New Physics Curriculum

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Abstract
Developing the critical thinking and problem-solving skills of students as rapidly as possible is a key requirement in improving learning outcomes at every stage of their degree. The Department of Physics at the University of Liverpool has entirely redeveloped years 1 and 2 of the undergraduate degree with a focus on students becoming independent learners as early as possible. The aims are to better integrate the undergraduate teaching provision and to complete the Institute of Physics core curriculum in years 1 and 2, in order to focus on research led teaching and independent projects in years 3 and 4. This new programme, entitled New Physics, starts in Welcome Week with the Undergraduate Physics Olympics and continues through the Year 1 Project (Mission to Mars) in the first week of semester one. The aim is to set the standard for collaborative achievement and introduce students to the way that physicists think. Innovative problem solving classes incorporating active learning such as peer-assessment, group learning and exemplars designed to improve these skills and enhance the quality of learning among its first-year students have been introduced.

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Why Make Changes 'We've always done it this way/This is how I learnt'
Prior to 2011/12 the Department of Physics at Liverpool offered a mainly traditional lecture-based curriculum. This did not cater well for the needs of a diverse cohort containing mature students, an increasing number of international students and those from a widening participation background.

Parallel to this, the style of teaching in schools often helps the students to achieve the marks for university while leaving them totally unprepared for the challenges they will face there. High achieving students arrive expecting to have their hand held; 'but my teacher would find the answer on the page and give me the marks if it was there, even if I didn't realise that was the final answer.'

A curriculum review led to the following observations:

- students are arriving with less physics knowledge and mathematical skills despite higher grades at A-level
- new students have little acquaintance with measuring instruments or laboratory skills
- many students, at the end of year 1, can not reliably perform algebraic calculations or simple differentiation or integration
- attendance at weekly tutorials is poor and very few students claim to do an adequate amount of private study
- students in the year 2 laboratory show an increasing tendency to rush heedless into taking measurements and then so not understand why their measurements and results are worthless
- students are particularly poor at unpicking a problem
- many students cannot cope with examination questions of a similar nature to those they have seen in lectures and tutorials
- students do eventually master laboratory and computing skills taught in a labour-intensive, hands-on approach in which the student works diligently under supervision

Which parts to change?
The aims of the changes introduced are:

- to develop students' problem solving skills
- to give students experience of collaborative and group learning
- to encourage students to think like physics experts
- to turn students into independent learners

In an ideal world, a perfect solution to the above problems would have been devised and implemented without regard to cost or consequences. However, here in the real world, based in a research-intensive department, the best solution was the one that achieved the aims while making efficient use of staff time. Therefore a compromise structure was developed based on lectures supported by weekly problem classes for the entire cohort, which offers the opportunity to develop the independent learning skills of our students at an early stage in order that they can gain the full benefit of later learning opportunities.

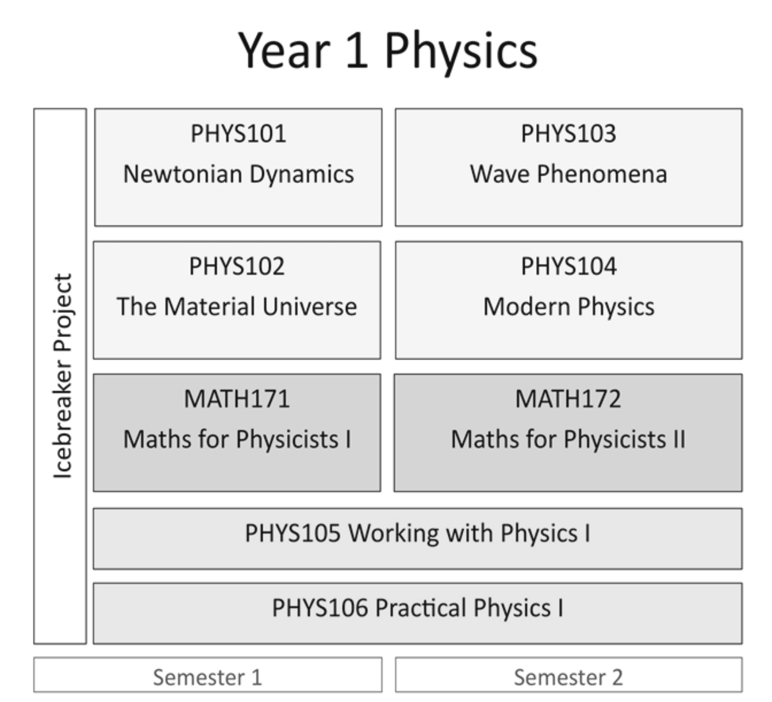

Figure 1: Year 1 timetable in New Physics Curriculum.

In the period 2008-11 pilot studies were conducted to inform the development *New Physics*; the appropriateness of problem-based learning, e-assessment (Mastering Physics, http://www.masteringphysics.com/) and problem classes were all investigated for the Liverpool cohort.[1-3]

Curriculum Outline
After much discussion it was decided that the Institute of Physics (IOP) Core Curriculum[4] should be covered entirely in years 1 and 2 of the degree programme to allow students to focus on a particular area in their final year(s). Further, the importance of introducing Modern Physics in year 1, which has attracted many of the students to the degree in the first place, needed to be balanced with the mathematical needs to gain an understanding of such material. The restructuring allowed for the consolidating of small modules, by removing the options of students are year 1 and 2 level.

New Physics is designed such that in each semester the content is divided, as shown in Figure 1, into 50% physics, 25% mathematics for physicists and 25% laboratory and other skills to support physics, such as computing skills and communication skills. The physics cornerstone modules in year 1 are Newtonian Dynamics and The Material Universe in semester 1, and Waves Phenomena and Modern Physics in semester 2. The students also complete a module entitled Mathematics for Physicists each semester. Each physics/mathematics module consists of 2 x 1-hour lectures and 1 x 2-hour problem class per week. A final examination for each is worth 60% (70% for mathematics) of the module, while the 40% (30% for mathematics) for continuous assessment is divided across the problem classes, homework assignments and e-assessments such as Mastering Physics and MyMathLab (<www.mymathlab.com/>). The Mathematics teaching has been taken in-house, is taught mostly by physicists and is strongly linked to the material covered in the physics modules, e.g. error analysis, with physics-related problems used whenever possible.

In conjunction with this, students have weekly sessions in the laboratory (2 x 3-hour) worth 12.5% of the semester marks. As well as developing their basic experimental and analytical skills, laboratory sessions have been introduced which develop the students' problem solving and group work skills by introducing real-world related (based on ideas from Derek Raine at Leicester[5]) and enquiry-based experiments.

Another module entitled Working with Physics I, 2 x 1-hour lectures, 1 x 2-hour problem class), assumes no prior knowledge from students in the areas of errors, computing, group work and communication skills and uses physics problems, open-ended where possible, to build their skills in these areas.

In order to accommodate large group problem classes for 120 physics students and up to 30 from other departments, a large room was refurbished into a 'flexible space' consisting of moveable tables and chairs with basic audio-visual equipment as in a lecture theatre. Staff time was optimised by the presence of approximately four postgraduate demonstrators in every problem class, who were often assigned to particular teams of students.

In year 2 the structure has been retained as shown in Figure 2, with four cornerstone modules in Electromagnetism, Condensed Matter, Quantum & Atomic Physics and Nuclear & Particle Physics. The Mathematics for Physicists continues and the laboratory and Working with Physics modules further develop the students' skills. In the year 2 laboratory the students will engage in more enquiry-based experiments, culminating in an open-ended, group research project. In the skills module the students will continue to support learning in other modules through an in-depth study of solving physics problems in Matlab and developing their communication skills through report writing and presentations of their results in the laboratory module.

Evaluation
The standard feedback form, completed at the end of each module by students, usually provides information about specifics such as suitability of lecture accommodation, therefore a full cross-module evaluation of the developments in year 1 was necessary. Focus groups containing students who volunteered their time were held near the end of semester 2. In all, 14 students participated in these and their responses were recorded and used to inform a bespoke questionnaire, which was given to all year 1 students of physics five days before the end of semester 2 (not including exam time). The questions were kept deliberately open in order to solicit the ideas and opinions of the students, rather than ask them to rank or comment on a pre-determined list.

In all, 47 of 103 students responded to the questionnaires. The questionnaire contained one closed question *Has year 1 required you to 'think'* with 5 options ranging from very seldom through sometimes to very often. Of those who responded 47% of students selected 'very often', 38% selected 'often' and of the remaining 15%, 6.4% (3 students) selected 'sometimes', 2.1% (1 student) 'seldom' and 6.4% did not respond to this question.

This was followed by an open question asking students to *Please give 3 examples of times you have been required to 'think'*; 3 blank lines were provided and the line *or write 'never' been asked to think.* Most students gave 3 responses, and the student who selected 'seldom' and those did not respond each gave at least 2 occasions on which they had been required to 'think.' Of a possible 141 responses, 115 were given as summarised in Table 1. The categories are those used by the students in response to the open question.

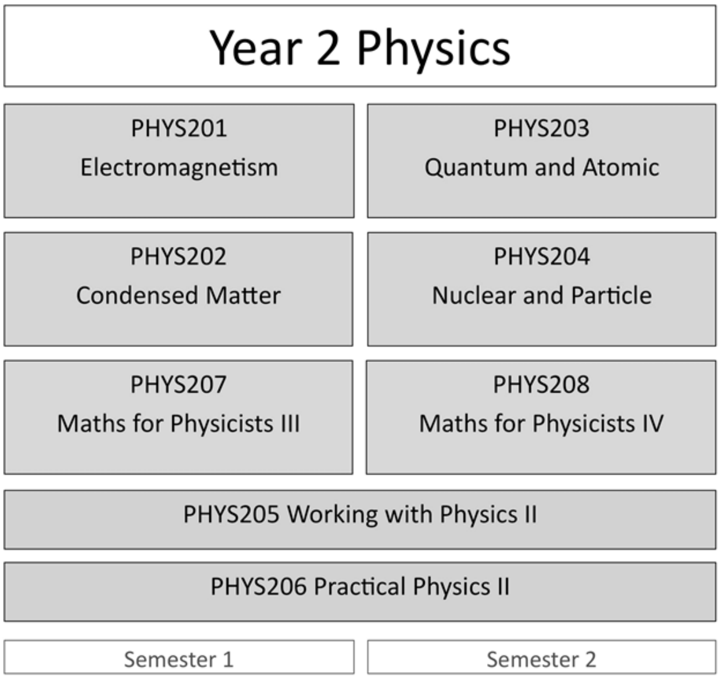

Figure 2: Year 2 timetable in New Physics Curriculum.

Students were also asked to list any skills that they have *learnt or improved* since the start of their degree and given 6 blanks lines to complete. On average each student provided 3 responses, giving 153 of 282 possible responses.

Students were asked in which module they believe they learnt most, and why, as well as for suggestions of a change in delivery they believed would *improve their learning*. These three open questions were asked in order to investigate where and how the students feel they are learning and to better understand their responses in terms of when they perceive that they have been required to 'think' and the list of skills they feel they have learnt or improved.

Table 1: Students' examples of when they were required to 'think' during year 1.

Type of Session	When have you been required to think
Laboratories	60 %
Problem classes	53 %
Modern Physics	28 %
Mastering Physics	21 %
Exams/revision	19 %
Homework	17 %

The results (Table 2) indicate that students mostly (72%) believe they learn most when the material or skill is new to them, while 12.8% mentioned problem solving and being required to 'think independently.' Students perceive skills they have learnt or improved as 'organisation' (17%), 'prioritisation/time-management' (12.8%), 'self-learning' (6.4%) and phrases using 'independent thinking' (6.4%). Specifically the students believe where they learnt most is in physics modules (46.8%): Mathematics for Physicists (21.3%), Practical Physics I (6.4%) and Working with Physics I (19%). One student mentioned both a physics module and Working with Physics I, while 3 students (6.4%) did not respond.

The final question asked students to suggest *one change in delivery (not a lecturer) that would improve your learning?* They were also asked to *explain how* this change would help. Only 38 students responded to this question, but 7 of these made 2 suggestions giving a total of 45 responses. These ranged from more(1)/less(2) content, to more lectures(1)/PBL(1)/real world examples(2)/problem classes(3). There were 2 suggestions of having better links between the material covered in modules and that in laboratory sessions to aid understanding. However there were individual suggestions of providing worked examples to everything, introduce tutorials, mark all work in problem classes (although students work in groups) and remove the laboratory module.

*Table 2: Students' examples of skills they have learnt or improved during year 1. (*JLInefit is an in-house program for data analysis).*

Skills	Learnt or Improved since start of degree
Computing Skills (Excel, Matlab, JLinefit*)	53.2 %
Problem Solving	51.0 %
Error Analysis	38.3 %
Maths	34.0 %
Laboratory Skills	27.7 %
Report Writing	25.5 %
Team Work	23.0 %
Organisation	17.0 %
Self-Learn	12.8 %
Applying physics to real-world problems	10.6 %

The focus groups were self-selecting consisted mainly of students who obtain better than average marks, but included male and female students, as well as mature students and those from non-traditional entry routes. These students perceived the links between modules, particularly between Working with Physics I and Practical Physics I, and between Mathematics for Physicists and the cornerstone modules. They also the liked real-world, open-ended problems (in the laboratory and elsewhere) and described an examination question as 'a waste of a question, it was just cut-and-paste.'

Conclusions

Overall the changes made at Liverpool were small, but well planned and integrated across the entire curriculum, and have made a huge impact on the students' engagement and approach. The teaching load per staff member has changed from 3 x 1-hour lectures and 1 x 1-hour tutorial to 2 x 1-hour lectures and a 1 x 2-hour problem class per week. This change in structure and how it is employed (problem solving, peer-assessment, group work) has seen the most positive reaction from the students as this is where many acknowledge they learn; 53% choosing this as an example of where they are required to 'think' and the overwhelming majority in the focus groups chose the problem classes in response to the question *Where do you learn?* This is in line with the findings of Hager et al. (2003) that when there is emphasis on critical thinking tasks linking the applications of physics to everyday life it is possible to/ enables the instructor to increase the 'degree of difficulty and rigour in the course content.'[7]

The integration across modules has been beneficial as physics students perceive links between them. However, some modules are open to or compulsory for students from other departments (e.g. Maths and Physics). The alignment was visible to them (a separate focus group), but their presence in only a portion of the overall curriculum led to distinct gaps in their knowledge/skills such as error analysis or presentation skills which were taught in Working with Physics I and Mathematics for Physicists, neither of which was open to them. This has been addressed with the creation of a new module which ensures they will benefit from the inbuilt links.

The aims of *New Physics* were met to different extents. The students' perception is that their problem solving skills have improved since they started and, in comparison to previous cohorts (which they resemble in all other respects), they are more willing to attempt to solve an unseen problem and have developed techniques to approach multi-stage problems. In the focus group, some highly able students requested that more unseen problems be included in the examinations.
Students have extensive experience of collaborating and assessed team work in Working with Physics I and Practical Physics I, and they also report working together in modules where it is not required 'the students helped each other to understand the concepts.'

There is anecdotal evidence... that students are approaching new material with a view to developing their understanding, rather than just passing the examination.

Bates et al. (2011)[6] reported that students at Edinburgh arrive possessing high-levels of 'expert-like thinking' in their approach to physics problems, and are 'relatively unchanged over the course of their undergraduate study.' They argue that their postgraduate students increase their level of expert-like thinking as they engage with the 'authentic practices of the discipline' at postgraduate level, although they would have had more expert-like views than the average of their cohort at final year level. Therefore the approach at Liverpool is to provide opportunities from year 1 for students to engage in applying their physics knowledge to solve real-world problems. As students meet more advanced problems of this nature later in their degree, such as the open-ended, group research project in the year 2 laboratory module, it will be possible to ascertain if this has been successful.

The aim to develop independent learners as early as possible has been partially met; though students are not yet all fully independent, the proportion of the cohort who are actively engaging with the curriculum throughout the year, forming private study groups and approaching lecturing staff with questions outside of class is markedly higher than in previous years. Attendance at lectures and in problem classes in year 1 has increased from an average of ~70% to >90% for lectures and from ~50% for tutorials to >90% for problem classes. The recent introduction of central timetabling system, which places lectures anywhere on campus, has corresponded to a decline in attendance across all years, and so this improvement in year 1 will be monitored as this cohort progress through years 2-4. With this decentralisation from a specific physics lecture building, the importance of and difficulty of organising private study groups has increased, but this year, for the first time, 2-3 groups of year 1 students have approached the Department to ask for space to work together in this fashion.

There is anecdotal evidence to support the indication in the bespoke questionnaires that students are approaching new material with a view to developing their understanding, rather than just passing the examination. This is evident both from the timing of their interaction with staff; engagement throughout the year, as well as comments (on the difficulties of too much content) 'you end up trying to memorise rather than understand!' To date, the structure and style of the examinations has not changed (although only two modules have not been changed substantially so it is difficult to make meaningful comparisons with previous cohorts). Examination marks did not change significantly to previous years. In time, and in response to evaluation, examinations may be adapted to match the new (and increased) assessment methods used throughout the year to better support student learning.[8]

Even the partial achievement of the original aims means that these students enter year 2 better prepared to learn and develop their skills through knowledge, skills and attitude and it is up to us to provide the opportunities to stretch them through research-led teaching and use of open-ended problems. The year 1 cohort starting in September (2012) will be benefit from more opportunities to work on open-ended research problems (at an appropriate level) and use team work skills during laboratory sessions. Areas where better integration across modules have been identified and will be addressed for the new cohort. In order to better understand their development a cross-sectional study of students in each of the first few years of the *New Physics* curriculum will be performed using such tools as the CLASS survey.[9]

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