Is there a right way to teach physics?

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Background

An important development in university physics teaching in the last two decades has been the emergence of a worldwide Physics Education Research community. In physics departments at relatively large numbers of institutions throughout the world, particularly the USA and Europe, academic physicists are doing research into the difficulties associated with teaching their subject.[1] Among the many directions this research has taken is the identification of 'misconceptions' (sometimes referred to as 'alternative conceptions'). These are ideas or concepts which students have constructed for themselves, based on their own experience of the natural world, which are often in conflict with the agreed view of practicing scientists. Research has shown that these 'misconceptions' are very widely shared, very often in conflict with other concepts the student holds, and very difficult to change.

Following on from this research, as it were, a lot of work has been done to develop special diagnostic tests to uncover which, if any, of these misconceptions particular students hold. They normally consist of series of multiple choice questions, in which the 'right' answer is hidden among very tempting distracters, each one targeting one or more common misconceptions. Among the best known of these tests, in the subject area of kinematics and dynamics, are the Force Concept Inventory (FCI)[2] and the Mathematics and Physics Concept Evaluation (MCPE)[3].

This research has, in turn, prompted the development of teaching strategies which target specific classes of misconceptions - in the (understandable) belief that, if students can get the fundamental concepts 'right', they have a better chance of understanding the rest of the subject. The results of these strategies are reported in the literature, and there is coming to be a consensus within the physics education community that, for example, traditional (chalk and talk, lectures plus laboratories) teaching is relatively ineffective in changing misconceptions. On the other hand, one recent survey of over 7000 students in the USA has shown that teaching which employs interactive methods can result in significant increases in understanding (as measured by these diagnostic tests).[4]

It would seem important therefore that teachers everywhere should take these findings seriously, and, where possible, test whether the same gain in understanding can be achieved in other teaching contexts.

Interactive lecture demonstrations

Many of the new techniques just mentioned involve quite elaborate teaching materials and preparation time on the part of the teacher. In today's university climate, increasing workloads and student numbers often mean that time is just what university teachers do not have. Therefore many of these new techniques are destined to be little used. However, one particular new technique, which originated at Tufts University, Boston, involves the use of **Interactive Lecture**

Demonstrations,[5] and which is designed to be used in a traditional teaching context, that is in an ordinary lecture. They consist of a number of simple experiments which use a microcomputer to log data from a motion sensor, and to display it in graphical form on a data projector, while the instructor performs a number of simple 'experiments'. Students are told what is going to happen, and write their predictions of what the graphs will look like on specially prepared sheets. Only when they have done this and resolved by discussions among themselves any disagreements, are they shown the actual experiment and the data the computer has collected and graphed. After this, class discussion is devoted to where any incorrect predictions went wrong.

Clearly such a technique means that the instructor must follow a pretty rigidly imposed scenario. Although the demonstrations are done in an ordinary lecture setting, there is little scope for the instructor doing what he or she wants to do. Questions of 'covering the syllabus' and 'giving good sets of notes' have to take second place. Luckily there are only four one-hour sessions specified, and the instructor has the rest of the allotted periods to do what is normally considered necessary in a lecture course (and which, it will be remembered, research shows to be not very useful).

Results from this teaching technique have been reported in the literature over the last five or six years. Typical are those reported from the University of Oregon in 1996, shown in Figure 1[4]. The diagnostic instrument used was the MCPE, and student responses are reported for four groups of questions concerning Newton's Laws, though it is not particularly relevant what material the questions covered.

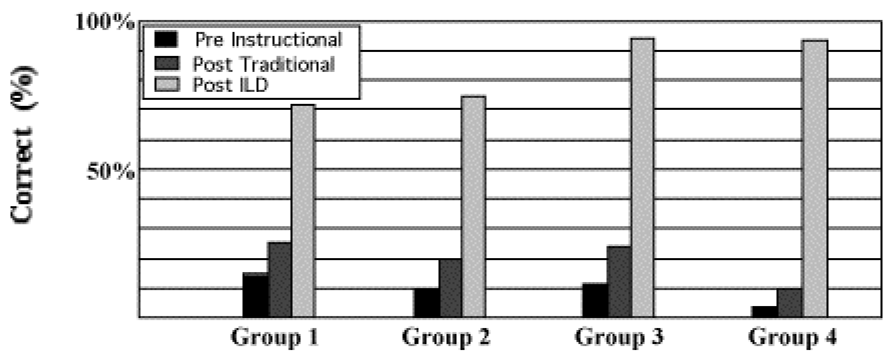

Figure 1. Showing the percentage of correct responses to questions in four groupings, as published by Thornton. Results are (1) responses from students in all classes before instruction, (2) responses after instruction from classes taught by traditional methods, and (3) responses after instruction from classes taught using ILDs. The figure is adapted from reference.

Several points will be noticed from this figure. Firstly that student 'understanding' (or whatever is being measured by these tests) is very low on entry. It must be noted that the physics course in question was calculus-based, and the students would be planning on a physics major. Some of the more prestigious universities in the USA have students who attain higher scores on entry, but nevertheless, scores similar to the above are not untypical of students just out of high school in the USA.

Secondly it will be noted that there is no very great improvement after a semester of traditional instruction. Such results are also typical of universities and colleges reported in the literature, and are part of the accepted body of evidence which suggests that traditional teaching is relatively ineffective in generating this kind of understanding.

Lastly there is the very impressive improvement in 'understanding' demonstrated by those students who were exposed to 4 one-hour sessions using the ILDs and the stipulated interactive teaching. The results reported here are not the only ones who show such improvements. Therefore this particular teaching technique seems able to claim, *prima facie*, to be one which promises that other teachers can expect similar improvement. It would obviously be important to test this expectation in another context - for example, with a class of Australian students.

Evaluating the effectiveness of ILDs

In March 1999, such a test was held with physics introductory students at The University of Sydney. The roughly 450 physics students are divided into four calculus-based classes, one at the 'Advanced' level and three at 'Regular'. Of the latter, one group was taught using ILDs, and the other two, taught by a different lecturer, were regarded as a control. The structure of the course is similar to most physics departments in the country. The areas of kinematics, force and motion, work and energy, collisions, rotational dynamics are taught over five weeks, usually by 15 one-hour lectures with a weekly tutorial and regular homework assignments. For the trial being reported, the experimental class had 11 one-hour lectures and 4 one-hour ILD sessions, but everything else was the same. All classes shared the same assignments and end-of-semester examination.

All 450 students were tested during the first lecture period, using the MPCE diagnostic test, and two weeks after the end of the module, in the seventh week of semester, all were asked to take exactly the same test again.

Results

Results of the experiment are shown in Figure 2, in which student responses are reported for ten groups of questions on that test, including the four groups singled out in Figure 1.

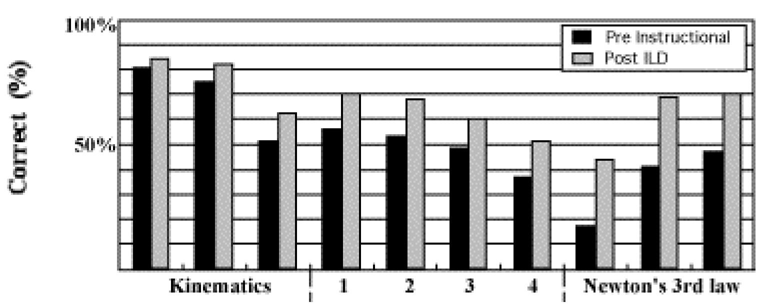

Figure 2. Showing the percentage of correct responses to questions in ten groupings, (including the four groups represented in Figure 1) as found in the current experiment.

Results are (1) responses from students in the experimental classes before instruction, and (2) responses from the same class after instruction using ILDs.

The first point to be noted is that Australian students are clearly very well prepared when they enter university. The on-entry scores are comparable with, or better than, the very best US institutions. In these times when high school teachers are being criticised, this finding deserves to be better known.

The second point, however, is less palatable. It is immediately obvious that the same gains in understanding, as were reported in the literature, did *not* occur. There was some gain, but the absolute values for the fraction of students answering the questions correctly fell far short of those in Figure 1. And the *relative gain* - the proportion of students who were unable to answer the questions before instruction, who were able to answer them after instruction - was even worse, considering that the Australian students had so much better scores on entry.

The teaching effectiveness of the ILD method, *compared with the control classes*, is shown in Figure 3, in which the *relative gain* for both groups of students is shown.

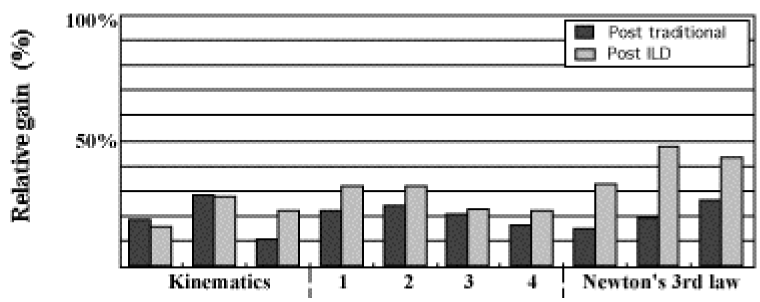

Figure 3. Showing the relative gain, as determined by post- and pre- testing (results expressed as a percentage) as a result of instruction for (1) students in the control class, taught by traditional methods, and (2) students in the current experimental class, taught using ILDs.

On the basis of this data, a case can be made that the new teaching technique is more effective than traditional methods, at least so far as student understanding (as measured by the MPCE test) is concerned. However it should be pointed out also that when comparisons were made between end-of-semester marks between experimental and control classes, no significant differences were noticed. In fairness, it should be further added that end-of-semester examinations were testing learning which took place during the whole 13 weeks of semester, not just the 5 weeks the mechanics module lasted.

Conclusions

The inescapable conclusion would seem to be that this new method of teaching, while effective in itself, does not yield the very impressive results claimed for it. There are of course many possible explanations for this. The teacher (IJ) may not have done things properly; the students may have been atypical; the testing protocols may not have been careful enough. To answer some of these, the experiment was repeated in 2000, exactly as in the previous year, but results are not yet available for analysis.

However the fact remains that the unstated hope driving the experiment in the first place was that the ILD method might have been a teaching technique that could in some sense *guarantee* student learning, given only reasonable teachers and teaching administration. The previously published results seemed to suggest that that might have been the case. We are tempted therefore to speculate on why this experiment did not come up to expectations. Three questions immediately suggest themselves.

- Is there a cultural difference between US and Australian students which would allow a particular teaching technique to be successful with one and less so with the other? If this is the case, the hope expressed above can still live. It simply remains for us to find the technique that will work for Australian students.
- Did the fact that the Australian students did so much better on entry mean that those who did *not* know the answers on entry had their own brand of particularly immovable misconceptions? Again this still allows hope. We must work hard at uncovering and eradicating these misconceptions.
- Is the whole exercise pointless? Is there no such thing as a magic bullet, no right way to teach physics (or any subject for that matter)? Many believe this to be the case, but it is a depressing conclusion to come to. It leads many university teachers to conclude that no form of teaching is better than any other. Therefore they are justified in the all-too-common strategy of ignoring what education research has to say and continuing to teach as they themselves were taught.

References

1. A comprehensive bibliography of this field can be found in: McDermott, L. C. and Redish, E. F., Resource Letter: PER-1: Physics Education Research, *Am.J.Phys*, **67**(9), 1999, 755-67.
2. Hestenes, D., Wells, M. and Swackhammer, G. (1992) The Force Concept Inventory, *Physics Teacher*, **30**, 141-158.
3. Thornton, R. K. and Sokoloff, D. R. (1998) Assessing Student Learning of Newton's Laws: The Force and Motion Conceptional Evaluation and the Evaluation of Active Learning Laboratory and Learning Curricula, *Am.J.Phys*, **66**(4), 338-352.
4. Thornton, R. K. (1997) Learning Physics Concepts in the Introductory Course, Microcomputer based labs and Interactive Lecture Demonstrations, Proc. Conf, on the Intro. Phys. Course, 69-85. NY: Wiley.
5. Thornton, R. K. and Sokoloff, D. R. (1996) Microcomputer-based Laboratory Tools, Using Interactive Lecture Demonstrations to Create an Active Learning Environment, in *The Changing Role of Physics Departments in Modern Universities,* eds E. F. Redish and J. S. Rigden, 1061-1074. American Institute of Physics.