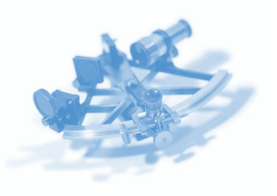

An Integrated Approach to Encourage Student-Centred Learning: a First Course in Dynamics

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Abstract
One of the most significant challenges facing Higher Education today is getting students to take responsibility for their own learning. In Science and Engineering this is complicated by the decline in the mathematical and problem solving skills of students entering university. Several techniques for addressing these issues have been applied to the Dynamics module on the first year Physics course at the University of Manchester over the last two years. These include the use of Just-in-Time Teaching, e-learning and e-assessment, interactive voting systems and peer instruction. We first encourage students to start to construct their own understanding via e-learning and then challenge their understanding during a lecture-based session using an interactive voting system. This is followed by more e-learning, which features formative e-assessment, and by a staff-supervised problem session using the Just-in-Time Teaching approach. Thus we have been able to improve student engagement with the course material and have achieved a significant improvement in examination performance. This paper will describe the implementation of the various new techniques and discuss their advantages and disadvantages.

We first encourage students to start to construct their own understanding via e-learning and then challenge their understanding during a lecture-based session using an interactive voting system.

Introduction

The School of Physics and Astronomy at the University of Manchester has a first year intake of over two hundred students. Like all sciences, we struggle with progression, which we would like to improve. One of the areas where improvement is needed most is at the interface of mathematics and physics.

All Physics students take Dynamics as a core module covering basic Newtonian Mechanics, in their first semester. Traditionally this module has suffered from mediocre student feedback and relatively poor examination results compared with other first year modules. Several initiatives have been tested over the last couple of years to improve the situation. We have aimed to get the students to engage more with the subject and to take more responsibility for their own learning. In 2006-07 we brought in Just-in-Time Teaching, e-learning and e-assessment and in 2007-08 we added peer instruction using an interactive voting system.

Initiatives in 2006-07

Just-in-Time Teaching

Just-in-Time Teaching (JiTT) is a student-led approach to teaching which was originally developed in the USA by Novak et al[1] as a collaborative project between the Physics departments of the IUPUI (Indiana University–Purdue University Indianapolis) and the US Air Force Academy. The idea of the approach is that the content of classes is decided at the last minute and is tailored to specifically address the concepts that the students have misunderstood or are having difficulty with.

When the JiTT approach is used in the USA, the students are required to do *some* preliminary self-study of new material before they attend the class. Having completed the self-study, they undertake an on-line assignment which assesses their understanding of the new material. Usually the on-line assignments focus on the concepts involved. The students submit their on-line assignments just a few hours before the class enabling the instructor to obtain an appreciation of the students' difficulties and misconceptions. He/she is then able to structure the content of his/her class according to the needs of the students. The class preparation has to be done at the last minute before the class is due to be delivered, hence the title 'Just-in-Time Teaching'.

The Just-in-Time approach was used with relatively small class sizes at IUPUI and elsewhere, whereas, as mentioned earlier, our student cohorts are in excess of two hundred. Another difference we perceived between IUPUI and our own institution was one of culture; the notion of pre-lecture study is quite alien to most UK students, so initially we adopted a slightly modified JITT approach.

Modified JiTT approach
The Dynamics lecture course runs for 11 weeks. Previously it had been delivered in a very traditional manner with two one-hour didactic lectures per week plus a one hour workshop where the students solved pre-set problems supported by a member of staff and post-graduate students. This was changed; the didactic lectures and workshop were replaced by one 'overview' lecture at the beginning of each week, followed by a Just-in-Time Response and Problem (JIRP) session at the end of the week. The overview lecture was used to 'set the scene' for the week. It was not the usual in-depth lecture but rather it was intended to give the students a brief introduction and overview of the material to be studied that week. The students were expected to follow up the overview lecture with several hours of self-study using a very comprehensive set of e-learning material provided on the university's Virtual Learning Environment (VLE), WebCT. Once they felt reasonably confident that they had understood the material, they were required to do an on-line assessment. This had to be submitted by 2.00am each Friday morning. The results of the assessment were reviewed by staff early Friday morning and preparation undertaken for the JIRP session which was held in the afternoon. The students were split into two groups for these sessions, each run by one member of staff.

The combination of the overview lecture, the on-line work and the JIRP session constituted a weekly cyclic process as depicted in Fig 1, with the normal small group (4 students) tutorials completing the loop.

E-Learning
All the material that the students were expected to learn for the Dynamics module was provided on WebCT. The lecture course was divided up into eleven topic areas corresponding to the eleven weeks of the course. For each topic area a rich suite of e-learning material was provided. This consisted of not just normal textual material but also 'talklets' and 'physlets'. Talklets[2] are small screencasts of animated PowerPoint diagrams with voice-overs. Over sixty talklets were produced and were used to explain difficult concepts or solutions to example problems. The physlets[3] are Java applets consisting of animations used to simulate concepts that it might be difficult to appreciate from other static media such as textbooks, eg the cycloid described by a point on the rim of a wheel as it rolls along the ground and the notion that its velocity is momentarily zero when it is in contact with the ground. Interactivity was also incorporated into many of the physlets.

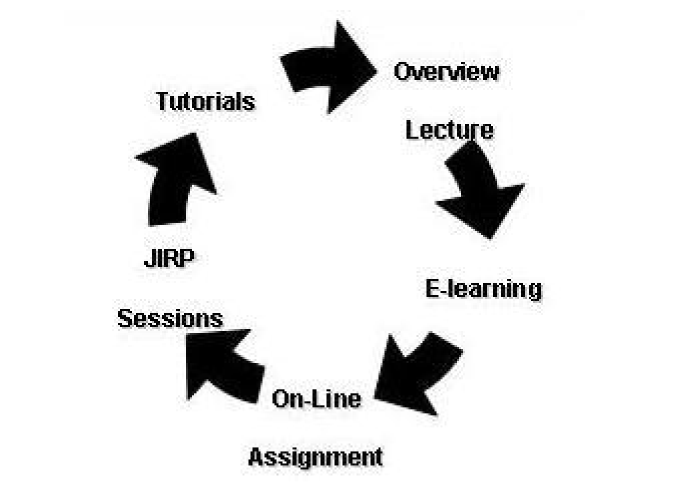

Fig 1. Weekly cyclic process for the Dynamics module

On-line Assessments
A commercial web-package called 'Mastering Physics'[4] was used for the weekly on-line assignments. 'Mastering Physics' is provided as a companion to the first years' core textbook, 'University Physics' by Young and Freedman[5], which all our first year students are required to purchase and provides them with an access code for the website. The package contains an extensive problem library organised by topic area, correlating directly with the chapters of the book. Weekly assignments were produced by selecting suitable problems from the library. Each assignment consisted of between 4-6 problems. The beauty of the package is that it provides hints for the students should they need them and tailored feedback on incorrect answers, since it has the capability to analyse algebraic answers and apply malrules (a malrule is an algorithm that gives an incorrect answer to a problem eg a differentiation where an integration is required.) The package automatically marks the assignments. Penalties for using the hints can be applied to the overall marks achieved and these can be set by the instructor. The instructor can also set the maximum number of attempts allowed for each question.

Once all the students have submitted an assignment, or the deadline has passed, Mastering Physics provides the instructor with a comprehensive analysis of the results. Information provided for each problem includes:

- the percentage of students who answered correctly
- the percentage of students who requested the answer
- the average number of wrong answers per student
- the average number of hints used per student.

Further diagnostics provided include histograms and cumulative frequency graphs of the time spent on the assignment and the overall scores. A gradebook provides a record of every student's marks for all the individual assignments, thus enabling weak students to be quickly identified. A list of the incorrect answers that students gave is also provided. Students are also able to feedback comments on each of the problems and grade them in terms of how difficult they found them. This wealth of information enables the students' difficulties, common misunderstandings and/or misconceptions to be easily identified, as well as the effectiveness of the questions, to be judged. This proved to be very important in developing our material.

JIRP sessions
The implementation of the JiTT approach requires the content of the JIRP session to be determined by the feedback obtained from the on-line assessment, giving very little preparation time on the Friday morning for the JIRP session in the afternoon. This meant that a few different scenarios had to be prepared for in advance. Different discussion ideas and problems had to be ready beforehand so that the most appropriate ones could be 'picked off the shelf' at the last minute.

Some time was usually spent during the first part of the JIRP session discussing the Mastering Physics problems that most students had had greatest difficulty with and then similar, often slightly more complicated problems on the same themes or concepts were introduced.

Outcomes of the 2006-07 initiatives
A very positive outcome of the 2006-07 initiatives was that examination performance improved significantly with the average examination mark increasing from 50% in the previous year to 67% in 2006-07. Also the tail of the Normal distribution of marks was significantly reduced, with the percentage of students failing the examination, (ie achieving less than 40%) decreasing from 32% in 2005-06 to only 10% in 2006-07.

Approximately 95% of the students submitted the electronic assignments each week. This was a much better submission rate than for their normal tutorial work, but was probably due to the fact that the Mastering Physics assignments were credit bearing (worth 15% of the module marks). Students obtained full credit for an assignment provided that they achieved at least two thirds of the average mark for that assignment. This meant that the assessment could remain formative, but there was an additional driver to return the work.

However, the student feedback was disappointing. The new approach required the students to take much more responsibility for their own learning and this was contrary to their expectations and their previous experience at school or college. Many of them objected to having to do this. Although there was favourable feedback on the talklets, some students commented that they found the e-learning component very solitary. One factor that did not help was that all the other first year modules were still being taught in a very traditional manner and the students did not understand why the delivery of Dynamics was different.

The majority of students did not like using Mastering Physics. There were teething problems and sometimes the students found the feedback that they got for incorrect answers not very helpful or even misleading. Also not all the problems had hints associated with them and students found this frustrating if they did not know where to start on a problem.

As staff, we found that the penalty we had set for using the hints was too low (only 2%), leading to some students merely opening all the hints without really trying to understand what the problem was all about.

The JIRP sessions quickly became poorly attended. We found it difficult to pitch the content such that everyone was satisfied. Those students who had not managed to solve the Mastering Physics problems would have preferred the whole session to be devoted to going over the problems whereas other students who had successfully completed them, would have found this a complete waste of time. By compromising and only discussing a few of the Mastering Physics problems at the start of the session and then following this with more complex problems, we failed to really satisfy anyone.

The overview lectures were also not well attended. Once students realised that all the material was on WebCT the attendance dropped to about 50%.

Initiatives in 2007-08
Several changes were made in 2007-08. Firstly, we changed the structure of the overview lecture given at the beginning of each week, quite dramatically. It had become clear from our experiences in 2006-07 that if all the learning material is placed on the VLE, there needed to be a reason for students to attend the lecture. They needed to gain more from it than they could by just studying the material on WebCT. A survey by Hake[6] indicates that interactive lectures are a more effective way of teaching than traditional lectures. So in 2007-08, we made the format of the dynamics lectures much more interactive by introducing an interactive voting system and peer instruction.

Interactive Voting
Interactive voting is the process whereby students answer, or ‘vote’ on, a question, very often a multiple choice question, using an electronic handset. The handset transmits a signal to a receiver which in turn inputs directly to the instructor’s computer. Once all the students have responded a bar chart or histogram of the distribution of answers can be displayed on the screen at the front of the lecture theatre. Excellent reviews of the use of interactive voting systems have been published by Duncan [7] and Bates et al[8].

There are two types of interactive voting systems on the market, infra red (IF) systems which only transmit data one-way from the handsets to a receiver, and radio frequency systems (RF) which transmit data in both directions, ie back and forth between the handsets and a transmitter/receiver. We chose a radio frequency PRS (Personal Response System) system manufactured by Interwrite[9]. Although more expensive than the IF systems, radio frequency systems have many significant advantages over the IF systems, eg:

- There is no need for several receivers to be permanently fixed in lecture theatres
- RF systems are readily portable
- The response time is faster
- RF systems can cope with several hundred students
- IF systems require a separate screen to display a ‘response grid’ which is needed to enable students to check if their answer has been received. With the two-way communication RF system a signal is returned to the handset and ‘answer received’ is displayed on the handset.

Two hundred and sixty handsets, known colloquially as ‘clickers’, were purchased. They were each labeled with an individual bar-code and every first year student was issued with one at the beginning of the first semester. They were issued by the library in exactly the same way that books are issued to students. Students were then responsible for bringing the clickers to each lecture. This meant that valuable time was not wasted at the beginning and end of each lecture distributing and collecting clickers. With over two hundred students this would have been totally impracticable. This process worked well, and we only had two clicker casualties during the semester, one which was broken whilst being in a student’s bag and a second one which was lost.

Peer Instruction
Peer instruction was originally developed by Eric Mazur at Harvard University[10]. The idea is that students teach one another. A multiple choice question is put to the students. They select an answer individually using their clickers. They

are instructed not to confer with their neighbours but to make up their own minds about their answer. What happens next depends on the distribution of responses.

If the majority of students give the correct answer, the instructor is reassured that most of his/her audience has understood and is following him/her satisfactorily, and a very brief explanation may be given for the minority of students who gave an incorrect answer. If, however, there is a significant number of students who give an incorrect answer, then peer instruction comes into play. The students are asked to turn to their neighbours in the lecture theatre, either alongside them or in the rows in front or behind them and find someone who gave a different answer from themselves. Then they must try to argue their reasoning for their answer with one another. After a minute or two's discussion, and much noise in the lecture theatre, the students are asked to vote again on their clickers. Usually the percentage of correct answers will have increased significantly.

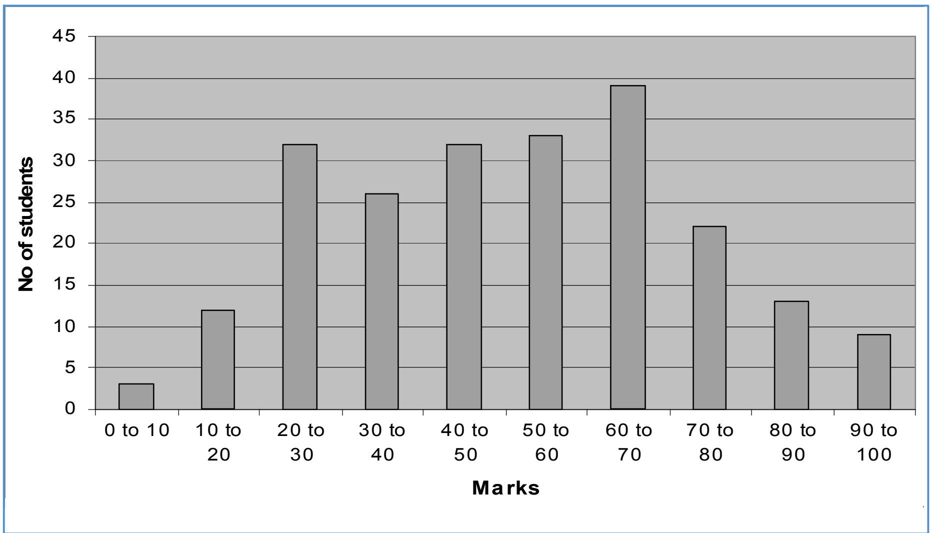

Figure 2: Examination Marks Distribution 2005-06

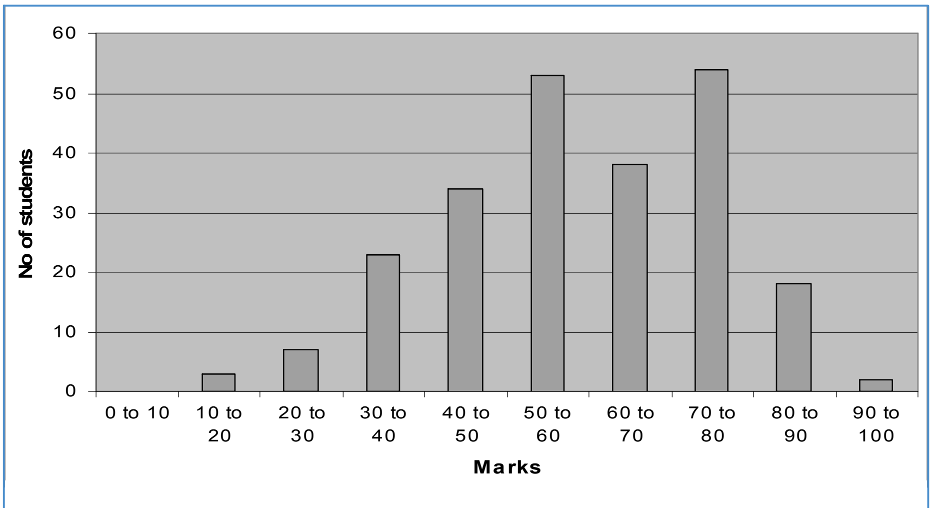

Figure 3: Examination Marks Distribution 2007-08

Peer instruction was used in the 'overview' lectures each week, and the length of the lectures was extended to two hours (with a ten minute break in the middle). Generally between 4-8 clickers questions were included in a lecture.

We also took the opportunity to introduce the idea of pre-lecture reading despite our reservation about doing this the previous year. Students were given a reading list of the required pre-lecture reading for each lecture at the beginning of the semester. This was sometimes textbook reading but more often it was study of the material on WebCT. The benefits of this were two-fold:

(i) It provided a good form of directed self-study
(ii) More time was freed up for peer instruction and the inclusion of more lecture demonstrations.

Familiarity with the subject matter set was assumed when the lecture was delivered. Very often lectures commenced with a 'clicker' question based upon the pre-lecture reading.

Clicker questions were also sometimes linked to lecture demonstrations by asking the students to predict the outcome of a demonstration by voting on it before it was performed. A good example of this is the classic monkey and the hunter[11] projectile motion demonstration. Generally the more counter-intuitive the clicker question the better, as these really test students' conceptual understanding. However, on two occasions during the semester, the percentage of correct answers to a clicker question decreased rather than increased after the peer discussion. The problems in question were particularly tricky counter-intuitive ones. Obviously in these instances it was clear that the students were lost and significant further explanation was required. Nevertheless, this demonstrates the usefulness of the feedback provided by the interactive voting system.

Improvements to On-line Assessments

We made significant improvements to the Mastering Physics assignments. The flexibility of the package enables problems to be adapted and modified, and new problems added. So for 2007-08 hints were added to all the problems and some of the feedback for incorrect answers was modified. In some instances we also changed the notation used so that it was completely compatible with that used in the lectures. This helped enormously and the students' feedback was much more positive.

JIRP Sessions

In response to the student feedback from the previous year we changed the structure and format of the JIRP sessions. We split the students into four separate groups (each facilitated by a single member of staff) as opposed to two groups previously. This year we made no attempt to go over the Mastering Physics problems in the JIRP sessions. Instead a set of new problems was prepared and then a number of these were selected at the last minute, the selection being informed by the analysis of the Mastering Physics assignment results. Students worked through these together in small groups.

Outcomes of Changes made in 2007-08

The average examination mark was 59% this year and although not quite as high as in 2006-07 was still higher than the original 50% average prior to the introduction of the Just-In-Time Teaching approach. The most significant change in the examination results over the last two years has been the increased progression rate of students as a result of the reduction in the tail of the distribution of marks. This can be seen by comparing Figures 2 and 3 which show the examination marks distributions for 2005-06 and 2007-08 respectively. In 2007-08 only 14% of students failed to attain the pass mark of 40% compared with 32% in 2005-06.

Conceptual questions were introduced on the examination paper for the first time in 2007-8 and we intend to gradually increase the proportion of conceptual questions in future. We are trying to move the students away from the 'plug and chug'[10], ie memorising algorithms, approach to problem solving where they expect all tutorial problems (and exam questions!) to be very similar to those given as examples in lectures. This alternative approach is quite different from their prior experience and they find it quite challenging.

The feedback from the students was very much more positive in 2007-8 as a result of the changes made. The majority of students enjoyed the interactive lectures and peer instruction to the extent that they have asked for the clickers to be used in other lectures. Attendance was generally around 70% which was much better than in the previous year.

Some of the comments made by the students were:

- *"The interactive lecture was a really good idea. It helped to be able to get direct feedback about questions and also to be able to discuss ideas with fellow students."*
- *"Clicker questions kept the lecture interesting and helped me to understand material and spot problem areas."*
- *"Clickers make lectures more enjoyable and interactive. I find it beneficial and more intellectually stimulating to be able to participate in lectures."*
- *"I found the clickers really enhanced my learning as areas that weren't understood were picked up on."*
- *"Clickers were a good idea: they showed how many people understood something; often people won't put their hands up to show they don't understand something. This was an anonymous way of doing this."*

Students appreciated the anonymity of the voting system. They felt that they were able to participate without the fear of embarrassment if they answered a question incorrectly.

These comments reflect the benefits of the interactive lecture. Students became much more active participants in the lecture. With traditional didactic lectures there is no guarantee that learning is actually taking place because generally there is only one way communication, ie from the lecturer to the students. Two way communication is required in order to know whether the students are actually learning anything. With small class sizes this is relatively easy using the standard 'question and answer' technique but with large lecture groups it is not possible to use this technique effectively. The interactive voting process goes some way to overcoming this problem by providing instantaneous feedback on the students' understanding during the course of the lecture. This enables misconceptions to be resolved immediately.

Students appreciated the anonymity of the voting system. They felt that they were able to participate without the fear of embarrassment if they answered a question incorrectly. With large lecture groups generally only a very small minority of students will be brave enough to answer, whereas with the clickers everyone can participate and it gives the instructor a much better appreciation of the level of understanding across the whole group.

The clicker questions also break up the lecture thus helping to reduce attention 'fade'.

A minority of students were not in favour of the clickers. The following comments indicate the general theme of the negative responses received:

- *"Clickers waste a lot of time. Could have gone through things in more detail in this time."*
- *"A lot of extra work was needed outside of the lecture."*

These two comments highlight one of the aspects of peer instruction which can be perceived by some as negative. However, we do not see them as such. In fact the concepts are actually investigated more thoroughly using this approach. It is true that one has to reduce the amount of material that is presented within the lecture, but it does encourage students to do more self-study outside the lecture.

One of the challenges of this approach is managing the students' expectations. Students entering Higher Education in the UK are not independent learners. The ideas of pre- (and even post-) lecture reading and constructing their own understanding are new to them. When we started making changes to the delivery of the Dynamics module we were very wary of introducing the pre-lecture reading. However, interestingly, our experience was very positive. As we were able to monitor students' use of WebCT, when the pre-reading was based on the WebCT material we could see that a good proportion of the students were in fact doing it. This was also reflected in the responses to the 'test' clicker questions given at the beginning of lectures. Indeed, on a week when no pre-lecture reading was prescribed, students made enquiries as to what they needed to read that week. Although there were some students who did not do the pre-reading, it was extremely encouraging that many took it quite seriously. We would suggest that if one expects students to do pre-lecture reading from day one, they are much more likely to accept the idea and just assume that this is the way that university learning works. First year students need pointing in the right direction as to how and what to study and this would appear to be a good way to start. Until entering university their learning experience was very much prescribed by their teachers at school/college and it is suggested that we may be expecting too much of them if we do not guide them more initially.

Other challenges of the interactive lecture are:

(i) Producing good thought-provoking clicker questions which offer sufficient challenge to the majority of students without being impossibly difficult, can be quite difficult and time consuming. Fortunately question banks do already exist. Mazur[10] provides an excellent resource in the form of a CD supplied with his book. The University of Edinburgh[12] also maintains a comprehensive question bank. Text-book publishers, such as Pearson, also often have collections of clicker questions available.

(ii) The level of background noise during a lecture can increase and can be more difficult to control. Duncan [7] also noticed this phenomenon. One minute you are encouraging the students to discuss issues with their neighbours and then the next minute you want them to be quiet whilst you are talking. In a large lecture theatre use of a microphone is essential when you want to draw the peer instruction component to a close. It is also important to agree some ground rules about this with the students at the beginning of the course so that they understand the format of the lecture.

Conclusions

Introduction of several different teaching strategies into the dynamics module over the past two years has resulted in an integrated approach which challenges students' conceptual understanding and encourages them to take more responsibility for their own learning. Students engagement with, and conceptual understanding of, dynamics has improved leading to better exam performance and increased progression rates.

When introducing e-learning into the delivery of a module one needs to consider carefully the impact it may have on attendance in lectures. Lecture format and content may need to be changed so as to provide more 'added value' than the normal traditional lecture. One way of doing this is the use of peer instruction using an interactive voting system.

There is a drawback to our approach as well: it is not efficient with staff time, and requires probably slightly more staff effort than standard teaching. However, on balance we feel that the positive outcomes achieved so far justify the extra effort.

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