# PHYS20X REDESIGN

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## 1) INTRODUCTION

Teaching in the Physics Department at the University of Auckland's has undergone dramatic redevelopments over the past year. In the departmental review in 2014 our research was highly commended but our teaching practice was unplanned and not current best pedagogy. Hence the department started a path that has led us to adopt the SCALE-UP (Student Centred Active Learning Environment with Upside-Down Pedagogies) or "Studio physics" pedagogy for our 1st year course. It was first introduced at North Carolina State University in 1997 (Beichner et al., 2007; Beichner 2008) and is a form of flipped classroom (Deslauriers et al., 2011; Berret, 2012). It was developed so that large enrollment courses could benefit from some of the active and collaborative learning techniques that increase student learning. In addition to incorporating active pedagogies, the sessions take place in a reformed studio classroom with round tables and whiteboards on walls. The sessions are a 2 hour combined lecture, laboratory and tutorial experience. The basic idea behind this is that students learn more in "doing" physics. In many places where this pedagogy has been adopted, significant learning gains are found for all students and the gains continue throughout their entire course of study (Beichner, Saul, Allain, Deardorff & Abbott, 2000; Redish, 2003; Beichner et al., 2007; Foote, 2015).

The restructuring of 1st year courses provides something of a challenge and opportunity for our 2nd year courses. While the students will be better prepared for the 2nd year, they may not find it straightforward to adapt to "standard" physics lectures. Thus we must redesign our 2nd year courses to account for this and to continue the process of active learning that the students experienced in their 1st year. The 2nd year physics courses have not been reviewed for a significant time and lecturers in these course have been muddling through as best we can (Brookfield, 2006). Having taught in each of the three main 2nd year courses I volunteered to oversee the redesign of these courses as a member of the Physics "Century 2" committee[1]. We have discussed at length on the format and structure of the 2nd year courses. The division of course content required a great amount of teamwork. In this report I have taken the opportunity to use my assignment for ACADPRAC701 to design a concrete foundation for the general structure of our 2nd year physics courses, defining a signature pedagogy for 2nd year physics (Shulman, 2005). This can then be transferred to any 2nd year course just by inserting the relevant course content. I demonstrate key aspects of the redesign by outlining how this would be enacted in one third of the electromagnetism and optics course, PHYS202, which are the first 2nd year lectures in 2017.

In this report, I first review physics education literature on redesigning advanced physics courses. Then I use constructive alignment to discuss the new structure for our 2nd year courses, describing the learning outcomes, assessment and teaching pedagogy. Finally I outline feedback from the stakeholders in these courses and summarize this report.

[1] A group planning the 2nd century of teaching of physics at the University of Auckland

## 2) PHYSICS EDUCATION RESEARCH LITERATURE ON ADVANCED PHYSICS COURSES

While there is a significant amount of research on physics education the majority is focused on 1st year courses or specific topics (see McDermott & Redish, 1999 for a review). The one well documented case of a redesign beyond the 1st year is the "Paradigms in Physics" by Oregon State University (OSU). They undertook a dramatic and wide ranging restructuring of their 2nd and 3rd year courses (Manogue et al, 2001; Manogue & Krane, 2003). They have also made much of their course materials available on the internet[2]. Their redesign had covered both the arrangement of course content and the teaching pedagogy. The most dramatic change was to redistribute the course contents. Rather than taking the typical course structure that are widely used, such as classical mechanics, electromagnetism and quantum mechanics, they reorganized the material into different paradigms that link together by how the physical phenomena are modelled. For example, students study waves by considering vibrating strings, electromagnetic waves, wave signals along cables and quantum particle wave packets. They see the same mathematical model applied to the waves in different physical systems. The full scheme is shown in Figure 1 which has been reproduced from Manogue et al. (2001). This arrangement helps students see how a physicist uses maths and the interconnectedness of physics and science.

OSU also adopted a new pedagogy for their courses; getting the physics off the page and into the classroom. This was achieved by using props and computer visualizations[3]. The students were expected to work together in groups to answer "small white board questions" that allowed them to think more deeply about the course material[4]. Importantly these activities are very similar to those of the SCALE-UP activities. Getting students discussing physics helps them achieve deeper learning (Bonwell & Eison, 1991; Prince, 2004). Dale (1969) talks about a "cone of learning" where students learn more as the experience becomes less abstract and more involved and physical. In this case it means moving away from absorbing facts in a lecture towards discussing with their peers how to solve problems. Each course also uses team teaching, with each lecturer instructing the class for 3 weeks in one topic. Allowing students to learn from physicists with different backgrounds and approaches. Team teaching can also provide other benefits (Anderson & Speck, 1998; Wenger & Hornyak, 1999).

The success of the Paradigms method has led to increased numbers of graduating physics students at OSU from an average 15 a year to 25-30 students in the space of a few years. This is in comparison to a 10% decline in the total number of US physics degrees. This is compelling evidence to transplant some of the above aspects to Auckland, especially as students will be more used to the more active and involved physics teaching from the 1st year SCALE-UP physics.

We cannot simply transplant the course structure directly for several reasons. First we need to prepare students for 3rd and 4th year physics courses that are more likely to depend on the transmission lecture model. Second we do not have the amount of staff time to redevelop the course to the dramatic Paradigm scheme. Third since increased numbers of engineering students take our course on electromagnetism and quantum mechanics, we are limited in how we can redistribute course content. Finally our class sizes (60 to 80 students) are three times the size of those at OSU and we do not have the resources, space and time to copy their fully active pedagogy.

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[2] http://physics.oregonstate.edu/portfolioswiki/doku.php
[3] http://physics.oregonstate.edu/portfolioswiki/props:start
[4] http://physics.oregonstate.edu/portfolioswiki/swbq:swbq

| Course unit | Mathematical Methods | Classical Mechanics | Electromagnetism | Quantum Mechanics | Thermal Physics | Not included in old courses |
|---|---|---|---|---|---|---|
| Vector Fields | Vector calculus<br>Visualization | | Statics, 3D geometry<br>Vector theorems | Delta functions | | Computer<br>Visualization |
| Oscillations | Fourier series, integrals<br>Complex exponentials | Small oscillations<br>Anharmonic pendulum | LRC circuit<br>Resonance | Orthogonal expansions<br>State space | State space | Lab component |
| Energy & Entropy | | | | | Probability<br>Thermodynamic potentials | Statistical inference |
| Waves in 1 Dimension | Normal mode expansions | Vibrating string | Standing and traveling waves<br>Coax cable | Eigenmodes<br>Wave packets | | Lab component |
| Quantum Measurements and Spin | Matrix algebra<br>Representations<br>Basis transforms | Hamiltonian | | Eigenvalues, probabilities<br>Repeated measurements<br>Spinors, spin 1/2 | Measuring probability | Bell inequalities |
| Central Forces | Legendre functions<br>Separability | Angular momentum conservation<br>Kepler, others | | Angular momentum conservation<br>Spherical harmonics | | |
| Periodic Systems | | Coupled oscillations | | Band structure | Distribution functions | Phonons<br>Bloch waves |
| Rotational Motion | Tensor notation | Rigid rotation<br>Inertial tensors | Tensor notation | Basis rotations | | Lab component |
| Reference Frames | | Rotating frames<br>Relativity | Relativity<br>Lorentz transf. | | | Lab component |
| Math Methods Capstone | Partial differential equations<br>Complex analysis | | Green functions | | | |
| Mechanics Capstone | | Formal Lagrange and Hamilton methods | | | | |
| Electromagnetism Capstone | | | Dynamics, media<br>Waves, radiation | | | |
| Optics Capstone | Boundary conditions | | 3D waves<br>Coherence | | | |
| Quantum Capstone | | | | Atoms, fine structure<br>Angular momentum coupling<br>Scattering | | |
| Thermal Capstone | | | | | Statistical mechanics and applications | |
| Not included in new courses | | | | Time dependent perturbation theory | | |

Figure 1: Table from Manogue et al. (2001) showing the redistribution of course material from the typical subject arrangement of courses (vertical columns) to the new paradigms arrangement (horizontal rows).

Nevertheless we can use some aspects in our redesign. We can at use the Paradigm scheme to highlight to students the interconnectedness of physics, which allow students to know many of the physical models are repeated throughout the courses. We can also have team-teaching to give students different lecturing and teaching styles through each course. Moreover we can make the classes more active by introducing group exercises to gain benefits of peer-instruction. We know that moving and modifying a pedagogy from one institution to another can reduce its effectiveness. The research however seems to suggest that the active learning and peer-instruction are the most important aspects to reproduce (Foote, 2015).

### 3) CONSTRUCTIVE ALIGNMENT OF 2ND YEAR AUCKLAND PHYSICS

In constructive alignment we first determine our learning outcomes, determine how these will be assessed and how we will help the student learn and achieve the outcomes. In discussions with other physics lecturers we all describe a similar profile for physics graduates. One danger is that we might think students should just end up looking like a physics lecturer! But most students do not become academics and we require a wider view of expectations of our graduates.

#### 3.1) Learning outcomes and objectives

Previously the learning outcomes for 2nd year courses were poorly defined. They just stated the course material students were expected to know. In this redesign the main learning outcomes for each 2nd year courses are the same, describing a student's ability to "do" physics rather than covering the course material. In all the 2nd year courses we expect therefore that a physics student:

1. Must be able to solve problems in [electromagnetism and optics], both to an order-of-magnitude estimate and in detail; by combining knowledge of physics and maths.
2. Must be able to solve these problems analytically, numerically and computationally.
3. Must be able to find the information required to solve problems and design and undertake experiments if required to gain this information.
4. Must be able to describe and communicate their method and results clearly so others can reproduce it.

The topic in the square brackets is replaced with the relevant course title in question. In the second year they are,

- PHYS201: classical mechanics and thermodynamics
- PHYS202: electromagnetism and optics
- PHYS203: relativity, quantum mechanics and nuclear physics.

By focusing the learning outcomes on skills not content, it emphasises that we really want students to apply their knowledge rather than just to know a catalogue of equations. These learning outcomes align closely to the graduate profile of the University of Auckland[5]. At the surface level, the graduate profile covers the aspirations for our graduates. These learning outcomes match the requirement to produce scholars and innovators who can be curious, critical and creative. These aspirations lead to the capabilities graduates will have, specifically in critical thinking, solution seeking, communication and independence. The graduate profile also covers, disciplinary knowledge and practice.

In this course redesign this course content is described as learning objectives in each lecture. The Century 2 committee has gone into substantial detail in putting together the specific content of these courses and we list this in Appendix B. Unfortunately this does not match the OSU Paradigm method, but we will strive to help students to realise the links between these courses. The course

[5] The graduate profile can be found at https://www.auckland.ac.nz/en/about/learning-and-teaching/strategies-goals-and-plans/graduate-profiles.html

content is described in a series of learning objectives for each lecture. We show an example of a third of PHYS202 below in the second column of Table 1.

One final level of detail to add to these learning outcomes is to discuss them in terms of Bloom's taxonomies, shown in Figures 2, and to put them into context. What level of achievement do we aim for the majority of our students to reach by the end of the second year. From the learning outcomes, it is clear that we need students to remember, understand and apply the knowledge. We also aim for them to begin to analyse and see connections. This will then set the foundation for their 3rd and honors years when students attempt to reach the peaks of Bloom's taxonomy.

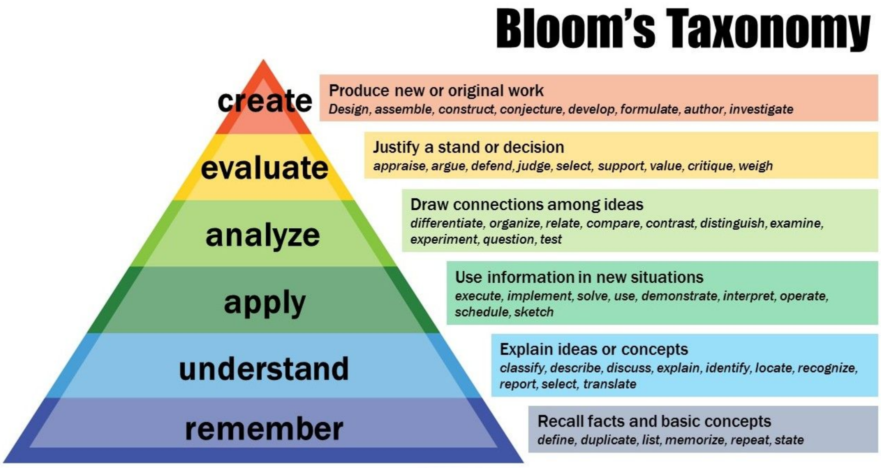


Figure 2, Bloom's Taxonomy (e.g. Wineburg & Schneider, 2009)

### 3.2) Assessment of learning

Currently 2nd year physics are assessed primarily by exams, laboratories and assignments. A problem is that beyond examples in lectures, little help is given to students in how to solve exam and assignment problems. Although there is a great deal of supervision in the laboratories but this is primarily concerned with how to plan and undertake experiments.

In course feedback via SET this semester for the 2nd year courses students requested more tutorials to help them develop their skills on solving problems. We had already planned to include an extra hour learning session a week for our 2nd year courses. It would not be a lecture but a tutorial or examples class. The question arises "what should this class be?". Should the sole reason be to just answer questions about assignments and go over examples or should we be more ambitious and turn these into a form of formative assessment.

The aim of these examples classes is to build students' ability to "think and solve problems like a physicist" rather than just "knowing physics". Giving them formative assessment to help them achieve the learning outcomes. The current plan is to have at least some, if not all, examples classes arranged so that the student work together. Students will be assigned into peer-instruction groups, each containing a strongly, average and poorly performing students to work together. There is strong evidence showing that student learning for all members of the group is significantly increased (e.g. Heller & Hollabaugh, 1992; Crouch & Mazur, 2001; Beichner et al., 2007; Shimazoe & Aldrich, 2010). Fortunately when students come through SCALE-UP 1st year physics courses they will be used to such groups. While it may be a challenge to begin with, it will improve with time.

The example classes would be arranged so that in each one a small part of a bigger problem can be tackled. In the final class of a all these parts come together to solve one larger problem. This scaffolded instruction can help students achieve their learning objectives (Sawyer, 2006). Student will be expected to get to a certain result each week and will get mores marks the closer that get to obtaining it. Importantly each result will be a "checkpoint" given to groups before the next examples class if they did not achieve the required solution. There will also be peer-evaluation, where students assess their group members involvement for an element of their mark.

An example in PHYS202 is to model a coaxial cable, such as those used for television aerials. The students would initially work out simple details for the cable before ending in a question requiring thought of: can you eavesdrop on the signal (i.e the wave) without cutting the cable? At one level the answer is no but it will require students to think about their assumptions in their modelling to see how it might possible. These classes will assess the students on learning outcomes 1, 2.

Beyond examples class assessment include laboratory experiments, assignments and exams. We are undertaking a staged reform and postponing significant changes to the lab experiments until seeing the results of this redesign. In general the labs work adequately. They just require more experiments that closely link to the course material. The labs are how students learn and are assessed for learning outcomes 3 and as student must write a report on their experiments learning outcome 4 is also assessed.

The labs also include computational experiments that require the students to write code in python. One aspect we are adding to the labs next year is, after successfully in obtaining a SEED grant, to hire teaching assistants to develop and create new computational learning resources. These will aid students to learn coding making computational experiments accessible to all students. We can then required students perform at least one computational experiment and two physical experiments of the four they must undertake.

Learning outcomes 1, 2 and 4 will also be assessed in assignments and a final exam with greater thought and planning. The questions will have to assess both simple "estimation/order of magnitude" questions and more complex questions where a detailed answer is required. The assignments will also be structured to encourage students to take more responsibility for their own learning. Currently students typically attempt questions they know they will get marks for.

To encourage more independent learning assignments will be designed to have more marks than are available. For example, the questions in an assignment will have a total of 30 marks but the maximum score possible is 20 marks. I have already tried out this idea and it was popular with students. They seem more keen to attempt questions when the pressure of trying to get everything correct is removed. It also reinforces the formative nature of assignments and making them a greater learning tool for students. Example assignment questions are included in the Appendix A.

Finally we must consider the exam. Over the past few years lecturers have been frustrated by how the a number of students seem not to be able to completely solve an exam question. This is likely due to lecturers not providing enough guidance and tuition to students on how to solve problems.

By stating in the learning outcomes that problem solving is key to the course this highlights to lecturers and students this is the important aspect of the course.

Current traditional physics exam question tend to be long asks students to begin by explaining an equation or deriving it, so called “bookwork”. Next this is applied to a presented physical situation. Finally the student is asked to interpret this. There is some variation around this but it does test the student’s knowledge and problem solving ability.

In addition to these longer questions we also need to include questions that simply test students’ problem solving ability. The short or “Section A” style questions have been used in the Physics at the University of Cambridge. They are “estimation” or “ponderable” questions, for example:

- How long does it take the cold air in a fridge to flow out when you open the door?
- Why is it possible to get electric shocks when touching a conductor when walking around shops in trainers?
- Can you reverse the polarity of a neutron flow?

What is being assessed here is how the student deals with an unknown or new situation and apply the physics they know from the course to give a rough order of estimate answer. Hopefully they should be able to do so in about 5 to 10 minutes. The advantage of these is the students know they can get up to 20% of the exam marks with some simple questions. These questions also require student to explain and show their thought processes to get full marks, again assessing learning outcome 4. The exam format will be 6 short questions that must all be attempted and 6 longer traditional question of which 4 must be attempted. These assess learning outcomes 1, 2 and 4. We show example questions for PHYS202 in the Appendix A.

In summary, linking assessments back to learning outcomes allows us to see what we must teach students. While we test for course knowledge it is through solving problems. Here we list the weighting of each of the assignments as follows:

- Final Exam 45% (previously 60%)
- Examples clases 5% (x3)
- Assignments 20% (6, each offering 30 marks but maximum mark 20)
- Labs 20% - 4 experiments (1 computational and 2 physical experiments).

The greatest differences are decreasing the final exam weight to 45% and including the examples classes. This is a significant change and again removes the pressure of having to perform on the exam to pass the course. It also reinforces the idea that all assessments are there to evaluate their ability to solve problems in physics.

**3.3) Learning and teaching style**

A danger when lecturing physics is to stick to the transmission lecturing model. After all it’s the scheme most academics have been through so it must be perfect? It can be done well, but students can get bogged down in an unending stream of equations, facts, diagrams and derivations.

In physics a lot of the threshold concepts tend to be misconceptions that students have about how the Universe works. For example, in special relativity all the weirdness comes about because the speed of light is constant for all observers and nothing can go faster than the speed of light. This is counter to common everyday experience, if you want to go faster than the speed of sound you just need to get a faster airplane but that isn't how light works. Once this vital piece of knowledge is obtained a lot of the later details of special relativity are easier to grasp. With these misconceptions we have to deconstruct student's previous incorrect knowledge and rebuild it so that when they learn more their knowledge is not based on incorrect foundations. Thus in designing each second year course we must identify the key threshold concepts, paying closest attention to the known misconceptions that students may have and prioritizing these in lectures and in assignments and examples we set.

Alongside this we need to emphasise in our teaching how to solve problems using physics knowledge. We have to teach students how to navigate around the knowledge they will gain in the course to find the correct approach to solve a problem. We can also use this at a learning too. Presenting students with the problem of why the misconception is wrong and how for them to determine the true model.

One key skill in physics problem solving involves learning how to visualize problems. For this we need to bring the abstract physics into the lecture room using analogies and props. Props, activities and simple experiments are easy ways to explain how a bit of physics works and make the learning environment more active. They also don't even need to be anything special. For example, in electromagnetism I have used the following:

- Various sized balls for explanations or electrons and protons.
- A necklace as a ring of charged particles or a ring of current (see Figure 3).
- A table as a parallel place capacitor.
- The lecture room itself as a surface through which electric flux permeates.
- A standard plastic ruler, that can be charged by rubbing with a jumper and held near water flowing from a tap (see Figure 3).

A key theme of all of these are that they are things students can try themselves. This allows students to get used to the idea of testing out their thoughts in the real world. After reading about the OSU Paradigm program it is possible to list the new props the department should invest in:

- Fishing nets to explain surface integrals and fluxes.
- A large number of arrows so students can hold them up and visualize vector fields throughout the lecture room.
- Hula-hoops to represent rings of charge and to describe surface integrals and vector fields.

There is also a large amount of work that can be done using computer programs to make visualisations. With the SEED grant we have won this year, one part of this is to create python computer code that students can use to learn to program and visualize physical systems at the same time.

As demonstrations and visualization will be key parts of the course, the lecture plan will reflect this. For example, in Table 1 not only are the learning objectives listed but also the examples, activity or demonstration required in the class. This amount of specification about the course prevents content creep, with material and demonstrations being lost or gained, and makes active learning and demonstrations embedded in the teaching of the 2nd year.

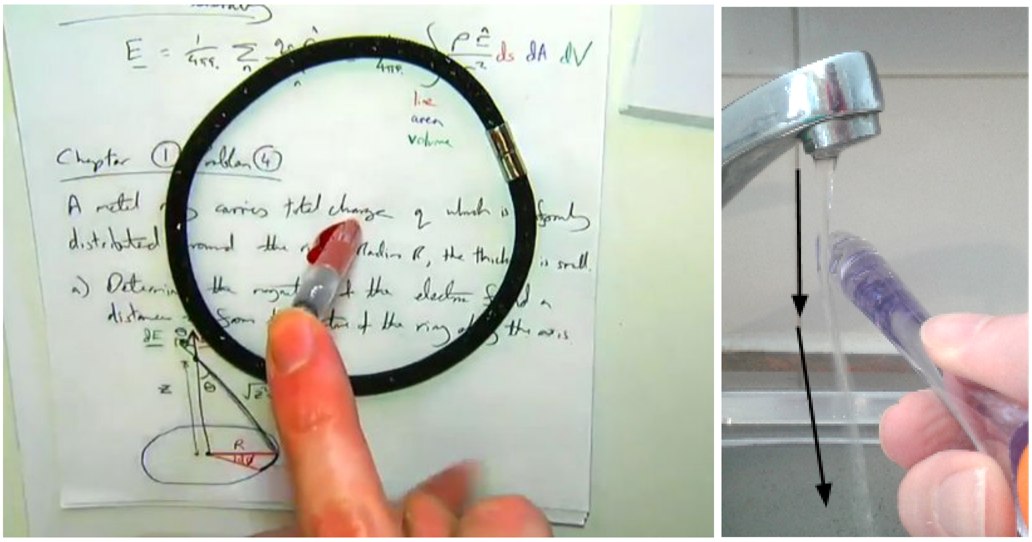

Figure 3, in class demonstrations, left: ring of charge, using a pen and necklace, can be scaled up to a hula-hoop and lecturer. Right: charged perspex rod/ruler deflecting water as its molecules are dipoles.

These changes will make lectures more active. The content of each lecture will be limited to maybe no more than 3 handwritten sides of A4 paper, enough to lecture for no more than 30 minutes. The remaining time is for interactive examples or driving a dialogue with the students and using their ideas to try and solve a relevant problem. A dialogue can be driven by using checkpoints during derivations to see if students can suggest or explain the next step. It might be daunting to try this kind of teaching but having attempted it I can see students feel more engaged and motivated. Moreover we will be able to use "clicker" questions during lectures via GoSoapBox for real time formative feedback to assess student understanding of the key concepts in the course. Each lecture will also have specified reading. In Table 1 we list the relevant reading from the current course notes[6] that will be updated for the 2017 course.

We have already mentioned above examples classes as formative assessment. These by their design also provide a learning environment for students. Designing a relevant question is the most difficult aspect. Currently we have several ideas and these all have novel, interesting and inspiring physics problems that the students can solve with the course material. For example designing the most efficient orbit to send their (least) favourite lecturer to Mars. Or for the electromagnetism course we would ask students to build up over the course a physical model of a coaxial cable. Their geometry is simple and as the students learn how to model something by combining their physics and maths knowledge. What they will find is that in theory it is impossible to detect any signal going down the wire without cutting into it. The final example class would ask them to think about the assumptions they've made and how it may be possible to do the "impossible".

Until we begin to run these example classes it will be difficult to estimate how much students can achieve in each lecture. But we hope that time can also be given over to answer student questions about assignment problems or running through the computer visualization codes. Although in a hour time will be limited. These example classes will be taught by the lecturer and a teaching assistant to provide enough supervision for the students.

[6] It can be found at https://drive.google.com/file/d/0Bwf2IkDZ3ywfbF9GMG4tMVMtQ0k/view?usp=sharing.

Table 1: lecture and example class list for PHYS202. Each lecture has assigned content, a key example to include, an in class activity/demonstration and the reading expected from the course notes (see footnote 6).

| # | Learning Objective | Example | Activity | Reading |
|---|---|---|---|---|
| L1 | Scalar & vector fields, gradient operators, monopole charges | Charged black hole | Students standing up and pointing to represent fields. | 1 |
| L2 | Electric fields - dipoles and groups of charges | Ring of charge (hula-hoop) | Charged ruler near a jet of water | 2 |
| L3 | Potential - equipotentials | Derive field of dipole from potential | Equipotential of each student for around a charge (football). | 3.1-3.4 |
| EX1 | Coax cable: field around line of charge/cylinder of charge | | | |
| L4 | Flux and Gauss' Law - simple capacitor | Thundercloud | Table/desk as capacitor. Gaussian surface and flux described by fishing net. | 4.1-4.9 |
| L5 | Stored energy in capacitor & integral form of Gauss' Law | Energy stored in capacitor (why are they in circuits?) | | 4.10-4.12, 5.1-5.2 |
| L6 | Capacitors with dielectrics & differential form of Gauss' Law | Make capacitors from tin-foil with cling film and paper. If you roll capacitor up, what changes? | | 5.3-5.8 |
| EX2 | Coax cable: capacitance of a coax cable<br>Electric circuits: discharge time of capacitor through a resistor | | | |
| L7 | Magnetic fields - ampere's law & biot-savart law | Field of long straight wire by both laws. | Rope and hula hoops for field around wire. | 6.1-6.5 |
| L8 | Magnetic dipoles & rings of current | Hula hoop for ring of current | Linking back to electric dipoles. | 6.6-6.13 |
| L9 | Faraday's law & inductance | Inductors and transformers. | Turning on a mobile phone inside a solenoid. | 6.15<br>7.1-7.10 |
| EX3 | Coax cable: current in cable and magnetic fields<br>Electric circuits: inductors and capacitors in radio receivers. | | | |
| L10 | Energy storage & magnetic materials | Derive energy stored in magnetic field. | Why are only some materials magnetic? | 7.11-7.14 |
| L11 | Maxwell's equations & displacement current | What is displacement current? | Turn classroom into circuit to help with visualization. | 8 |
| L12 | Electromagnetic waves | Show wave is solution to equation. | Slinky spring 1D wave motion. Why does mobile phone reception vary inside a room? | 9 |
| EX4 | Faraday cages: wrapping mobile phones up in foil.<br>Coax cable: transmission of EM waves can you eavesdrop? | | | |

**4) DISCUSSION AND SUMMARY**

I have mentioned and discussed aspects of the redesign with students, including current and future 2nd years. In general aspects of the redesign seem appealing to the students, especially the inclusion of examples classes. We have carried out SET evaluations on all our second year courses this year and will compare against next year's evaluations. We will also compare the exam and overall grade performances of students to evaluate the effectiveness of this redesign. Another important measure of success of this redesign will hopefully be increasing numbers of graduating physics students as found by OSU.

In terms of resources required for his course redesign they are as follows:

- 36 lectures, split into 3 sections and sequentially team-taught.
- 12 examples classes, run by lecturer and a TA.
- Second year lab content unchanged at 8x3 hour labs and a number of demonstrators.

The teaching load per course has increased by 12 classes and extra time for a TA. This redesign has support from the head-of-department and other academic staff. This load has already been included in the physics teaching allocations for 2017.

Other points that have arisen from discussion with other lectures and students:

- Prerequisites for the course are required and students must have taken PHYS121 and relevant maths courses.
- The drive to make sure students realise maths and physics are connected we must repeated make this clear and also highlight links between physics course, using the OSU paradigms to explain this.
- The structure defined here has been clear enough that another lecturer has already used it to designed a thermodynamics course for PHYS201.
- Current and retired lecturers in physics department have recognized the importance of this report and how it will become important to raising the ability of our graduates.
- Looking ahead it will be interesting to think what aspects of this pedagogy and be incorporated into our 3rd and 4th year courses in future.

In summary we have presented the outline for new signature pedagogy for the 2nd year physics courses at the University of Auckland. The learning outcomes now concentrate on stating that students will learn how to solve problems in physics with a variety of methods and also be able to explain their solutions and findings. Assessment concentrates on testing students achievement of these outcomes. Finally the teaching style will be changed to become more active with a greater emphasis on teaching students how to solve problems and use their knowledge of physics. The new structure has received positive feedback from all relevant stakeholders and will be implemented from first semester in 2017.

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## Bibliography


- Anderson R.S., & Speck B.W., 1998, “Oh what a difference a team makes”: Why team teaching makes a difference. *Teaching and Teacher Education, 14*(7), 671-686.
- Berrett D., 2012, *How "flipping" the classroom can improve the traditional lecture.* The Chronicle of Higher Education, *12*, 1-14. (http://chronicle.com/article/How-Flipping-the-Classroom/130857/).
- Beichner R. J., Saul J. M., Abbott D. S., Morse J., Deardorff D., Allain R. J., Risley J. S., 2007, *The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project*. Research-based reform of university physics, 1(1), 2-39.
- Beichner R., 2008, *The SCALE-UP Project: a student-centered active learning environment for undergraduate programs.* Invited paper for the National Academy of Sciences. (Retrieved from http://www7.nationalacademies.org/bose/Beichner_CommissionedPaper.pdf).
- Beichner R. J., Saul J. M., Allain R. J., Deardorff D. L., Abbott D. S., 2000, *Introduction to SCALE-UP: Student-centered activities for large enrollment university physics.* US Department of Education, Office of Educational Research and Improvement, Educational Resources Information Center.
- Biggs J., 1996, *Enhancing teaching through constructive alignment.* Higher education, 32(3), 347-364.
- Bonwell C.C., Eison J.A., 1991, *Active learning: Creating excitement in the classroom.* ASHE-ERIC Higher Education Report No. 1. Washington, DC: The George Washington University, School of Education and Human Development.
- Brookfield S., 2006, *Experiencing teaching.* The Skillful Teacher (2nd ed., pp. 1-16). San Francisco, CA: Jossey Bass.
- Crouch C.H., Mazur E., 2001, *Peer instruction: Ten years of experience and results.* American Journal of Physics, *69*(9), 970-977.
- Dale E., 1969, *Audio-Visual Methods in Teaching*. Holt, Rinehart, & Winston.
- Deslauriers L., Schelew E., Wieman C., 2011*, Improved learning in a large-enrollment physics class. Science*, *332*(6031), 862-864.
- Foote K. T., 2015, *Diffusion, Implementation and Reinvention of a University Physics Reform: The Case of SCALE-UP.* Doctor of Philosophy Thesis, http://www.lib.ncsu.edu/resolver/1840.16/10231
- Heller P., Hollabaugh M., 1992, *Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups.* American Journal of Physics, 60(7), 637-644.
- Manogue C.A., Siemens P.J., Tate J., Browne K., Niess M.L., Wolfer A.J., *Paradigms in Physics: A New Upper-Division Curriculum*, American Journal of Physics 69, 978–990 (2001).

- Manogue C.A., Krane K.S., *Paradigms in Physics: Restructuring the Upper Level*, Physics Today 56, 53–58 (2003).
- McDermott L.C., Redish E.F. (1999), *Am. J. Phys.* **67, 755**
- Prince M.J., 2004, *Does active learning work? A review of the research. Journal of Engineering Education, 93*(3), 223-231.
- Redish E.F., 2003, *Teaching physics: with the physics suite* (p. 105). Hoboken, NJ: John Wiley & Sons.
- Sawyer R.K., 2006, *The Cambridge Handbook of the Learning Sciences.* New York: Cambridge University Press.
- Shimazoe J., Aldrich H., 2010, *Group work can be gratifying: Understanding & overcoming resistance to cooperative learning*. *College Teaching*, *58*(2), 52-57.
- Shulman L., 2005, *Signature pedagogies in the professions. Dedalus,* 52-59.
- Wenger M. S., Hornyak M. J., 1999*, Team teaching for higher level learning: A framework of professional collaboration.* Journal of Management Education, *23*(3), 311-327.
- Wineburg S., Schneider J., 2009, *Was Bloom's Taxonomy pointed in the wrong direction?* Phi Delta Kappan, 91, 56-61.

# APPENDIX A - Example Assessments

**PHYS202 Exam Questions:**

Students attempt all 6 section A short questions and best 4 of 6 section B longer question. Below are listed sample questions for the electromagnetism third of the course.

Section A

1) A neutron star is a sphere 10 km across and can have magnetic fields of up to $10^{15}$G on the surface. Modelling this as a magnetic dipole, what is the current required to form this field? [5 marks]
2) Walking around wearing rubber soled shoes it is possible to build up a charge. Modelling a person as a parallel plate capacitor with their shoes as the dielectric material between the plates, what charge can a person build up? Given the relative permeability of rubber is 3 and the breakdown voltage of air is 3e6 V/m. [5 marks]

Section B

1) This question is about magnetic fields.
    a) State the the Biot-Savart law and give the meaning of each term in the equation. [6 marks]
    b) Consider a circular ring of wire, radius a that carries a current I. Using the Biot-Savart law derive that the expression for the magnetic field, B(z), along the central axis of the ring at a height, z, above the plane of the ring. Make sure you draw a clearly labelled diagram to illustrate the geometry. [10 marks]
    c) Now consider another wire or radius b that is place in the same plane, with its axis aligned to that of the first ring but with the current flowing in the opposite direction. Derive the resultant field from the two rings. [4 marks]
2) This question is about electric fields.
    a) A capacitor is formed from two square parallel air-spaced plates with sides of length l and a distance d apart. What is the capacitance of capacitors? [2 marks]
    b) By considering moving charge from one plate to the other calculate the energy stored on the capacitor. [3 marks]
    c) Dielectric material, with permittivity, $\varepsilon$ r = 5, is now put between the plates filling the distance between the plates filling the area completely. What is the new Capacitance? [1 marks]
    d) If the charge on the plates is kept constant as the dielectric material is inserted between the plates, how much energy is then stored in the capacitor? Why is there this difference in energy? [2 marks]
    e) If instead the voltage on the plates is kept constant as the dielectric material is inserted between the plates, how much energy is now stored in the capacitor? Why is there this difference in energy? [2 marks]
    f) Write SHORT notes on TWO of the following:
        i) What is the displacement current? [5 marks]
        ii) Gauss' law for electrostatics. [5 marks]
        iii) Electric dipoles. [5 marks]
        iv) The Hall Effect [5 marks]

**PHYS202 Assignments:**

Below we list some sample short and longer questions for formative assessment assignments. Typically questions will be combined such that each assignment will have questions worth 30 marks but the maximum score will be 20 marks.

**Shorter questions (typically worth up to 5 marks each).**

1) Two charges of +*Q* and -*Q* are separated by a distance of 2*a*. Using the electric potential of the two charges derive the electric field at large distance from the dipole.
2) Estimate the current that flows through a lightning strike. Given that the breakdown voltage of air is $3\text{x}10^6$ V/m and a lightning strike lasts for 30 microseconds.
3) Consider a Hall Probe, if a current *I* flows through the probe and it is in a magnetic field *B* perpendicular to the surface of the probe or area *A* and thickness *t*, what is the resultant potential across the probe?
4) Given a radio transmitter has a power of 10kW and a radio receiver requires an electric field strength of 1V/m to receive a clear signal, what is the range of the radio broadcast?

1. A black hole can has only 3 properties, mass, spin and charge. Consider a charged black hole with the mass of the Sun ($2 \times 10^{30}\text{kg}$), how much charge does the black hole need so that it can't accrete electron? [Hint: compare the graviatational and electric forces between the black hole and electron.]

2. A coaxial cable has equal and opposite currents flowing in the inner and outer conductors. Sketch the electric and magnetic fields. Also explain why the field *outside* the cable must be zero.

3. Calculate the mutual inductance of a long straight wire running through a toroidal coil, the toroidal coil has width $W$, inner radius of $R$ and height of $h$. [Hint: look at pages 79 and 80 of the textbook].

   Would same same expression hold when the current is passed through the toroid? What would you have to assume about the circuit that completes the conducting path of the wire?

4. Estimate the capacitance of a thundercloud, take reasonable estimates for its size and that the permeability of air is $\approx 1$. If the breakdown field of air is, $3\times10^6$V/m, what charge flows down a lightening bolt? [Hint: the answer on really depends on how big you assume a cloud, about $1km$ in size?]

**Longer Questions (typically similar to past exam questions so worth 10 to 20 marks each).**

2. Two spheres have an identical mass $m$ and charge $q$ and they hang from two non-conducting, massless threads of length $L$ that are hanging from the same point. Because of the repulsive electric force between them they move apart so that each thread makes an angle $\theta$ to the vertical.

   (a) Draw a diagram to represent the forces acting on this system.

   (b) Assume that $\theta$ is small so that $\sin\theta \approx \theta$. Show that in equilibrium,

   $$x = \left(\frac{q^2 L}{2\pi\epsilon_0 mg}\right)^{\frac{1}{3}}$$

   where x is the separation between the spheres.

   (c) If $L = 120$cm, $m = 10$g and $x = 5$cm, what is q?

5. A coaxial cable consists of inner and outer conductors having radii, $a$ and $b$ respectively. They also have charges of $+\lambda$ and $-\lambda$ respectively. For this arrangement calculate by using Gauss' theorem or otherwise,

   (a) The electric field at a distance $r$ from the centre of the cable.

   (b) The potential difference between the conductors.

   (c) The capacitance of the cable per unit length.

   (d) The field outside the cable.

6. An air-spaced parallel plate capacitor has plates 10 cm by 10cm, spaced 2mm apart. It is charge to 100V. No charge is allowed to be added of removed in the following operations. Calculate the following,

   (a) What is its capacitance?

   (b) What is the energy stored in the capacitance?

   (c) A slab of material, $\epsilon_r = 5$, is slid between the plates, completely filling the gap. What is the new capacitance?

   (d) What is the energy now stored in the capacitor? If not equal to the original energy where did the energy come from or go to?

1. A high voltage 50 Hz transmission system has 2 conductors spaced a distance $d$ apart, suspended at a high $h$ above the ground. They carry equal and opposite currents of $I$ Amps. Assume the wires are straight and infinitely long.

   (a) Explain why the magnetic field on the ground directly underneath the *centre* of the system is almost zero.

   (b) Find the magnetic field directly at this central point if $d = 10$metres, $h = 30$metres and $I = 100$Amp.

   (c) Show that as the conductors are brought closer together the magnetic field of part (b) ends asymptotically to,
$$B = \frac{\mu_0 I d}{2\pi h^2}$$

4. This question concerns the Biot-Savart law.

   (a) Give the meaning of each term in the equation and describe how the equation is used to calculate a magnetic field strength. [4 marks]

   (b) Consider a circular ring of wire, radius a that carries a current $I$. Using the Biot-Savart law derive the expression for the magnetic field, $B(z)$, along the central axis of the ring at a height, $z$, above the plane of the ring. [6 marks]

   (c) Now consider a circular wire that has no flowing current but has a total electric charge q that is evenly distributed around the ring. Derive an expression for the electric field, $E(z)$, along the central axis of the ring at a height, $z$, above the plane of the ring. [7 marks]

   (d) Consider a point charge, $-q$, placed at rest on the ring axis, a small distance above each ring plane. Qualitatively describe how the charge will move when a current flows in a ring and when the ring holds a stationary charge. [3 marks]

# APPENDIX B - Learning Objectives for 2nd year courses

Here we list the learning objectives for each of the 3 main 2nd year courses along with the relevant examples that have been thought of to date for each course. These have been created by the Century 2 committees and are still at a draft stage. These will provide the skeleton to design the courses around.

**PHYSICS 201 Classical and Thermal Physics**

This course covers classical mechanics and thermal physics. Key topics are linear and rotational motion in three dimensions, fluid motion, oscillations and mechanical waves, and the laws of thermodynamics.

**<u>Learning objectives/lecture list:</u>**

**Classical Mechanics**

1. introduction
2. kinematics
3. dynamics
4. rotating frames
5. Kepler's laws
6. systems of particles and rigid bodies
7. fluid dynamics
8. elasticity
9. Chaos

**Oscillations and Waves:**

10. power series, complex numbers: phasors
11. SHM; damped harmonic motion
12. critical damping and time constants; forced harmonic motion
13. resonance and the Q factor
14. coupled oscillators
15. normal modes and beats
16. The one-dimensional wave equation: general solution, separation of variables
17. fundamental modes
18. boundary and initial conditions; eigenfunctions and eigenvalues
19. superposition and travelling wave solutions
20. Fourier series
21. periodic functions and Fourier coefficients

**Thermodynamics:**

22. internal energy
23. 1st law and ideal gas law
24. enthalpy
25. specific heat and Poisson's relations
26. specific heat of gas molecules
27. entropy of the ideal gas
28. entropy and the second law
29. thermodynamic efficiency
30. phase changes and SVP
31. free energy and Clausius-Clapeyron
32. the van der Waals equation of state

33. thermal emission and Kirchhoff’s law
34. Stefan-Boltzmann and the Planck function

**Examples in lectures and examples classes:**

- Rocket equation; orbital dynamics: transfer orbits, gravitational slingshot
- What is the minimum safe distance when parked at traffic lights?
- Two masses connected by string falling off table edge compared to a chain
- Motion of hanging slinky once released from top
- Bicycles: when you put the breaks on how easy is it to go over the handlebars when you jam on the front/rear brakes?
- American Ninja Warrior: how high can you run up a wall?
- spaceship design in sci-fi (e.g. Star Wars vs Battlestar Galactica)
- bridges as oscillators (Mythbusters episode)
- everything experiences SHM: resonance in computers (why do they hum) - DVD players, power supplies
- waves on a string/slinky
- Musical instruments: recorder/violins/pianos
- Steam engine, (e.g. MOTAT or https://en.wikipedia.org/wiki/Crossness_Pumping_Station)
- Car engines
- Air conditioners
- Fridges
- the atmosphere: Temperatures of the planets - habitable zones around planets
- evaporative cooling
- Is the three bears fairy story correct?

**PHYSICS 202 Electromagnetism**

This course covers electromagnetism. Key topics are electric and magnetic fields, the generation of magnetics fields by currents, the derivation of Maxwell’s equations, the interpretation of light as an electromagnetic wave and polarisation.

**Learning objectives/Lecture list:**

1. Introduction, gradient operator & charges
2. Electric fields, dipoles and potential
3. Equipotentials, flux and Gauss's Law
4. Capacitors, dielectrics and energy storage
5. Gauss's law: with dielectrics and the integral form
6. Magnetostatics: Biot-Savart and Ampere's Laws
7. Magnetic dipoles
8. Faraday's Law; Inductance
9. Energy Storage, Magnetic Materials
10. Maxwell's Equations
11. Electromagnetic waves
12. boundary and initial conditions; eigenfunctions and eigenvalues
13. superposition and travelling wave solutions
14. Fourier series (and transforms?)
15. periodic functions and Fourier coefficients
16. Poynting flux, energy

17. momentum, radiation pressure, Wave optics
18. photons, wave-particle duality, electromagnetic spectrum
19. Diffraction
20. Diffraction Examples, Gratings
21. Dipole oscillators
22. Dispersion
23. Interference and Huygen's Principle
24. Interferometers
25. Coherence, Resolution
26. Polarization and polarisers
27. Stokes formalism and Matrices
28. Fresnel Reflection
29. Fabry perot interferometer
30. Lasers and their applications

**Examples in lectures and examples classes:**

- rings of charge and current,
- transmission lines, transformers (not robots in disguise-this joke is mandatory), and electricity distribution networks
- Electric motors & alternators,
- Hall effect - accretion disks,
- van allen belts - compare Earth's and Jupiter's?
- charged ruler and jet of water (i.e. water flowing out a tap - very easy example of dipoles and electric fields),
- faraday cages and why your phone doesn't work in elevators,
- coax cables,
- radio telescopes,
- synchrotron radiation,
- Why does the strength of a radio signal vary as I move around a room
- Antenna design - why linear and circular components?
- Mobile phone compact antennas?
- Can you reverse the polarity of a neutron flow
- Optical illusions using polarisation, reflection and refraction
- Optical activity of biological tissue
- Fabry-perot spectroscopy

**PHYSICS 203 Relativity, Quantum, and Nuclear Physics**

This course covers relativity, quantum, and nuclear physics. Key topics are the principle of relativity, relativistic energy and mass, de Broglie waves, wave functions and the Schrödinger equation, nuclear structure and radioactive decay.

**Learning objectives/lecture list:**

1. What is a theory of relativity
2. The Michelson-Morley Experiment
3. Biot Savart and static EM fields
4. Lorentz transformations, time and length contraction
5. Relativistic invariants and kinematics

6. Mass-energy equivalence and 4 vectors
7. matter waves & de Broglie wavelength
8. electron diffraction & wave particle duality
9. Wave functions and the Born interpretation
10. Schrödinger equation and the HUP
11. particle in a box
12. observation, QM operators, and expectation values
13. quantum oscillator and quantum tunneling
14. Schrödinger equation 3-D
15. particle in 3-D box
16. central forces; angular momentum
17. hydrogen atom
18. orbital magnetism; Zeeman effect
19. electron spin; Stern-Gerlach experiment
20. the Dirac equation and the positron
21. bosons and fermions and Fermi-Dirac statistics
22. two-electron wave functions and the exclusion principle
23. molecular bonding; rotations & vibrations
24. intro to band theory
25. Nuclear structure: protons/neutrons, island of stability
26. Nuclear models: liquid drop model, semi-empirical mass formula, shell model
27. Nuclear fission, controlled and uncontrolled energy release
28. Nuclear fusion, quantum tunnelling and fusion reaction rates
29. Nucleosynthesis
30. Radiation-matter interactions: Bethe’s description
31. Rayleigh scattering and fluorescence
32. Raman and Compton scattering
33. Radiation dose and damage
34. Radiation safety
35. Nuclear Medicine
36. Medical Imaging

**Examples in lectures and examples classes (more requires):**

- stability chart of nuclear matter
- radioactive sources of alpha, beta and gamma rays
- construction and design of nuclear reactions for power generation,
- nuclear waste storage
- stars as gravitationally confined fusion reactors,
- production of primordial light nuclei
- production of heavy elements in stars
- Bethe energy loss in matter equation
- time, distance and shielding in radiation protection
- Natural sources of background radiation
- The bragg peak and radiotherapy
- production/transportation and use of technetium-99m
- Iodine-131 treatment of thyroid cancers
- Raman spectroscopy of carbon allotropes

# APPENDIX C - Answers to interesting questions in text

- How long does it take the cold air in a fridge to flow out when you open the door?

Answer: about a minute, the cold are at the same pressure at the air outside is denser and so flows out of the fridge. However it’s only slightly less dense so it takes longer.

- Why is it possible to get electric shocks when touching a conductor when walking around shops in trainers?

Answer: your trainers are effectively like a dielectric in a capacitor so as you walk around you build up a charge on you. If you touch something metal you discharge that which you feel as an electric shock.

- Can you reverse the polarity of a neutron flow?

Answer: at a simple level no as they’re neutral. But neutrons are made up of quarks which have a “spin” and thus do have a magnetic field which can be reversed from “up” to “down” or vice versa.

- Why is water deflected by a ruler?

Answer: if you rub a perspex ruler or rod with a cloth you charge it up. Putting it near water the water has a positive and negative side to the molecule so it arranges itself relative to the charged ruler and is attracted towards it. Try it yourself!