanations can be uncovered.

### 3.3. A more intricate experiment: hysteresis in ferromagnetics and the Barkhausen effect

*The context.* Students have studied ferromagnetic materials and the difference between hysteresis loops for hard and soft ferromagnetics has been demonstrated. The general shape of such loops has been explained invoking the Weiss domain model. Subsequently the following experiment is performed.

[3] Because of the brittleness of ceramic magnets, some care has to be taken to let it land on a soft surface and not on a tiled floor.

A 10 cm long coil is wound upon a hollow plastic core holding an iron rod, diameter 1 cm. The coil is connected to an audio frequency amplifier, the output of which feeds a loudspeaker. When a strong AlNiCo bar magnet is moved either towards or away from the iron bar the loudspeaker produces a hissing noise. When the experiment is repeated with a brass rod substituted for the iron rod no noise is produced under any circumstance. Students quickly realize a ferromagnetic core is crucial for the noise. Students are told how this Barkhausen effect can be explained: each time a Weiss domain boundary in the iron rod shifts or flips over, the magnetic flux through the coil changes. Students are now asked why this changing flux would produce such a noise.

*Comments.* Students are supposed to remember Faraday's law: a changing flux $\Delta\Phi$ gives rise to an emf induced in the coil and—provided the frequencies are in the audio range—this produces an observable sound.

In a second series of experiments we demonstrate that the noise grows louder when the motion of the magnet is faster. Quickly flipping over the bar magnet corresponds to the loudest noise. Students are asked to explain this.

*Comments.* It takes quite some peer-to-peer interaction as well as coaching from the lecturer before a reasonable consensus is established: fast motion creates a higher induced emf; the highest emf is observed when the magnet is flipped over while being very close to the iron bar so that a complete hysteresis loop exhibiting saturation magnetization is obtained.

When this explanation has been accepted and understood, students are asked to fill in a form with the following questions.

- Has this demonstration contributed to your understanding of ferromagnetism?
- How do you rate your understanding of ferromagnetism on a scale of 'very confident, somewhat confident, not confident at all'?

After collecting the answers, a nickel rod is substituted for the iron rod and the demonstration is repeated. The results now appear to be quite complicated.

(1) When the magnet approaches the nickel rod from far away for the first time, noise is produced fairly similar to the iron rod.
(2) In contrast with the iron rod there is no noise when the magnet is subsequently removed, nor is any noise produced on a second, third etc approach.
(3) When the magnet is flipped over, the noise is clearly louder than with the iron rod.
(4) When approaching the rod with the north pole of the magnet a noise is produced and on subsequently removing it there is no noise, as observed in numbers (1) and (2). However when the magnet is turned around while being far removed from the nickel rod and subsequently approaches with the south pole facing it, a noise is observed again!

*Comments.* An adequate explanation involves good insight into the behaviour of hard (nickel) and soft (iron) magnetic materials. Students should remember from a previous lecture that a soft ferromagnetic such as iron produces low remanent magnetization while in a hard ferromagnetic such as nickel remanence is high. With a strong magnet sufficiently close to the rod saturation magnetization results. When the magnet is subsequently removed—whether slowly or quickly—almost no change in magnetization occurs in nickel, so few Weiss domains flip over and no noise is heard. In iron, however, a large number of domains flip over on each leg of the hysteresis loop, i.e. whether $B$ increases or decreases. This explains phenomena (1) and (2). However, when the magnet is flipped over while far away from the coil, $B$ is reversed and on subsequently approaching the nickel bar a large number of domains flip over, producing noise as demonstrated in (4). To explain (3) students should realize that flipping over the magnet, i.e. reversing $B$, produces a much more gradual change in magnetization in

**Table 1.** Students' performance on the MCI.

| | *N*<br>(participating students) | Pre-test (%) | Post-test (%) | Hake $g$-factor |
|---|---|---|---|---|
| Group I | 150 | 31 | 58 | 0.39 |
| Group II | 130 | 26 | 70 | 0.59 |
| Physics majors | 39 | 35 | 56 | 0.32 |

iron as compared to nickel. In the nickel rod $\Delta\Phi$ is therefore larger, the corresponding emf is larger and consequently the noise is louder.

This demonstration comes at mid-semester, and by that time students are familiar with PI. In particular the peer-to-peer interaction has become rather efficient and they are really able to discuss these quite intricate observations. Before PI was introduced, an *ex cathedra* explanation of all the phenomena was given. At examination time, a mere 10% of the students could adequately answer questions related to this demonstration. Using PI, this rises to almost 50%. This tallies with the above-mentioned survey, where only 20% of non-PI students feel their understanding has been enhanced by the demonstration, versus 50% of the PI students. The 'confidence level' survey is always interesting: almost no students declare themselves as 'very confident' but in the PI group quite a few come up with the (almost) right explanation of the last series of experiments. Again, given the complexity of the problem even partially correct answers give students a confidence boost.

## 4. Testing student performance

To evaluate the impact of PI we used the 19-question MCI test as described in [6], adapted somewhat to reflect the high school curriculum of our students[4]. Both groups took the MCI as a pre-test at the start of the semester and as a post-test after instruction. The results are shown in table 1 as percentage scores. Following Hake we introduce the normalized gain factor $g$ defined by

$$g = \frac{\text{post} - \text{pre}}{100 - \text{pre}}$$

where 'pre' and 'post' are the pre-test and post-test percentage scores. This 'Hake $g$-factor' is a significant measure for the efficiency of instruction because it blurs out the influence of the different starting levels of the students, as it is equivalent to the maximum possible gain students can achieve. The results are summarized in table 1.

Group I, without the benefit of PI, showed an average $g = 0.39$ ($\pm 0.08$) while the PI group II showed a gain $g = 0.59$ ($\pm 0.10$). Using the FCI as a gauge, Hake reports an average gain for traditionally taught introductory mechanics courses of $g = 0.23$ while courses using various 'active engagement' instruction methods yield gains between 0.34 and 0.69, averaging $g = 0.48$. Consequently, for introductory mechanics, PI yields on average a gain improvement $\Delta g = 0.25$. For our magnetism course we obtain a similar improvement in the normalized gain of $\Delta g = 0.20$, which can be considered a clear success for PI.

The positive influence of PI is corroborated by the result obtained for physics majors, also included in table 1. Using a different textbook and with a different instructor but with traditional methodology, this reference group shows a normalized gain of $g = 0.32$, significantly below what can consistently be achieved with PI.

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[4] In Flanders, high schools are either government run or privately run. The way magnetism is introduced is quite different and we adapted some MCI questions so as not to favour any system.

## 5. Further comments

Our comparison between PI and traditional lecturing constitutes a once-only experiment made possible because of a curriculum change. It is rather improbable that another occasion will arise, at least at Ghent University, where the effectiveness of PI can be evaluated by comparing two very similar student groups. While other factors may have contributed to the different performance of both groups the results seemed nevertheless convincing to the authors and they have applied PI in subsequent years to other physics courses.

While PI does improve conceptual understanding, some—especially engineers—may argue that solving traditional numerical problems is more important. In response to that criticism we continue testing the problem solving skills of our students in the same way as before the introduction of PI. Examination results over several years indicate that these skills, if anything, have improved, and the findings of other PI users (e.g. [2]) corroborate this.

A quantitatively measurable improvement has definitely occurred for examination questions relating directly to lecture demonstrations. Prior to the use of PI, such questions scored extremely poorly. These results, in the range of 10–20% correct answers (with some exceptions, e.g. the falling magnet), could even cast some doubt on the general advisability of lecture demonstrations. Using PI enhanced demonstrations, such questions consistently score at least as well as the more traditional ones, i.e. 60–70% correct answers.

Finally, the attendance of the PI lectures is consistently greater by 10–15% compared to traditional lectures. We consider this as another indicator for the success of PI because, as Adam Smith remarked in *The Wealth of Nations* some 200 years ago, ‘No discipline is ever requisite to force attendance upon lectures which are really worth the attending, as is well known wherever any such lectures are given’ [8].

The question remains: why is PI so effective? This very important issue has, to the best of our knowledge, never been researched properly. No doubt the active involvement of students is important, but then practicals surely show still greater active involvement and they are not all that effective. The collaborative aspect is also important, but again, similar collaborative techniques have failed to improve the effectiveness of practicals. An important issue is in our opinion the confidence boosting factor of properly conducted PI. What seems a small step in the eye of the lecturer is considered a big step by many students, making them better aware of their capabilities. The lecturer, as an expert, often takes so many things for granted that students fail to see the basic concepts and resort to rote learning strategies. The knowledge of students is on a much more equal level and rote learning is of little use in their peer-to-peer discussions. In fact, it seems to us that PI fits perfectly within the framework of Vygotsky’s zone of proximal development (ZPD), especially as interpreted and moulded into means of facilitating learning by Tharp [9]. This line of reasoning could therefore establish some sound pedagogical foundations for PI.

## 6. Epilogue

PI may be low cost in money terms, but developing, testing and improving resources for PI is an ongoing effort which is very time consuming. One cannot expect that every lecturer, even when able and willing, has that much time available. The physics community would be well served by some ‘open source’ kind of programme, where all members have access to the materials developed by any one of them. Only then will the pedagogical instruments such as PI be able to contribute significantly to the whole educational community.

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