Teacher resources in kinematics: a project for the Physics Olympiads

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Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma at any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except when due reference is made in the text.

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Abstract

This study is concerned with the creation of resources for high school physics teachers at the request of the organisation Australian Science Innovations (ASI). The aim of the study is to create resources that are based on the latest research in teaching and learning methods and are relevant to all teachers across Australia. The resource are to be used by ASI to attract more students to the Australian team that participates in the International Physics Olympiads competition.

In order to create suitable resources, the questions of what would constitute a relevant and adequate resource were considered. The main knowledge emphases for science education were researched, and the literature on learning theories was reviewed. Ways to make science more appealing to school students were discovered, including ways to make the science classroom more inclusive for female students. The way teachers preferred their resources to be presented was also found through a review of the literature.

The relevance of the resources to Australian teachers was ensured by examining all the science curricula of the states and territories of Australia and finding common topics of physics. The topic of kinematics was chosen for the resources. Common difficulties students have with kinematics were then investigated through research of the literature, and some currently available resources on this topic were reviewed.

Finally, two resources were created. *Survival Physics* is centred around an unlikely story of being lost in the desert, tracking footprints, catching a tiger and putting it in a zoo. *Traffic Physics* is a mixture of craziness and caution: there are stunts from movies and TV, and there are lessons in crashes and how to survive them.

It was found that these resources encapsulated much of what was learned throughout the study, but that because the study was limited in scope all recommendations could not be incorporated into just two resources. The main limitation of the study was that, due to the size of the study, no evaluation of the resources was carried out.

This study provides a template for the future creation of similar resources for ASI, not only in physics but also in chemistry and biology. The resources were delivered to ASI at the conclusion of the study.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1   Introduction

This thesis concerns the creation of resources for high school physics teachers to use in the classroom. The thesis topic was developed after conversations with Australian Science Innovations (ASI)[1].

This chapter first describes the background to the thesis, the organisation ASI, and the purpose of the study. Following this, three research questions are identified and the method used to address each of them is outlined. The significance of the study is then discussed, followed by its limitations.

1.2   Background to the study

ASI is a not-for-profit educational organisation that runs the Australian Science Olympiads (ASO)[2].

The Australian Science Olympiads test the science knowledge of Year 11 or younger school students from around the country, with the ultimate aim of selecting students to be in the team that participates for Australia in the International Science Olympiads. There are three International Science Olympiads, one each for physics, chemistry and biology. There is also an International Mathematical Olympiad and an International Informatics Olympiad, but ASI does not have any direct involvement with these. More detail on the International Olympiads can be found in Section 2.2.

Science is a core subject in all states and territories across Australia, and it is well

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[1]Homepage at `http://www.asi.edu.au/`
[2]Homepage at `http://www.aso.edu.au/`

known that science teachers are in short supply, and are typically very busy. Resources for teachers are therefore seen as a valuable tool in the classroom. Resources are generally intended to supplement the standard textbooks and activities created by the teacher.

ASI supplies many resources for science teachers across all school age ranges in the subjects of chemistry, biology, physics and astronomy. These resources are primarily from two independent programs: Rio Tinto Big Science Online (RTBSO) and **LAB**LINKS, and are both delivered online. The RTBSO resources are interactive exercises for students to complete, while the **LAB**LINKS resources are for teachers and consist of suggestions for activities that incorporate information communication technology.

This study focuses on the subject of physics. This subject readily lends itself to resource creation, as many physics experiments and activities require only commonly available materials. It is anticipated, however, that the results of this study could quite easily be applied in a chemistry or biology setting.

1.3   Statement of Problem

The problem addressed by this study, and as stated by ASI, is that the ASI wishes to make more teachers aware of the Australian Science Olympiads. A way to do this, proposed by the Executive Director of ASI, Dr Chris Stewart, is to create resources for teachers to use in the classroom that are linked to the Australian Science Olympiads. As was seen in the previous section, the resources currently supplied by ASI are not directly tied to the Olympiads. In addition, the states and territories of Australia each have a separate school curriculum and the **LAB**LINKS and RTBSO resources provided by ASI do not attempt to adhere specifically to any of these curricula.

The resources provided by ASI are generally created by practitioners of the specific science topic. For example, as someone with some background in astronomy, I created a **LAB**LINKS experiment on the topic of parallax.[3] Although I used my best judgement, the brief I was given did not include scope for research on whether the topic would be relevant for schools, whether the questions would engage the students, or whether the resource would create a loathing of astronomy instead of an interest in it.

The problem that this thesis will address, therefore, is ASI's lack of resources tied to

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[3]*The Speed of the Stars*, available from `http://www.lablinks.edu.au/www/index.cfm?ItemID=162`. I have also been employed by ASI to proof-read resources for RTBSO.

the Australian Science Olympiads, that are curriculum-relevant, and are researched as to their effectiveness in classrooms.

1.4   Purpose of Study

The purpose of this study is to create some exemplary resources for teachers, in a particular area of physics, that are relevant and researched.

The resources will be on curriculum topics that are relevant to as many teachers as possible across all states and territories of Australia. The resources will contain the most up to date methods of teaching in the particular area of physics chosen, and thus will ensure that students are engaged and interested. Finally, the resources will be relevant to the Australian Science Olympiads.

This study will also have the effect of creating a model for the future creation of similar resources for ASI, allowing others to follow in different areas of physics, and in different science subjects.

1.5   Research Questions

The research questions are as follows:

1. *What do I need to consider when designing an adequate resource?* Work on this question will mean the resources are more likely to engage rather than disengage the students.

2. *What areas of the state and territory curricula are relevant?* The answer to this question will ensure that the resources created are relevant to all teachers in Australia.

3. *Can a resource be designed that is relevant and adequate?* Resources will be created with the previous two questions in mind.

1.6   Overview of Method

The question "What do I need to consider when designing an adequate resource?" was answered by reviewing the literature. Several topics in education research were covered and the results are given in Chapter 2. These include the currently popular knowledge

emphases, learning theories, how to make science appealing to students and the physical realities of resource design.

To answer the question "What areas of the state and territory curricula are relevant?", all the Year 10-12 science curricula in Australia were obtained and the common topics in physics were found. A topic within physics that is common to all states and territories was chosen and then it was determined where the students are coming from (Year 10 topics), where they need to be (Year 12 topics), and what knowledge they need to bridge the gap. This question is answered in Chapter 4. Also in this chapter, the commonly held misconceptions and general difficulties students have with the chosen physics topic are investigated. Along with this, some currently available resources in the chosen topic are reviewed.

"Can a resource be designed that is relevant and adequate?" is demonstrated by the creation of two sets of resources. These resources contain activities that are based on the results of the first two research questions.

1.7   Significance of Study

This study is significant in that it results in the creation of fully-researched and curriculum-relevant resources for Australian high school teachers in one area of physics. This is significant for teachers as they will be able to seamlessly integrate the activities contained in the resources into their lessons, safe in the knowledge that the activities are relevant to the curriculum.

This study is also significant because it is useful to ASI as it will provide a template for the creation of future resources. Using the results of the literature review and the methods outlined in this study, ASI could then commission a full set of resources across all three science subjects that would complement the work of the Australian Science Olympiads. The ultimate result of this could be that more students will want to take part in the Australian Science Olympiads and more will continue with further study in science.

1.8   Limitations of Study

Due to the size of the study, only one area of physics is addressed in the resources, and only two resources are created. It is anticipated that this will be enough, however, to provide an adequate template for the creation of future resources.

Due to time constraints, no interviews with teachers on their opinions, and use, of resources in general could be undertaken. If this study were done on a larger scale, discussions with teachers known for their innovative lessons would be undertaken to gain some insight as to what activities particularly work with students.

Finally, because of the limited size of the study no evaluation of the resources could be undertaken. This is a critical limitation and one that should be addressed by ASI before further resources are created. The evaluation could be on several levels: the first level could involve giving the resources to selected teachers and letting them report on criteria such as the success of the resources in the classroom and their usability; the next level could involve larger scale tests, where resources were used in some classrooms and not others, and test scores and student and teacher opinions of the lessons could be found.

1.9   Overview of the Thesis

The next chapter (Chapter 2) contains the literature review. In this chapter, the first research question is answered ("What do I need to consider when designing an adequate resource?"). An introduction to the International Olympiads is given, then the literature on educational research is investigated and questions as to the currently fashionable knowledge emphases, learning theories and techniques to make science appealing to students are discussed.

In Chapter 3, the method for designing the resources is outlined, with the reasons behind the selection of content and the physical design being discussed.

Following this, Chapter 4 contains the results of the study. Research questions two and three are answered ("What areas of the state and territory curricula are relevant?" and "Can a resource be designed that is relevant and adequate?"). The various school curricula of Australia are studied and the topic for the resources is chosen. Misconceptions and student difficulties in this topic are discovered, and some current resources on the chosen topic are briefly evaluated. Then, two resources are created with this knowledge in mind.

Chapter 5 contains the conclusion of the study, including setting out the limitations and recommendations for further work.

1.10 Conclusion

In this chapter the background to the study was outlined. This began with a discussion of ASI and the need for resources for teachers. Then the problem to be addressed in this study was stated, followed by the resulting purpose of the study. The purpose was stated to be to create resources for high school physics teachers to use, which have the additional purpose of advertising the existence of the Australian Science Olympiads.

Next, three research questions were stated which were answered over the course of this study. An overview of the method to answer these questions was outlined. This included a review of literature, a study of the curricula from across Australia, and the actual creation of two resources for teachers to use.

The limitations of the study were discussed, and these included the fact that the resources could not be evaluated in the time available in the study. Finally a summary of what will follow in the thesis was given.

In the next chapter, the literature related to the first research question "What do I need to consider when designing an adequate resource?" is reviewed.

Chapter 2

Review of Related Literature

2.1   Introduction

The aim of this chapter is to answer the research question 'What do I need to consider when designing an adequate resource?'. The focus is on physics as this is the subject for which the resources will be created.

The starting point for the chapter is the Australian Council for Education Research's (ACER) Australian Education Review. As part of the ACER Review, a document called "Re-imagining Science Education: Engaging students in science for Australia's future" was published which was the result of the 2006 ACER conference,"Boosting science learning – What will it take?" (Tytler, 2007). This document is particularly important in terms of this study because of its focus on Australian schools.

The chapter will begin by investigating the International Olympiads and the process students go through to make the Australian team. What knowledge do the organisers expect the entrants to know, and why? This is outlined in Section 2.2. Participation in the International Olympiads is the highest goal for students who are associated with the Australian Science Olympiads.

Then, with this in mind, the main knowledge emphases currently fashionable in science education will be discussed. Knowledge emphases describe what students learn in the classroom. Do they learn pure facts and formulae, or perhaps how science can affect their everyday lives, or how science is done? All of these topics are discussed in Section 2.3 and they are important to know for two reasons: resources that are created with the current favourite emphases in mind are more likely to be used by teachers; and research into what is best for students to learn should inform the contents the resources created for this study.

In Section 2.4 the main learning theories associated with science are reviewed. These include conceptual change, context-based learning and inquiry-based learning. Knowing how students learn best means the resources created on this basis will be useful for students and teachers alike.

Making science appealing to students is critical to this study. The aim is to get more students interested in science, so that more students express an interest in participating in the Olympiads. Several ways of making science classes enjoyable for students are discussed in Section 2.5. These include considerations of practices that avoid bias against gender and culture, and incorporating practical work into the class in an effective way.

The final section, Section 2.6, discusses the current best practice for designing resources for teachers. This includes discussion of the format teachers prefer for their resources (e.g. paper, CD, online), the adaptability of resources and the language level used. This is important for the study as saving teachers extra work will mean the resources are more likely to be used.

In the conclusion to the chapter (Section 2.7), the findings are summarised. This summary is used as a guideline for creating the resources for this study.

2.2   The International Olympiads

In this section the process students must complete to become part of the Australian Science Olympiad team is outlined. Then the questions of what knowledge students need and why they need it are answered.

Students wishing to participate for Australia in the International Olympiads must first take the National Qualifying Exam (NQE), administered by the Australian Science Olympiads, in either physics, chemistry or biology. This exam is open to students in Year 11 and below. According to the Australian Science Olympiads website, the NQEs test students' "problem solving ability as well as their ability to understand science concepts" (Australian Science Innovations, 2005a).

The top 20 students in each of the three subjects are invited to the Australian Science Olympiads Summer School held in Canberra each year. During the Summer School students typically cover the material seen in a first year university course in an intensive fortnight of study (Australian Science Innovations, 2005b). The most successful students are then chosen to represent Australia at the International Olympiads. In physics there are five students per team, and in chemistry and biology there are four.

The International Physics Olympiads were first held in 1967 (International Physics

Olympiads, 2008a). The reason for the competition's conception is noted on the Olympiads website (International Physics Olympiads, 2008c):

> In recognition of the growing significance of physics in all fields of science and technology, and in the general education of young people, and with the aim of enhancing the development of international contacts in the field of school education in physics, an annual physics competition has been organised for secondary school students.

On the first day of the two-day competition students are given three theoretical problems to solve "involving at least four areas of physics taught in secondary schools". Thus, multiple topics and concepts from different areas of physics can appear in one question. On the second day one or two experiments are performed (International Physics Olympiads, 2008a).

There is some basic information on the Olympiads website about the types of questions and their difficulty: "Secondary school students should be able to solve the competition problems with standard high school mathematics and without extensive numerical calculation." and "the standard of problems should attempt to ensure that approximately half the students obtain over half marks" (International Physics Olympiads, 2008c).

The 2007 papers give more clues (International Physics Olympiads, 2008b). A copy of these papers can be found in Appendix B. The experimental problem consists of a set of instructions for performing a complex and precise task: determining the energy band gap of semiconductor films (Green Question). Little background knowledge of the specific problem appears to be required as the theory is described at the start and throughout the experiment notes. The experiment is unlikely to have been performed at school due to the complexity of the equipment involved, although the general topic of quantum mechanics may have been covered by this stage. The knowledge that *is* needed however, is university-level procedures for carrying out experiments, including estimating precision and error analysis.

The 2007 theoretical problems are varied in their scope. One requires a set of quantitative calculations and knowledge of a specific topic in physics, in this case, static electricity and mechanics (Orange Question). Another tests physics skills such as equation manipulation and dimensional analysis within the topic of cosmology (Blue Question). A third question is on the interpretation of observational astronomy data (Pink Question).

In summary then, the starting point for students wishing to participate in the International Olympiads is the NQEs, in which the students are tested on their problem solving ability and their understanding. At the International Olympiads the selected students are tested on their knowledge of physics facts, processes and methods, as well as their experimental skills. The reason the Olympiads test this knowledge is simply because the knowledge itself is being widely taught in schools.

The resources created in this study should therefore aim to equip students with problem solving abilities, understanding and knowledge of physics topics, and experimental skills and techniques.

2.3 Knowledge Emphases – what to teach?

There are several different motives for teaching school students science, and the ones that are favoured determine the curriculum focus, and what students will learn.

Reported in Tytler (2007, p. 22) are Roberts' (1988) Seven Knowledge Emphases for science curricula. These emphases are designed to encompass all the various themes that Roberts believes should be included in a curriculum. These are (with an added interpretation afterwards):

- "an everyday coping emphasis" – don't drink the bleach.

- "a structure of science emphasis" – how to do science.

- "a science, technology and society emphasis" – putting science in an everyday life context.

- "a scientific skill development emphasis" – how to do experiments.

- "a correct explanations emphasis" – theories, laws.

- "a self as explainer emphasis" – science history, science as part of culture.

- "a solid foundation emphasis" – to allow the student to go on to further study.

It is possible to group the emphases into several broader motives. First there is the traditional motive: that students should know a certain amount of specific science knowledge (i.e. facts, laws). This is discussed in Section 2.3.1.

Then there are the skills the students might need in their future lives to understand and participate in debates on science matters affecting society. These might include such

topics as global warming or whether to spend tax-payers' money building a telescope. This aspect is known as Scientific Literacy and is discussed in Section 2.3.2.

Lastly there is also the need for students to learn the principles of science, for example, the 'scientific method' and how to do effective experiments. This is known as the Nature of Science and is discussed in Section 2.3.3.

All three of these broad emphases could be applied in this study, depending on their advantages and disadvantages, as discussed in the following sections.

2.3.1   Learning science knowledge

It could be argued, for the purposes of this study, that gaining pure knowledge is the most important motive for learning science. The students who participate in the International Olympiads will need to know facts, laws and be able to solve problems. This covers Roberts' "correct explanation" and "solid foundation" emphases. The main reason students in general need science knowledge is to progress to further years of study.

It is likely, however, that 'learning science knowledge' is covered extensively in classrooms already, through the need to pass exams and complete homework. Therefore introducing specific resources to just teach facts may not be very useful for teachers.

2.3.2   Gaining scientific literacy

Scientific literacy is defined on the Organisation for Economic Co-operation and Development website in the following way (OECD, n.d.):

> Scientific literacy is the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.

Having scientific literacy is supposed to make students more capable future-citizens as well encourage them to be more 'science friendly'. In terms of Roberts' knowledge emphases, this would include "an everyday coping emphasis" and "a science, technology and society emphasis".

Millar & Osborne (1998) say in their *Beyond 2000* report that a curriculum focussed on scientific literacy should allow students to feel confident when interacting with scientific matters; understand the basis on which scientific advice is given; understand

media reports on science and feel confident holding an opinion on them; and be able to acquire new knowledge when needed.

To explore the importance of scientific literacy in schools, Tytler & Symington (2006) consulted Australian scientists to discuss, among other topics, "the skills and understanding needed by citizens to respond appropriately to advances" in their areas of research. These scientists were concerned about community attitudes to, or lack of engagement of the community with, various science-related topical issues such as water strategies and protecting Australia from pests. The solution to improving attitudes and engagement in future citizens was suggested by the scientists to be to make school science more relevant to students. The scientists noted that students also need certain capabilities which can be taught at school. These included:

- appreciating the importance of asking questions and being open-minded,

- the ability to judge the reliability of sources of information,

- different ways of thinking, including lateral thinking.

Tytler & Symington (2006) see "school science as a lifelong process of the education of citizens". To achieve this they suggest that school science should reflect real science, as practiced by scientists, as closely as possible. This would not only make students good future citizens, but also make science more interesting for them.

Millar & Osborne (1998) said that compulsory school science in the UK at that time was still designed solely to train future scientists. Since only a small proportion of students actually go on to be scientists, they argued that school science should cater more for students who will become citizens, interacting with science from the outside. This would not only benefit the students, but society as a whole. Millar & Osborne noted that future scientists do need to learn science knowledge to progress to further years of study though. The solution they suggested is to separate school science into two parts. The first part would be taken by all students and encompass the scientific literacy element. Following courses would offer a range of options, including vocational topics as well as more academic ones, allowing some students to continue with more 'fun' topics and the future-scientists to get the training they need.

Tytler (2007, p. 21) notes, however, that there are several questions that need to be considered when discussing the relevance of scientific literacy to the classroom. With reference to a particular situation encountered by a citizen involving science, these questions ask: Who is the citizen, what are the circumstances, how will the person

interact with science? The citizen could have a personal concern, such as the use of a medical drug. The concern could involve the local environment, such as the construction of a mobile phone tower. Perhaps the citizen is a politician voting on a science funding application, or maybe the citizen is a physics professor trying to decide whether to worry about a nearby plantation of genetically modified crops.

Another important question asked by Tytler (2007, p. 21) is, "What sort of knowledge would best serve the future needs of students as citizens?". Is the pure scientific knowledge relevant to an issue such going to be important, or is it better to understand how science works so the citizen can find sources of information, evaluate their trustworthiness and then apply the information to the situation?

Rennie (2006) reports that the major incentive for introducing scientific literacy into the classroom is the falling numbers of students who go in to take post-compulsory courses and higher education. She says that the majority of students find science to be irrelevant to their lives because of the emphasis on concepts and facts. She then goes on to point out that students who are comfortable with the traditional forms of teaching are more likely to go on to become scientists. This would suggest that scientific literacy cannot be used as a tool to get more students to continue with post-compulsory science and become scientists.

Creating resources for ASI with scientific literacy in mind would not appear to be the most appropriate approach as it is unclear exactly what should be the focus of the lessons. As will be seen in the next section however, a branch of scientific literacy is finding a niche in schools in the form of the Nature of Science.

2.3.3   Learning how science works

The Nature of Science is the learning theory that focusses on 'how science works'. It has a scientific literacy bent but it concentrates on students understanding the methods and processes of science, rather than on the detail of a particular social issue. In terms of Roberts' curriculum emphases, the Nature of Science covers "a structure of science emphasis", "a scientific skill development emphasis" and "a self as explainer emphasis".

A study by Osborne, Collins, Ratcliffe, Millar, & Duschl (2003) aimed to get agreement by 23 experts from the science community including scientists, educators, historians, philosophers and sociologists on the answer to the question "What should be taught to school students about the nature of science?". The experts were asked what they thought should be taught about the "processes of science", "the nature of scientific knowledge", and "the institutions and social practices of science".

They came up with nine themes, in the following order of importance (Osborne et al. (2003)):

1. "Scientific methods and critical testing". This is the testing of scientific hypotheses through experiments. The view was expressed that currently experiments in the classroom are seen as demonstrations, or practice at techniques, rather than as a source of testing of ideas.

2. "Creativity". School science does not generally allow students to be creative in the same way other subjects such as English or History do. Incorporating the Nature of Science however, would mean students could come up with their own models and ideas and test them, rather than just being taught facts and theories continuously.

3. "Historical development of scientific knowledge". The experts thought this was important because it brings a human aspect to science, something that is often lacking in science lessons. It would allow students to appreciate developments in science over time, and may create interest in students not keen on science.

4. "Science and questioning". Questioning should be central to science lessons, according to the experts, because "the more pupils question, the more they understand the thinking behind the scientific knowledge", and because questioning is central to real-life science.

5. "Diversity of scientific thinking". The aim here is to give students a "toolkit" of possible methods for dealing with and solving scientific questions. It highlights that "science is not rigid", that different methods can be used for the same problem and that sometimes new or adapted methods are developed.

6. "Analysis and interpretation of data". The most important idea in this theme is that different scientists can have different interpretations of the same data. This is useful for the future citizen, even if they do not become a scientist. One expert suggested a classroom activity where students were able to generate their own data, then different groups in the class could "highlight the data in different ways", giving students the opportunity to question each others' interpretation.

7. "Science and certainty". Emphasising the difference between the 'right' answers of school science questions and the inability of scientists to give answers to modern questions was thought to be important. It may encourage students towards

a career in science when they discover that, contrary to their classroom experience, not all questions in science have been answered.

8. "Hypothesis and prediction". Students ought to be immersed in the idea of making hypotheses and testing predictions as this is the "very basis of science". Some of the experts linked this theme to the "creativity" theme.

9. "Cooperation and collaboration in the development of scientific knowledge". This theme is concerned with showing students the social side of doing science, the team work and the peer review process. The experts suggested this could be incorporated in lessons with teamwork along with criticism of work of other students.

Osborne et al. (2003) conclude that the consensus among the experts in this study shows that these themes could be used as a basis for incorporating the Nature of Science into the school curriculum. They suggest however that the curriculum should not be divided along the lines of the themes and then have them taught separately, but that the themes should be used as a checklist to "to see that the activities in the curriculum provide sufficient opportunity to introduce, elaborate on, explore, and develop students' understanding of these components of science and its nature".

Tytler (2007, p. 24) reports that there is a consensus among "curriculum commentators" that curricula should include the provision for students understanding the Nature of Science.

The Nature of Science will be relevant to this study as, although it does not focus on acquiring 'hard' science knowledge, it is likely to make science more enjoyable for the student and have the added result of giving students some training in the tools and techniques of science.

2.3.4   Summary

In this section, three broad motives for teaching science to students were discussed. Teaching science knowledge was found to be important for students wishing to pass traditional exams and go on to further study. However, since most school science lessons are currently focussed on doing exactly this, the resources created for this study should not focus too heavily on this area.

Next, the idea of scientific literacy was investigated. Teaching for scientific literacy, it was argued, prepares students for their future lives, and makes science lessons more

interesting. As future citizens, scientific literacy advocates say, students should have the tools to interact with all kinds of science that they might come across in society. It was found, however, that there are some questions about this angle, mainly because it is not clear what sort of knowledge would be most useful to students.

Finally, the knowledge emphasis based on the Nature of Science was explored. This means teaching students how science works, the tools, techniques and culture. Nine themes emerged from experts in science on how to incorporate the Nature of Science into the classroom, ranging from better classroom experiments to encouraging creativity and diversity in thinking. The Nature of Science was found to be relevant for this study as it is likely to provide students with a broader understanding of science, which, if combined with learning science knowledge, could give students an edge in the Olympiads.

With the knowledge of *what* to teach students, the next section will discuss different ways to teach it.

2.4   Learning theories – ways to teach

Methods of teaching science have remained the same over the last 50 years, according to Tytler (2007, p. 3). In the traditional teaching method, the knowledge students are expected to gain is broken up into disciplines, students address standard problems where context is an afterthought, and they have practical work to "illustrate principles and practices".

This section will briefly review the different learning theories that exist. Learning theories endeavour to explain *how* people learn any kind of knowledge, not just science. Knowledge of the best way to help students to learn will be valuable in the process of creating effective resources.

2.4.1   Conceptual Change

In the 1960s and 1970s new science curricula began to appear all around the world, the heart of which was the notion of 'concepts' (Leboutet-Barrell, 1976). Examples of concepts in physics include Force and Heat.

Concepts acquired through everyday experience can often be incorrect, in which case they are known as misconceptions. An example of a misconception is that heavier objects fall faster than lighter objects. Misconceptions are also known as common-sense theories, alternative conceptions or pre-instructional conceptions. Misconceptions can

prevent students from understanding fundamental science concepts.

Duit & Treagust (2003) define conceptual change as the process of "fundamentally restructuring" students' misconceptions so the students can fully understand what is being taught. This is different from simply aiming to replace a student's misconception with the correct concept, as was promoted in the 1980s literature on the subject (see for example Champagne, Klopfer, & Anderson (1980), and discussed below).

Conceptual change theories are related to the Constructivist Learning Method, which is outlined in Yager (1991). Constructivism says that everyone starts off with their own personal knowledge of a situation, and to learn more, it is best to build on that knowledge. Examples cited by Yager of ways teachers can take a constructivist approach to learning include

- "Using student thinking, experiences and interests to drive lessons."

- "Encouraging students to test their own ideas, i.e. answering their questions, their guesses as to causes, and their predictions of certain consequences."

- "Seeking out student ideas before presenting teacher ideas or before studying ideas from the textbooks or other sources."

Ogborn (1997) says that the appeal of a constructivist way of teaching is that students gain ownership of the science they learn since, under this model, the knowledge is owned by the students to start with. Ogborn believes this method helps prevent students feeling alienated by science.

The consensus reached in Duit & Treagust (2003) is that, in principle, conceptual change approaches work better than traditional approaches in teaching science. The conceptual change learning theory is the one that is relevant to this study, as the aim of the International Olympiads is for the students to 'get the right answer' in a series of questions that test their conceptual understanding of a situation.

2.4.1.1   How to teach for conceptual change

McDermott (1984) says that if "conceptual understanding" by the student is required, then traditional teaching methods will not work. The teacher must deliberately address particular difficulties, and qualitative questions must be incorporated into all aspects of the class, including homework.

The 'Discovery Method' of teaching was the first method used to help students overcome their misconceptions (Hise, 1988). Using this method the student 'discovers'

how things work for themselves. This is achieved by giving the student tasks that are "not beyond the unaided accomplishment" of the student at any stage, and through solving these problems the student gains understanding (Belbin, 1969, p. 15). Hise says this approach was soon found to be ineffective, and in some cases caused the students misconceptions to be reinforced instead of removed.

In the past, the most commonly reported way to incur conceptual change in a student was to undertake a three step process: first, get the student to articulate their conceptions on a situation; second, challenge these conceptions with a demonstration or experiment involving the student making predictions; third, establish the correct explanation as the only explanation. Reporting on the results of a workshop held by D. Nachtigall on "New Approaches to Teaching in Teacher Training", Hise (1988) outlines the steps to conceptual change:

- "Ensure that students are aware of their preconceptions.

- Allow them to make their ideas explicit and test them.

- Confront them with situations where their preconceptions cannot be used as explanation.

- Let students become aware of this conflict.

- Help them to accommodate the new ideas presented to them.

- Make them conscious of the fact that their new knowledge is more 'powerful' than their previous ideas.

- Give them the feeling of progressing, of growing mental power. Help them develop confidence in themselves and their abilities."

Halloun & Hestenes (1985a) agree, saying it is difficult for students to work out whether to trust their common-sense knowledge without an "explicit critique" of common-sense concepts, and that these beliefs should be thought of as 'alternative hypotheses' to be tested. The message in Champagne et al. (1980) is the same: that a conflict between students' common-sense beliefs and the accepted theory must occur before "reconceptulisation" can take place. Clement (1982) suggests giving students the opportunity to make predictions and give explanations for phenomena, and letting them work out the implications of these explanations. Then the conflict of these explanations with the accepted theory can occur and the student will learn.

Hestenes, Wells, & Swackhamer (1992) say, however, that teaching to overcome specific misconceptions cannot be the last word in science teaching. Their suggestion is that "the instructor must *anticipate* when the discussion of specific misconceptions is likely to be most profitable, *focus* student attention on the crucial issues, and bring the discussion to a satisfying *closure*".

In more contemporary work, Duit & Treagust (2003) reaffirm the research that has shown that the conceptual change approach will only work if the resulting explanation is intelligible, plausible and fruitful. That is, the explanation can be understood, believed and it helps the student with other related questions.

2.4.1.2   Example: Hise's Method

A method employed by Hise (1988), who taught high-school students in the USA, mostly involved the students doing open-ended experiments in class. The class discussed the results of the experiments as a group and learned how to compare their results to experimental errors. To reinforce their knowledge on a topic, the class was given homework to perform a relevant demonstration for, and do an accompanying survey on, five friends or family. Hise reports that the class enjoyed this assignment because allowing the students to become researchers "gave them a feeling of confidence in the new concepts" they had learned.

Hise's method could certainly be implemented in this study through the introduction of similar activities in the resources.

2.4.1.3   Example: Peer Learning

A teaching technique called "Peer Learning" was created by Mazur (1997) for use with first year university physics students. It was developed based on the research of Halloun & Hestenes (1985a, 1985b, 1987) and Hestenes (1987). The technique involves more interaction with the lecturer than is usual in a university setting which is why it could also be relevant in schools. The aim is to "focus attention on the underlying concepts without sacrificing the students' ability to solve problems" (Mazur, 1997, p. 10).

The first step is for the teacher to give a short exposition on the concept being discussed in class, then give a 'concept test' which involves the following procedure (time in brackets is the time available for the activity) (Mazur, 1997, p. 10):

- "Question posed (1 min)

- Students given time to think (1 min)

- Students record individual answers (optional)

- Students convince their neighbours (1-2 mins)

- Students record revised answers (optional)

- Feedback to teacher: Tally of answers (show of hands, cards)

- Explanation of correct answer (2+ mins)"

This technique is designed to cement the concept under discussion in the students' minds through the process of convincing their neighbour. Having just learnt about the topic, the students are more likely to emphasise the important parts of the concept when convincing their neighbours, whereas the teacher giving the explanation may have been teaching the same topic for years and may have forgotten their initial difficulties. This technique can also be used with demonstrations that either pose the question or serve as an explanation of the answer.

The result is that students have a better understanding of the topics after arguing about the correct explanation. The added advantage for teachers is that they then know how many students in the class have grasped the concept, and whether further time needs to be spent on it.

2.4.1.4   Example: Modelling Instruction

Hestenes (1987) is of the view that "mathematical modelling should be the central theme of physics instruction". He believes that the reason students are failing to learn physics under traditional instruction is that they are not taught the absolute basics of the subject. Scientific knowledge, he says, is divided into factual and procedural knowledge, and students must learn both.

His audience for this teaching method is university students however, and so it is not entirely relevant for this study. One sentiment is relevant though: he says "the modelling techniques we teach should exemplify good scientific practice, to minimise the artificiality of textbook exercises and maximise transferability to genuine scientific research".

Halloun & Hestenes (1987) describe a study using this modelling instruction technique with first year university students. The aim of the study was to use the technique to challenge the students' misconceptions about a topic and then introduce modelling strategies to help them understand and solve problems in that area.

The interactive approach taken by Halloun & Hestenes (1987) is naturally similar to the Peer Learning seen in the previous section, and is very interactive. The technique is this:

- A problem is posed to the class and the students are asked to list all relevant ideas, which the teacher writes on the board

- There is a class discussion in which the irrelevant ideas are weeded out

- Then the students suggest problem solving ideas which are also listed on the board

- Groups of students then critique other groups' ideas and defend their own on the basis of physics

- If a consensus on the way forward is found, the teacher summarises the steps of the solution and solves the problem

- If not, the teacher suggests ideas to help the students until the problem is solved.

Halloun & Hestenes (1987) report that in the study where this technique was applied, students achieved better marks in exams than the control group, with the gain being highest for the "low-competence" students. They do suggest however that this method is more suited to later-year physics classes where the students are accustomed to thinking in an advanced way.

In terms of this study, it may be that the modelling instruction technique is too advanced. The interactive classroom environment may be suitable for schools however, and this method should not be ruled out in the creation of resources for this study.

2.4.1.5 Example: Primary Connections

A project called *Primary Connections* has been set up in Australia as a partnership between the Australian Academy of Science and the Department of Education, Employment and Workplace Relations (Australian Academy of Science, n.d.-b). It has the aim of increasing scientific literacy in primary schools (up to Year 6). Scientific literacy in this case means reading, writing and experimenting in science, rather than the scientific literacy referred to in Section 2.3.2. Although this technique has been tested on younger students, it could still be adapted to have a place in this study.

The model used is called the "5Es" which is based on constructivism (Australian Academy of Science, n.d.-a). The 5Es stand for Engage, Explore, Explain, Elaborate and

Evaluate. The aim is to encourage students to work out explanations for phenomena by themselves with teachers assisting in the five stages.

First, to *engage* the students with the topic to be learned, a lesson is given, and the students are given a chance to "express" their views on the topic and what they already know about it. Then the students *explore* the topic through an experiment. The key here is that the students write down or talk about their findings in their own words, and this is a key part to improving the students' literacy.

Next the teacher *explains* the topic and the associated terms to the students, allowing them to make connections between the experiment and the explanation. The words the students used in the exploration are converted into scientific language by the teacher.

Following this the students *elaborate* on the topic to apply their explanations to other, related, topics. At this point it is very important for students to discuss their findings with each other.

Finally the *evaluation* takes place, and the students reflect on their work, and see how their beliefs have changed since they started learning the topic.

The program reports success in its trial in 2005 (Australian Academy of Science, n.d.-c). It was found that, among other reported successes, teachers had more confidence, students "responded positively" and the status of science in the schools increased. On that basis, even though this study is not concerned with primary school students, *Primary Connections* should be considered as a potential model for the resources created.

2.4.1.6   Example: Concept Cartoons

Concept cartoons were developed by Keogh & Naylor (1999) in the 1990s in response to the lack of resources for teaching in a constructivist manner. These cartoons are not 'funny', but instead consist of a picture that presents several alternative and plausible ideas about a situation. An example can be see in Figure 2.1.

These cartoons cause the intellectual conflict required for conceptual change to occur, since they present a range of plausible alternatives with only one being correct. Keogh & Naylor (1999) also say that the cartoons have everyday settings to give relevance to the concepts. The method they suggest for using the cartoons is as follows:

- "a brief introduction to the activity,

- an invitation to the learners to reflect on the concept cartoons and to discuss in groups what they think and why,

Figure 2.1: A concept cartoon from Keogh & Naylor (1999).

- interaction and intervention by the teacher as appropriate during the teaching session,

- practical investigation or research-based activity to follow up the learners' ideas as appropriate, encouraged and supported by the teacher as necessary,

- a whole class plenary to share and challenge ideas".

Keogh & Naylor (1999) report that the students enjoyed working with the cartoons and were more eager than normal to discuss and to carry out investigations on the topics. Normally quiet students were taking part and the discussions were long and involved. Disadvantages noted were that occasionally one student would become dominant in the group and prevent further discussion, or that the group would not be interested in discussion. Teacher intervention was put forward as the solution to this problem.

The reported uses for the concept cartoons included for discussion generation, to encourage investigations and to assess students' learning. Other applications relevant to this study included homework, making resources more interesting and helping students to ask more questions. Keogh & Naylor (1999) cautioned against using the cartoons for every single lesson, however, as they may lose their effectiveness.

The concept cartoons could be used as part of the resources created for this study, as they do not require many instructions. A change of pace in the form of a discussion could make the class more enjoyable.

2.4.1.7   Critique of the conceptual change approach

Tytler (2007, p. 33) reports that the conceptual change approach is losing favour as research demonstrates "difficulties in changing students' naïve ideas to more scientific conceptions". There are some who critique the constructivist position and say that it is too narrow a focus.

It is thought that the conceptual change model may not be the revolution needed in science education, that it does not provide the answers it promises. A new theory, Tytler (2007, p. 33) says, should focus on three things: "the learner, the task and the role of the teacher", and he outlines where the conceptual change theory is deficient in these three areas: the learner is one-dimensional – only defined by their pre-conceptions; the task is one of "establishing canonical abstract ideas" but conceptual change theory gives no clue how to achieve this; the role of the teacher is not outlined in conceptual change theory – it says nothing about how to help students overcome their preconceptions.

Conceptual change methods do have a place in this study, however. The resources ASI have in mind are likely to consist of group work, either in small groups or as an entire class, meaning the discussion-based techniques suggested by Mazur (1997) and others will be relevant.

2.4.2   Context-based learning

Tytler (2007, p. 39) points out the paradox that scientists writing journal papers have the tradition of removing all context from their work, whereas popular science books written by the same scientists are full of context.

Context-based learning, as its name suggests, advocates presenting science in a context that students can relate to. One of the main arguments in Tytler (2007, p. 38) is that the way science is taught today mainly teaches the knowledge required, and does not take into account "the realities of students' own lives, interests and feelings". In this way, context-based learning is related to scientific literacy discussed in Section 2.3.2.

Tytler (2007, p. 42) makes bold claims as to the importance of context in school science learning. He claims that equipping students with the science knowledge needed for their future lives is more important than teaching them abstract science ideas. Thus, the science students learn should be able to be used as a "tool" for interpreting future science-based situations. As a result, he says, learning about "cells and genes and acids and energy and the Earth's radiation balance" is probably more important than knowing, for example, lens formulae in optics.

In terms of this study, this is not a position that can be taken in its entirety. Students entering the Olympiads will very much need to know abstract ideas and lens formulae. They may also benefit from having some context for the abstract ideas, but the benefit-to-future-lives context should not be the sole focus of science lessons for these students.

In a review of context-based approaches documented in the literature, Bennett, Campbell, Hogarth, & Lubben (2005) noted that this teaching method, on the whole, motivated students and made them more positive about science. They also report that students still understand as much in the way of science ideas as students in traditional courses.

Examples of context-based learning approaches are discussed in the following sections.

2.4.2.1   Example: Narratives

Boström (2006) found, in a study of school teachers and students in chemistry, that teachers make the subject more meaningful by using "narratives" in their explanations. Boström describes narratives as stories that are used to share experiences. And while the teachers use narratives to make the subject more interesting, students use narratives to make sense of the subject. Boström suggests that narratives then should be used alongside traditional teaching, and in context-based approaches to teaching.

2.4.2.2   Example: Twenty First Century Science

An example from the UK of a scheme that is geared towards scientific literacy in a context-based manner is *Twenty First Century Science*. It is for UK students age 15-16 who want to take either the basic general science course, or the separate three science subjects of physics, chemistry and biology (Oxford University Press, 2008).

Millar (2006) reports that the scheme started as a three year trial in 2003. The curriculum that was developed aimed to resolve the conflict between teaching science knowledge and teaching science literacy. It did this by offering two parts to the course: the Core part dealt with scientific literacy, and the Additional part contained the knowledge needed for students to progress to higher level courses. The task for the Core program is to give the students the tools to "deal intelligently and appropriately with scientific knowledge (and information claiming to be 'knowledge') in the forms in which they encounter it".

Millar (2006) says the new curriculum was partly based on science topics commonly found in the media, namely health and medicine, the environment, space and dinosaurs. Also included was the topic of the nature of risk, since health and medicine articles generally make claims that something will improve or harm an aspect of the consumer's life.

Some science knowledge is needed to respond to these media articles however, and Millar (2006) says that this knowledge should be confined to that which will make a difference to a decision or viewpoint of a student, or be of cultural significance. The student should also learn about how scientific knowledge is obtained and verified.

The topics of the core curriculum are of interest to this study, as they may inform the topics on which to create resources in physics. They are (Millar, 2006):

- "You and your genes

- Air quality

- Earth in the Universe

- Keeping Healthy

- Material Choices

- Radiation and Life

- Life on Earth

- Food matters

- Radioactive materials"

Millar (2006) notes that in terms of Roberts' curriculum emphases, all are covered, but the "solid foundation" emphasis is minimised.

To improve the students' scientific literacy, case studies are used as teaching tools. This is the heart of the context-based approach. The case studies are based within the above topics on current news and events. A physics example provided is this (Millar, 2006):

> Radiation and life: Data and information on the risks and benefits of UV in sunlight are presented. This provides a context for reinforcing key ideas about radiation (spreading out with distance from a source; possible

consequences when absorbed, etc.). Also leads to discussion of risks of
microwave radiation, and how related health studies might be made more
convincing (large samples; better matched samples; better control of other
variables, etc.)

The associated assessment for the case study work is in the form of reports. Students
write a report on a case study for one part of the assessment, and in another part, collect
data and analyse it, draw a conclusion and comment on their confidence in the
conclusion.

Teachers who were part of the pilot scheme commented that students were much
more engaged in the science lessons, though this did depend on the topic. The higher
achieving students appeared to enjoy the course more than lower achieving students.
Other teachers commented that the lack of practical work was turning off some students.
As a result, the second phase of the project had an increased amount of practical work.

Tytler (2007, p. 51) sees *Twenty First Century Science* as a possible model for
education in Australia. The core content, he says, would probably be suitable for the
lower years of secondary schools, and then the content should move towards "more
structured, conceptual versions of science" in later years.

2.4.2.3   Example: Community-based Projects

Another way to incorporate scientific literacy into the classroom is through
school-community partnerships. This gives students the opportunity to engage in a local
issue and have some impact on the situation (Rennie, 2006).

An example of this is the Australian Science Teachers Association *School Industry
Partnerships in Science Program* that concluded in 2005. An example project was one
undertaken by students in Western Australia called "Identifying and Processing
E-waste". In this project, students were involved in the collection of printed circuit
boards from various sources. They learnt about the chemical processes for leaching
various chemicals from the boards and were able to take away coins they had pressed
from the gold they recovered (Centre for Sustainable Resource Processing, n.d.).

There does not appear to be any project that relates to physics topics in this scheme
however, and so it is possible that this approach may not be ideal for this study. The
other disadvantage of the school-community projects is that funding is often required,
which means these projects are unlikely to be inclusive enough to apply to all schools.

Tytler (2007, p. 52) notes however that these community based projects tend to be
more popular in rural settings. This might fit with the aim of this study, which is to

ultimately get more students entering the Olympiads. If community based approaches are what work for rural schools, perhaps a resource should be attempted along those lines.

2.4.2.4   Example: The PLON Course

An example of a context-based course in physics for high school students is PLON, developed in The Netherlands in the 1970s (in Dutch PLON stands for Physics Curriculum Development Project) (Wierstra & Wubbels, 1994). Its major goal was to increase student motivation about physics. The PLON project provided resource for teachers and had four main themes. The first theme was to teach physics that was "recognisable, relevant and useful" in students' everyday lives, but also be enough to enable students to enter tertiary education. The second was to not disguise physics, to show it as a pure and applied science, with its associated methods and history. Third, teachers were to recognise the differences in ability among students, as well as students' different plans for the future and interest in the course. The final theme was to encourage students to take part in typical scientists' work such as experiments, literature reviews and data analysis. Kortland (2005) reports that the project aimed to cover all seven of Robert's knowledge emphases.

The way a PLON based lesson might be organised is very similar to the *Primary Connections* 5Es approach (Section 2.4.1.5). There is the *orientation* where students encounter the everyday applications of the topic. This is followed by the *basic skills and knowledge* where the actual physics is introduced and the students perform experiments. Next is an *options* section where groups of students work on different aspects of the topic in more detail. *Reporting* comes next and the students share their findings with the class. Finally *broadening and deepening* occurs where the information students have learned is applied to related physics topics.

The effectiveness of the PLON course according to Wierstra & Wubbels (1994) has been demonstrated. Students were found to agree that the course was reality-centred, and that this made it seem more instructive, and more enjoyable.

The downside however, is that student "affective outcomes" (i.e. grades) were lower under the PLON scheme. The authors suggest this might be because of the nature of the lessons. Teachers have much less time to give feedback to students because the classes are so busy compared to traditional classes. The other problem is that the PLON course is focussed on increasing motivation in students, and so the focus on learning the physics content is lost. Teachers have to use students' experiences as starting points for the lessons, and so have to work very hard to turn this into physics knowledge gained by the

student. Kortland (2005) says that if they were to develop the PLON course over again, they would include more support for teachers through coaching.

Kortland (2005) reports that as a result of the PLON scheme being implemented and the increase in context-based teaching in schools, theoretical physicists have started to complain about how "the fascination of 'pure physics' was lost in the muddle of 'applications'". This should serve as a warning for this study because the students entering the International Olympiads will need to know some pure physics.

2.4.2.5   Critique of Context based learning

Context-based learning approaches have been attempted by curriculum writers in Australia but have encountered the problem of the nature of traditional assessment and exams which require formulae and set knowledge. Thus, teachers are not encouraged to incorporated context-based learning into their lessons (Tytler, 2007, p. 43). But Tytler, (p. 60) reports that the teachers who attended the ACER conference in 2006 were "almost unanimous in calling for more context-based teaching".

Tytler (2007, p. 44) notes that this type of curriculum can cause stress for teachers as it requires a different way of thinking, and potentially more work. Other problems include criticism by parents, exam boards and the media that introducing context based curricula is 'dumbing down' traditional, rigourous science.

The argument from Aikenhead (1996) is that even those students on track to become scientists should benefit from context based learning, even though they might see it as 'soft'. He says this will serve the "long-term interests of an equitable and socially responsible society" if our future scientists, who tend to embrace science at school to the exclusion of other subjects, are required to learn of issues they would not normally consider.

In terms of this study, the influence of parents and exam boards should be of no importance as the resources created will not form an entire curriculum, only provide a few suggestions for class work here and there. The fact that the resources will likely be provided with teacher notes should eliminate some of the work involved in applying any new teaching method.

2.4.3   Inquiry-based learning

Inquiry-based learning started life as the result of the work of Schwab (1964), who discussed it in terms of all sciences, not just physics. Schwab, (p. 12) described inquiry

having its origin in concepts: with the conceptual structure in place, such as the knowledge of waves and particles, scientists are able to ask questions, do experiments and interpret the data and thus gain new knowledge. He points out, though, that if a student's knowledge depends only on this conceptual structure, it will be of temporary use only, unless it is used to discover new concepts, which result in new enquiries leading to new knowledge (p. 13). Schwab, (p. 14) comments:

> Unless we intend to treat all knowledge as literal, true dogma, and thereby treat students as mere passive, obedient servants of our current culture, we want our students to know, concerning each body of knowledge learned, how sound, how dependable it is.

Schwab (1964, p. 24) says that the meaning of physics 'facts' are "only understood properly within the context of the inquiry that produced them". He says that this aspect has been completely overlooked due to the improper training of teachers who are told that the 'scientific method' is something simple and well defined.

The place of inquiry in curricula is also outlined by Schwab (1964, p. 30). If students are to be taught a given body of knowledge, then they should also be taught how this knowledge came about (the structure) as well as the strengths of, and alternatives to, the structure. Students will then better understand the knowledge, as well as be more open to future developments and revisions. Students will also understand how "one body of knowledge succeeds another".

Inquiry based curricula, notes Tytler (2007, p. 47), come in many forms including set-piece experiments, teacher-led investigations, or open-ended investigations. See Section 2.5.3 for a discussion of the issues concerning classroom experiments and investigations.

2.4.3.1   Example: CASSP

An example of an inquiry-based curriculum project in Australia is the *Collaborative Australian Secondary Science Program* (CASSP) which was trialed in all states in 2002. The aim of this program, described in Goodrum (2006), was to provide teachers with a whole package of professional development, resources and curricula to teach students in an inquiry-based way. The aim of the curriculum was scientific literacy (in the sense of Section 2.3.2, for the future-citizen) and was centred on "student-centred approaches to learning" and "inquiry and investigative approaches". The hope was that this would make science more engaging and relevant for students.

Teachers were very positive about the scheme, although the students were less so. Only one-third of students were happy with science in the new classes and the main concern was expressed by high-achieving students. These students tended to associate pure memorisation of facts with learning and achieving high grades. The CASSP scheme, with its inquiry focus, did not generate bodies of knowledge to memorise and so these students did not feel they were learning.

The main challenge for teachers in the inquiry-based learning scheme is to effectively sum up the results of the class investigations in a way that is useful for students. Without this, the lessons may not achieve anything for the students.

Another project in which Goodrum is involved in is *Science By Doing*. This program, still in its pilot stage, claims to be a "creative web-based, inquiry-based program designed to promote active learning and stimulate student interest" (Science by Doing, n.d.).

2.4.3.2   Critique of Inquiry-based learning

Tytler (2007, p. 48) argues that there is a need for curricula to include inquiry-based learning on broader topics than can be found in the classroom. These topics would be issues in the media at the time (e.g. the Large Hadron Collider), issues of local interest (in Canberra this might include the proposed Data Centre at Tuggeranong), or perhaps issues of longer term relevance such as Global Warming. The aim again is to increase the student's scientific literacy.

The problem with this broader approach, notes Tytler (2007, p. 49), is the potential complexity of the science involved in order to understand the issue. One proposal is to pre-package the data and material needed to cover the topic.

In terms of this study, prepackaging material is an excellent suggestion. If the advocates of this approach are to be believed, this will have the effect of giving students knowledge, as well as context, which is exactly what the Olympiad participants need.

2.4.4   Summary

In this section, three learning theories were discussed. This first was the conceptual change learning theory which, at its heart, is based on constructivism. This is the practice of using students' own experiences as a starting point for building knowledge. The key to teaching using conceptual change is to provide a place for students common-sense beliefs to be challenged, and for the resulting explanations to be

understandable, believable and useful. Examples of the teaching techniques discussed all had the same theme: that of teacher interaction, experimentation (either on the bench or via thought experiments), class discussion and persuasion, and finally synthesis of ideas.

Conceptual change is not universally popular, however, because it does not always result in students excising their misconceptions. Nevertheless, it does have a place in this study as the resources created are likely to be suitable for small group work, or class discussion.

The second learning theory discussed was context-based learning. The aim here is to immerse classroom science in topics that students can relate to. It has a scientific literacy angle as it is suggested that by learning about topics prominent in the media, students will gain tools for interpreting future science issues and thus become better citizens. The teaching methods discussed were largely found to separate the 'literacy' teaching from the 'knowledge' teaching into different courses, so that students aiming for further study were not disadvantaged. The topics were often framed as case-studies and students were generally found to enjoy the lessons.

Some disadvantages of context-based learning were that some community-based case studies required financial support; parents and the media thought that these lessons were 'dumbing down' science; and that student grades were often lower under this scheme as teachers had less time to give students feedback. The advantages, however, were that students enjoyed science more, the future-scientists broadened their education to include issues of public interest, and that rural schools particularly appreciated this technique.

Context-based learning has a place in this study as the resources created will not form an entire curriculum. Instead they will provide material for an occasional lesson which should have the effect of increasing interest among the students and providing a change of pace to class.

Finally Inquiry-based learning was considered. Under this method, students learn how the knowledge they are taught came about, which should allow them to better understand it, and cause them be open to future revisions of this knowledge. The aim is for lessons to be closer to the way 'real' science is done. The teaching methods are similar to the context-based lessons in that they generally revolve around something relevant to the students' lives. The disadvantage of this method, reported in the literature, was that some high achieving students did not feel they were learning enough knowledge to memorise and pass exams. This method may have a place in this study if a way to pre-package data for a case-study can be found.

Now that learning theories have been reviewed, the next section will explore what

can be done to make science more appealing to students.

2.5 Making science appealing to students

A particularly important consideration for this study is: What will make these resources enjoyable for students? In Section 2.4 it was seen how having topics that are centred around students lives can achieve this. Tytler (2007, p. 43) reports that there were teacher forums at the ACER conference in which the teachers were asked to suggest ways to "make science more engaging for the students, to boost learning, and to encourage more students into post-compulsory science". The following is a selection of reported comments which directly relate to physics and the research question "what do I need to consider when designing an adequate resource?"

To make the science curriculum more meaningful it should (Tytler, 2007, p. 43):

- "Tap into kids' interests by looking at using technologies such as mobile phones

- Use open-ended projects related to real-life issues valuing creativity, for instance, the solar car challenge

- Study the science of sport – interpret the intent of the syllabus and depend less on the text book

- Use contemporary science issues; more debate; research in the classroom; interdisciplinary topics

- Develop skills in students on researching issues; courses are too content prescribed – they should be issue based"

The Relevance of Science Education (ROSE) study asked students what topics they would like to learn about in science if they had the choice. The results were generally split along gender lines. Boys wanted to know about space, explosions and dangerous practices and girls wanted to know about health, dreaming and the soul. That said, both girls and boys wanted to learn about space and about dreaming. Table 2.1 shows the top ten topics for boys and girls (Jenkins & Pell, 2006, p. 15).

This table could inform topics for resources that will be of interest to both boys and girls, although the topics that are favourite among females do not, at first, appear to lend themselves to physics. What particularly can be done to make science more enjoyable for females is discussed in the next section.

Table 2.1: The top ten topics girls and boys would like to learn about in science lessons, from Jenkins & Pell (2006, p. 15).

Boys	Girls
Explosive chemicals	Why we dream when we are sleeping and what the dreams may mean
How it feels to be weightless in space	Cancer, what we know and how we can treat it
How the atom bomb functions	How to perform first-aid and use basic medical equipment
Biological and chemical weapons and what they do to the human body	How to exercise to keep the body fit and strong
Black holes, supernovae and other spectacular objects in outer space	Sexually transmitted diseases and how to be protected against them
How meteors, comets or asteroids may cause disasters on earth	What we know about HIV/AIDS and how to control it
The possibility of life outside earth	Life and death and the human soul
How computers work	Biological and human aspects of abortion
The effect of strong electric shocks and lightning on the human body	Eating disorders like anorexia or bulimia
Brutal, dangerous and threatening animals	How alcohol and tobacco might affect the body

2.5.1   Taking into account gender

The National Science Foundation (2003, p. 2) confirms the statistic that by middle-school females start to turn away from science. The resources developed for this study should aim to be appealing not only to males but also females.

The discussion here focuses exclusively on the information needed to develop the resources for the study, and not on the solutions to the general issue of gender bias in science.

Rosser (1990, p. 37) describes her research with women scientists in which she attempted to discover if there was anything about the way these women did their science that differed from the standard "procedural" method. These differences are outlined in the following sections, and suggestions for classroom practices are described.

2.5.1.1   Language

Rosser (1990, p. 11) outlines several simple steps that can be taken to ensure language used in the classroom is not male-biased or sexist. The general use of male terms such as 'he' or 'man' when discussing the whole population implies that being male is the norm

for the topic under discussion. Rosser suggests eliminating or replacing pronouns in sentences, or making pronouns plural, for example, 'each professor must record the number of papers he publishes each year' could be 'professors must record the number of papers they publish each year'.

Another suggestion by Rosser (1990, p. 13) is to include the full names of scientists when talking about them. The example given is 'J Watson and R Franklin' and Rosser reports that when initials are used, students believe they refer to males. Even though using initials is equitable, better treatment would be 'James Watson and Rosalind Franklin'.

2.5.1.2   Contents of the curriculum

Rosser (1990, p. 18) says that the ideal curriculum will not "replace the woman-less curriculum with the man-less curriculum", but will instead have women's contributions and presence in all parts.

The Institute of Education Sciences report (Halpern et al., 2007) notes that incorporating news and information about current and past female scientists is of benefit to female students.

Making the topic under discussion relevant to students' personal lives not only is appealing to females but also to males, reports Rosser (1990, p. 60). Rosser, (p. 61) suggests that female students are less likely to be interested in problems "that only seem useful for calculating rocket or bomb trajectories", and the lesson should start with familiar topics. This way female students will be more confident when moving on to unfamiliar topics. Being able to place the science into social contexts would also appeal to female students (p. 51).

Miller, Blessing, & Schwartz (2006) suggest that incorporating topics that focus on popular areas of science with females, such as biology, would make classes more interesting for these students. In physics this could include biophysics, which covers anything from population statistics, cell-level physics, to solar cells from plant material. Bringing a human aspect to applications and how they can help people and animals would also make physics appealing to females.

Halpern et al. (2007, p. 23) also suggest incorporating activities, specifically word problems, into the classroom that are interesting to both girls and boys. The report also suggests introducing novel, fun activities into the class, such as group work or games, to get the students interested. Other techniques suggested include putting problems to solve into an interesting context, and providing "rich" reading materials to accompany a topic

or investigation. If possible, Halpern et al. say, teachers should incorporate topics of current interest to the students (e.g. through popular culture).

Also of benefit to the students, Halpern et al. (2007, p. 9) notes, is connecting the classroom activities to science careers that "do not reinforce existing gender stereotypes of those careers".

2.5.1.3 Experiments

Rosser (1990, p. 63) found that women sometimes take a different approach to data gathering to the traditional scientific method. One difference is that females are less likely to want to sit back and objectively take data on an experiment: they want to be involved and they want to make qualitative observations.

An important point to note in relation to classroom experiments is that females are less likely than males to have had extracurricular experiences with tools of physics, for example, a telescope or compass, or experience with electricity or magnets (Matyas, 1985). Females want to have experience with these items however.

Matyas (1985, p. 38) says that because female students lack the familiarity with the tools of science they may be less confident in approaching classroom experiments, despite being given full directions. As a comparison, she asks the reader to imagine what an male student would feel if asked to cook a meal (given a recipe), which he will then be graded on, whilst in competition with female students. Although the female students may not have cooked this particular meal, they are more likely to have had experience in the kitchen, and so feel consequently more comfortable.

Rosser (1990, p. 59) suggests that in the classroom, time for experiments is lengthened as females tend to remain longer at the experimental stage, and that females work with females (to avoid the common practice of the male doing the experiment and the female writing down the data). Also, doing experiments rather than just handing over data to analyse is important for females as this allows them to get practice with equipment.

Alongside traditional classroom experiments which are designed to demonstrate a particular concept, some experiments that are more complex, and show relationships between several variables should be included. Rosser (1990, p. 68) suggests that female students will be more interested in experiments if they have the opportunity to find out relations between one experiment's data and another.

Rosser (1990, p. 90) suggests that 'motivating elements' for females could easily be incorporated into activities in the classroom. These include getting the students to

scientifically predict the outcome of an experiment, rather than being told it in advance; having activities that draw on students personal experiences; and having activities that allow for creativity in approach.

2.5.1.4   Classroom Environment

Rosser (1990) has also researched the different ways women scientists practice science. Firstly Rosser, (p. 69) reports that female students learn better when cooperative methods are used in classrooms. Taking part in science communication activities was found to be an activity females participated in more often (p. 51). Creating resources that incorporated explaining the results of an experiment to the class or student's families would not be difficult.

Halpern et al. (2007, p. 28) suggest encouraging students to offer "spatial displays" and verbal responses to problems. This means teaching the students how to draw useful diagrams to solve problems and creating 3D models. This training is reported to especially benefit female students, and while this suggestion does not really come under the heading of 'making science appealing', it should make science a little *easier* for female students.

Finally, Miller et al. (2006), suggests that teachers should show that scientists do care about improving people's lives, and generally do not like their research to have military applications. Resources for this study could easily incorporate information about the passion of science and scientists, which would appeal to female students.

2.5.2   Taking into account culture

The reason it is important to take into account the different cultures of students, reports Aikenhead (1996), is because if a student's culture is different to the culture of western science, then key concepts taught will not be "encultured" but instead "assimilated" to sit alongside cultural beliefs.

Aikenhead (1996) talks about Border Crossings, when people cross borders that can be either, physical, or cultural. All students have to cross a border into the culture of science, and it is hardest for non-western students to cross into the western science culture taught in Australian schools. The culture of western science is defined by the words, symbols and meanings associated with it.

In terms of this study, however, the focus is on the border crossing all students make from their non-science culture to the culture of science. The recommendation in

Aikenhead (1996) is that science should be taught in a way that fits in with students' worlds. This is a similar idea to Context-based learning that was discussed in Section 2.4.2. Aikenhead suggests however that the border crossing from the science culture to the student's culture should be made explicit in the classroom, which could be achieved by getting the students to realise which culture they are talking in at any given moment.

Aikenhead (1996) has a suggestion for how to achieve this practically in the classroom. After a topic has been discussed in class, students should divide their notebook in half down each page, with one column being where they write "their" culture's ideas about a topic, written in their language, and on the other side write the "science" culture version, using the appropriate language. This is rather like the 5Es classroom technique discussed in Section 2.4.1.5. The key however, says Aikenhead, is to not require the students to "adopt a scientific way of knowing as their personal way". In this way the student will learn some science without compromising their own culture.

Aikenhead (1996) says this type of border crossing, using scenarios that are relevant to students, is suitable for students for whom science is 'just another subject' they must endure at school – one that is "neither personally meaningful nor useful to their everyday lives". The advantage for the teacher is that these two sets of notes can guide their lessons, and the advantage for the students is that the task of crossing the border into science is made easier.

2.5.3   The fun of practical work

Laboratory work or experiments are likely to form a large part of the resources created for this study as, according to Tytler (2007, p. 45), practical work is consistently ranked as a favourite activity by students learning science. He says practical work is important for reinforcing learning, as well as teaching students about the validity of evidence, and how to make judgements about evidence they obtain. This is important, he says, in a science literacy way, in that the future citizens will benefit from this knowledge. Practical work has an important place in the Inquiry-method of teaching (see Section 2.4.3). Tytler notes that in some Australian school curricula sections have been introduced on 'working scientifically' and 'investigating', which cover practical work.

Tytler (2007, p. 45) also states that there are many methods of scientific investigation, and the 'scientific method' should not be the only one students are confined to using in practical work. The aim of science is to isolate the factors that cause the effect under investigation, says Tytler, and whether this is done systematically or through "inspiration

and guesswork" should not matter. Students should be given the opportunity to try out all methods, says Tytler, and thereby see that real science has "breadth and flexibility". Tytler, (p. 47) says traditional experiments "limit the potential to explore interesting ideas through investigation and ... fail to capture the imagination of students".

Hofstein & Lunetta (2004) note that laboratory sessions are generally more informal than normal lessons, which can promote a fruitful learning environment as well as encourage students to develop teamwork and collaborative skills. Hofstein & Lunetta says the problem with practical work, however, is that students often do not grasp the point of the activity. They see practical work as an exercise in manipulating equipment or getting the right answer, rather than learning some science, for instance why the particular experiment design was chosen for the task. In this case, Hofstein & Lunetta report that Wilkenson and Ward found that pre-lab and post-lab exercises are beneficial to students. The pre-lab helps the student understand the goal of the experiment, and in the post-lab, this is goal is reviewed.

The way practical work is presented to students is important, says Hofstein & Lunetta (2004). A recipe approach, with a lot of information, can distract the student from the actual purpose of the exercise, and prevent them from asking good questions.

The use of technology in experiments is also discussed in Hofstein & Lunetta (2004). They say, though, that the technology must be "properly used". As will be discussed in Section 2.6, however, the need to use computers in the resources developed for this study will be minimised, as this may exclude some less well-off schools.

2.5.4 Summary

In this section strategies for making science appealing to students were discussed. Making the resources created for this study enjoyable is important because if students do not enjoy the resources teachers will not use them.

Suggestions for making science lessons more engaging included looking at real life science issues and having more debate in the classroom. Some research indicates that topics students want to study are generally divided along gender lines, with boys wanting to learn about dangerous things, and girls wanting to learn about the human body, and both wanting to learn about the universe.

Following this, tactics to make science more appealing to females in particular were discussed. Some strategies to make science lessons more inclusive for females included taking care with the language used in resources; including curriculum topics that were of interest to females; giving female students a chance to practice with the tools of science

in experiments; allowing for creativity; incorporating some science communication activities; and including information about real scientists lives, especially female scientists.

Then the issue of students 'crossing the border' into the culture of science was discussed. It was found that all students experience difficulties with this and one strategy to help with the crossing was for students to explicitly write down the 'science' version of the topic alongside their 'own' culture's version.

Finally, the fun of practical work was explored. Although practical work is a popular activity among students, it was found that students often do not get the point of the work. Strategies to help make practical work more meaningful included prelab and postlab exercises; making the experiments more realistic by not always sticking to the 'scientific method' when doing investigations; and taking care in the way the experiment notes were presented by avoiding putting in too much information.

In the next section, the current best practice for designing resources is determined. With the knowledge of the previous sections in mind, the task now is to find out how to present resources in a way that will be most fruitful for the teachers using them.

2.6 Nuts and Bolts: resource design

This section focusses on the design of resources as evaluated by teachers. The resources created as part of this study should conform to any recommendations in the literature.

Resources provided for CASSP (see Section 2.4.3.1) were evaluated by Goodrum (2006). The resources package consisted of teacher professional development, student resources and teacher resources. It was found that teachers perceived the professional development to be the most useful item in the program and the teacher resource the least useful. On the other hand, the majority of the teachers wanted more CASSP resources for different topics. Pertinent to this study though, are the comments about the format of the resources. The teachers wanted the student resources to be in print format, due to a lack of adequate computer facilities. The teachers used the student resources in their original form, or adapted them to suit the class. Some teachers commented that they would have liked the student resources to have more theory in them. Some teachers rarely used the teacher resource book. The conclusion Goodrum draws is that the student resource was the most powerful item because it enabled the teachers to implement the new ideas gained in the associated professional development.

In the *Twenty First Century Science* project, the language used in resources was

identified as an issue (Millar, 2006). Some of the language was too advanced for the lower ability students in the class, and as a result, the organisers published two separate resources. The Higher resources had 250 words per page, and the Foundation resources had 200 words per page. The type of resources provided for the *Twenty First Century Science* project are out of range of this study, but included full colour textbooks, files with photocopyable resources for lessons and teacher notes, as well as a CD with Microsoft® PowerPoint slides and electronic, linked, versions of the resources.

Rosser (1990, p.88) talks about how textbooks can influence female students. This is relevant to this study as the resources created may look similar to pages of a textbook. She reports the results of her study into subtle sexism in school textbooks. In most of the books she studied there were more illustrations of males than females, more males pictured in more active roles, and fewer descriptions and pictures of female scientists than male scientists.

The value of Information, Communication and Technology (ICT) in science education is unclear. Not all schools have sufficient computers to make ICT a viable option, and any computer controlled experiments rely on the school having the appropriate equipment. Since ASI already has online and computer based resources for teachers, the resources created for this study will be explicitly paper based. As a result, the value of ICT will not be explored further.

Tytler (2007, p. 61) says that new ways to teach (as seen in Section 2.4) usually result in the generation of new resources, which have the benefit of "clarifying the nature of the innovation". One problem, he says, is that teachers often do not use the resources in the way the writer intended, defeating the purpose of having them. Another problem is that teachers do not feel they 'own' the resources if they cannot personalise them; and the resources are unlikely to be exactly right for the particular class in which they are used (p. 62).

The solution to these problems, says Tytler (2007, p. 62), is to not only develop resources, but also a set of teaching principles, and incorporate some teacher professional development. The latter two items are not within the scope of this study, but introducing the ability to adapt the resources to the classroom is something that should be included.

2.7   Conclusion

In this chapter the following research question was answered: 'What do I need to consider when designing an adequate resource?'.

First, the International Science Olympiads were investigated. The Olympiads inform the study as to what the students using the resources might need to know. It was found that the important skills were: problem solving; understanding of physics concepts; and experimental skills and techniques.

Next, the main knowledge emphases for school curricula were discussed. This was so that the type of learning the resources could focus on could be determined. It was found that the need to provide pure science knowledge did not need to be the sole focus of the resources since this aspect is covered in classrooms all the time. The science literacy approach of making students better future citizens was found to be appropriate if the Nature of Science aspect was emphasised. The Nature of Science was found to be a way of enabling students to appreciate the processes and techniques of science.

Following this, different learning methods were explored. Conceptual change was found to be not just about replacing student misconceptions with the correct concept but about restructuring students' knowledge. Techniques to teach conceptual change all involve four basic steps: introduction to the topic; exploration through experiments (thought or practical); discussion; and teacher synthesis. It was found that conceptual change was hard to teach for, and often did not work.

Context-based learning was found to be based on science literacy, and it was found that this theory did not result in much science knowledge being learned. Another disadvantage was that the local case-studies used in teaching had the potential to cost money, something out of the scope of this study. Context-based learning was found to be popular with students however.

Inquiry-based learning, which was the last learning theory considered, aims to show students where science results come from and the process of science, which leads to a better understanding by the student. This technique is student-centred which makes it harder for teachers to make the class productive. One way of making it easier for teachers to use this method is to pre-package data in a resource.

How to make science appealing for students was discussed next. To make science lessons more relevant for female students, recommendations regarding appropriate language were found. It was also suggested that classroom topics could include those that female student would enjoy, and that experiments could last longer in order to give female students a chance to practice with the laboratory equipment. In class, it was recommended that the environment be cooperative, involve some communication activities, and include positive images of current and past female scientists.

Another way to make science appealing to all students was to manage the student's

border crossing into the culture of science effectively. And for practical work, although this is a popular activity, it was found that students needed to be able to see the point of the work.

In terms of the 'nuts and bolts' of resource creation, it was found that teachers preferred their resources in print format. They needed them to be modifiable, and the language needed to be suitable for all abilities of students. Finally no ICT was to be included as this could exclude some schools without computer facilities.

In summary then, to design an adequate resource, the following need to be considered:

- The skills students need to be successful physics Olympians

- The knowledge emphases currently prominent in Australian schools

- Learning techniques that have been found to work in the classroom

- What makes science appealing to students, especially female students

- The 'nuts and bolts' of resource design.

In the next chapter, the research design is outlined.

Chapter 3

Research Design

3.1   Introduction

The research questions to be answered in this study are as follows:

1. What do I need to consider when designing an adequate resource?

2. What areas of the state and territory curricula are relevant?

3. Can a resource be designed that is relevant and adequate?

The first research question was answered in Chapter 2 and the second two questions are answered in Chapter 4. This chapter outlines the rationale behind the design of the actual resources and the limitations of taking this approach to the design. How material was selected to go in the resources is described first, followed by an outline of the plan for their physical appearance.

3.2   The Resource Design

3.2.1   Selection of material

As was seen in Chapter 2, ASI stipulated that the resources should be relevant to as many school students as possible. To this end, the first stage in the resource design is to review all state and territory curricula and find the common topics. From this, the knowledge the students have when finishing Year 10, the knowledge they need to have when finishing Year 12, and the knowledge needed to bridge this gap can be found. The resources are aimed at Year 11 students, hence these curricula are the most relevant.

The aim of the resources is important to remember. As seen in Chapter 2 the aim of the resources is to equip students with problem solving abilities, an understanding and knowledge of physics topics, and experimental skills and techniques. The design of the resources should take this into account.

The most important knowledge emphasis discussed in Chapter 2 was that of the Nature of Science. The aim here is to give students a broad understanding of how science works, its tools, techniques and culture. To do this, innovative classroom experiments should be designed, and activities encouraging creativity and diversity of thinking should also be included.

In terms of learning theories relevant to this study, it was found in Chapter 2 that there were three theories. The first was the conceptual change theory which involves teacher interaction, experimentation, class discussion and persuasion, followed by a synthesis of ideas. Activities in the resources involving this learning technique should be included.

The second and third learning theories (context-based and inquiry-based learning) both involve using case studies. Context-based learning focusses on the discussion of issues prominent in the media at the time, whereas the inquiry-based learning requires the use of a large amount of pre-packaged data and material on a particular case study. While these both could be incorporated into the resources, they should not take precedence over other suggestions listed here, as the case studies may not have a wide enough relevance.

In Chapter 2, making science appealing to students was discussed. Many ways to do this were outlined, and all should be considered in the design of the resources. The first of these techniques were: looking at real life issues; including more debate in the classroom; using topics involving dangerous things (for the males), the human body (for the females) and the universe (for both).

Specifically for females, incorporating topics of interest, allowing females a chance to practice with equipment, allowing for creativity, including science communication activities, and using examples of real scientists, especially female scientists was found to be important. As many of these ideas as possible should be incorporated into the design of the resources.

Included in making science appealing was the idea of helping students cross borders into science. One way to do this involves getting students to write down the 'science' version of various concepts alongside their 'own cultures' version to allow students to appreciate the similarities and differences. This activity should be included in the design

of the resources if possible.

Finally, practical work was found to be a valuable tool in motivating students, so this should also be included in the design of the resources. To make it more useful, pre- and post-lab activities should be included, as well as suggesting more realistic experiments and presenting the experiment notes without too much unnecessary information.

Naturally, it would be very difficult to incorporate all these design elements into a limited set of resources. It is hoped that if a full set of resources across all topics of physics were developed that the majority of these suggestions would be included somewhere within the resources.

3.2.2 The physical design

The rationale for the physical presentation of the resources is described in this section. The resource design is considered in light of the findings of Chapter 2, conversations with ASI and from knowledge obtained in the course SCOM8012 ("Design and Process for the WWW", which I took in Semester 1, 2008 at The Australian National University).

In Chapter 2 the 'nuts and bolts' of the resource design was discussed. It was found that teachers preferred their resources to be in print format, that the resources should be modifiable, that they should contain a suitable level of language for the students, and not require the use of ICT. As well as this, it was found that including images of female scientists was beneficial to female students. ASI indicated that the resources should be a collection of stand-alone exercises or activities, rather than a textbook chapter on the chosen topic.

The physical design of the resources is undertaken with the knowledge gained from SCOM8012. This includes incorporating plenty of white space to create and uncluttered look, the use of colour to separate out sections and make the resources visually appealing (but including the ability for the resources to be used either in colour or black and white), general consistency across pages in terms of fonts, titles and design elements, and the facility for the resources to be placed in anything from a website to a full colour book.

3.3 Limitations of this approach

A limitation of this approach to designing the resources is that it requires many different elements to be incorporated into a small set of activities. The way to overcome this difficulty is to assume that over the full set of physics resources, all these elements would

be accounted for somewhere.

The limitations of the 'nuts and bolts' requirements are that it restricts the type of resources to activities that can be described in words and static pictures rather than video or animation, and that the types of experiments are limited to those that use commonly available materials. This, however, is desirable for this study as no teacher or school should be excluded from using the resources due to lack of suitable equipment.

The limitation of the physical design is that it is nearly impossible to simply create an aesthetically pleasing document in a format that is easily modifiable. This is a significant limitation and a compromise needed to be found.

3.4   Conclusion

In this section the design of the resources was discussed. First, the reasons behind the selection of material to go into the resources were outlined. These included ideas such as finding the common ground in the state and territory curricula, incorporating elements that will help female students, and choosing activities that can realistically be used by a wide range of teachers across Australia.

Then the rationale behind the physical design was discussed. This included both the realities of how teachers prefer to receive their resources, and the aesthetics of the design.

Finally, the limitations of this approach for designing resources were considered. The main limitation was that of the competing requirements of designing aesthetically pleasing documents that also could be modified.

In the next chapter the process of designing the resources is described. The curricula are researched, existing resources are examined, and the final design of two resources is presented.

Chapter 4

Results

4.1 Introduction

In Chapter 2 it was determined what types of resources should be designed for this study, what their knowledge emphases should be, and how they should be designed to ensure the maximum number of students would enjoy the lessons and learn something.

This chapter contains the answers to the second and third research questions: 'What areas of state and territory curricula are relevant?' and 'Can a resource be designed that relevant and adequate?'.

In order to answer the first question, the areas of physics that are common to all Australian state and territory curricula are found. It is important that the resources are in a common area of physics as ASI wants the maximum number of teachers to use the resources. Then, from this, a narrow area of physics is chosen on which to create resources. The reason the topic is limited is so that the study remains a manageable size.

Following this, both the Year 10 and Year 12 curricula are examined to find out what knowledge students will already have when using the resources, and what knowledge they should gain as a result.

Then, typical students difficulties with the chosen topic are outlined, and current resources available on the topic are described. A detailed evaluation of current resources was not carried out as this is a separate research question.

Finally, the created resources are presented.

4.2   What areas of the state and territory curricula are relevant?

The aim of this section is to find the common ground among all the curricula, including that of the ASI National Qualifying Exam, to answer the research question 'What areas of the state and territory curricula are relevant?'.

Throughout the following discussion, references to *junior* means Year 10, and *senior* means Year 11/12. Note that in this thesis the Curricula Reference section is separated from the main references, and that the relevant pages of all curricula consulted can be found in Appendix C.

The curricula, syllabuses and learning statements (all described as curricula from now on) for the states and territories of Australia are varied in both content and scope. At one extreme is the Northern Territory's very brief outline of topics to be covered: for example, in Year 10 under Energy and Change, one of four science learning outcomes is "*analyse the historical role of science in developing systems of energy transfer*" (Department of Education, Employment and Training, Northern Territory Government, 2008). At the other extreme, the Victorian senior curriculum contains detailed areas of study including "Outcomes" and "Examples of Learning Activities" (Victorian Curriculum and Assessment Authority, 2004).

Figure 4.1(a) and Figure 4.1(b) summarise the topics broadly covered by the curricula and indicate the common topics. As can be seen from the figures, kinematics is the common topic across both age ranges and across all states and territories. Kinematics is closely linked with Forces and Newton's Laws, but to ensure the study remains a manageable size these topics will be excluded from consideration.

4.2.1   Detail on kinematics

Kinematics is the study of motion and its study caused the creation the discipline of physics in the 1600s (Tipler, 1999, p. 19). Kinematics generally covers motion in one, two or three dimensions, including the concepts of position, displacement, velocity and acceleration and normally also includes work with vectors and interpreting graphs. This topic is usually the first that students encounter in physics.
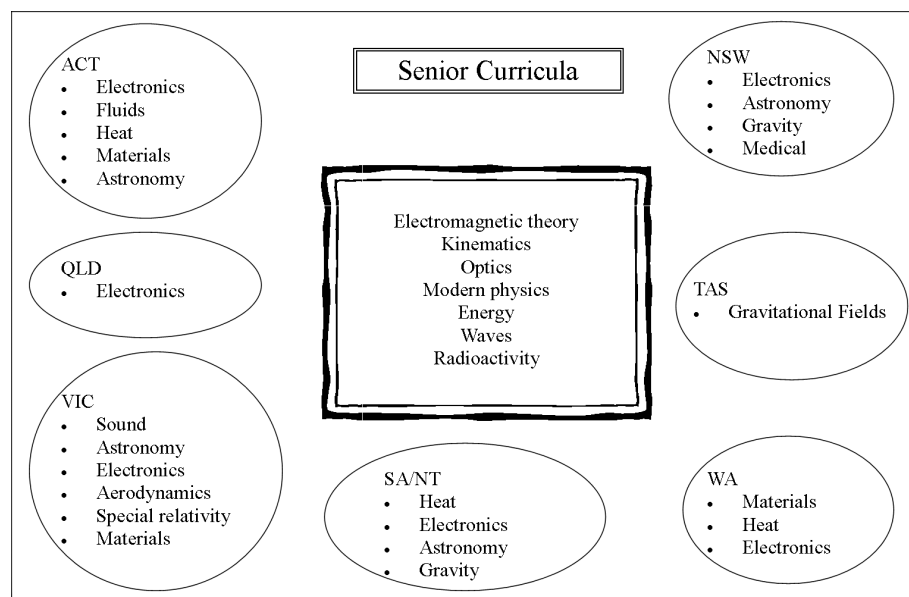
The symbol convention used in this chapter is as follows:

s = displacement or distance,

u = initial velocity,
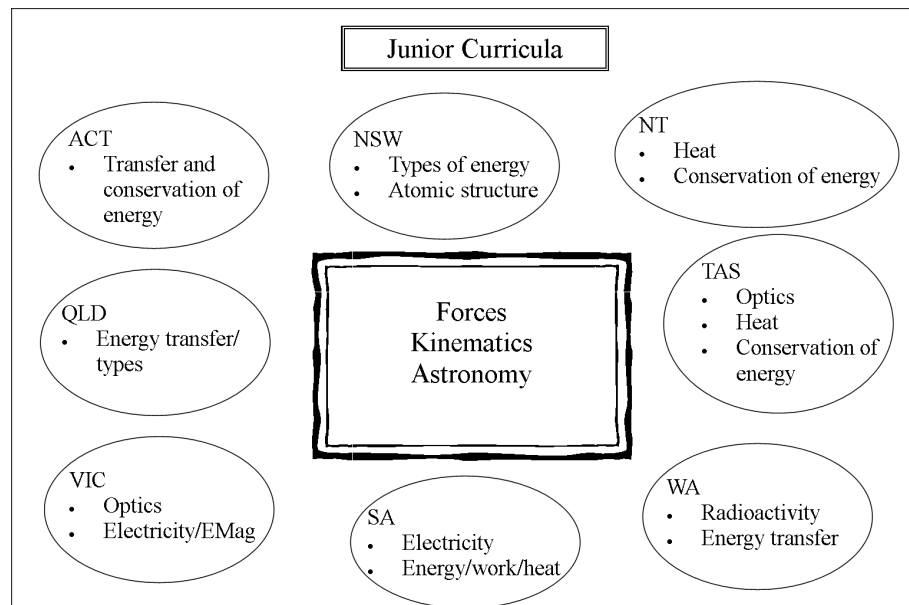
(a) Junior Curricula

(b) Senior Curricula

Figure 4.1: Summary of the junior and senior curricula for the states and territories of Australia. Common topics are contained in the central square; the remaining topics are in the ovals.

v = final velocity,

t = time,

a = acceleration,

Δ = an interval.

The consideration when designing a resource for Year 11 students is: 'where are the students coming from?'. The answer to this is in the knowledge students are expected to have when they finish Year 10. The second question is: 'where do the students need to be?'. The answer is the knowledge students need to have gained by the end of Year 12. In the following two sections these questions are addressed.

4.2.1.1   Year 10 knowledge

Investigating the eight junior curricula for the states and territories, it was found that each contained a varying level of detail.

The Northern Territory and ACT curricula talk only about motion in terms of it being caused by a force (Department of Education, Employment and Training, Northern Territory Government, 2008; Curriculum Renewal Taskforce, 2008).

The Victorian curriculum is also quite vague on the topic, talking again in terms of forces. It does, however, mention describing formal relationships between force, mass, acceleration and velocity using quantitative data, and suggests applying these relationships to examples from transport, sport and recreation. An example experiment is described, where students use a ticker timer to produce a graph of motion for a trolley rolling down an incline (Victorian Curriculum and Assessment Authority, 2002).

The South Australian curriculum mentions applying "quantitative relationships between forces, energy and energy transfer in order to explore the properties of the physical world". A suggested activity is for students to describe the operation of a bicycle in terms of properties such as acceleration (Government of South Australia, 2001).

The Queensland curriculum is more definite about what the students should be taught. One learning outcome is that "students scientific ideas of motion (including action and reaction) to explain everyday experiences". The core content specifically mentions speed, velocity and acceleration but in terms of forces causing motion (Queensland School Curriculum Council, 1999).

The Western Australian Curriculum puts motion into an 'extension' section, and again refers to it in terms of forces. The students need to know the definition, and units, of velocity and acceleration, and be able to do calculations involving the expressions $v = s/t$ and $a = (v - u)/t$ (Department of Education and Training, Government of Western Australia, 2008a, 2008b, 2008c).

Under the NSW curriculum students are expected to be able to "explain qualitatively the relationship between distance, speed and time". As an extension students should know the difference between speed and velocity and be able to use the equations of motion involving time, velocity and acceleration quantitatively (Board of Studies NSW, 2003).

The Tasmanian curriculum is the most comprehensive, with the overall aim of the relevant section being for students to be able to "work with established scientific laws and theories to predict the behaviour of objects (e.g. equations of motion) including quantitative calculations" (Department of Education, Tasmania, 2007).

4.2.1.2   Summary – the starting point

It can be seen that there is range in the depth of coverage of kinematics required by each state and territory. The Northern Territory and ACT barely mention motion, except in terms of forces. Victoria suggests a learning activity where students produce a "graph of motion" from a ticker-tape experiment. South Australia is also quite vague, requiring students to "investigate and experience a wide range of physical phenomena relating to . . . motion" and gives a suggested example of riding a bike.

The Queensland curriculum has a topic of "speed, velocity, acceleration" but gives no further details. Western Australia mainly deals in forces but as an extension students can go into detail on velocity and acceleration and also use some basic equations of motion. Similarly with NSW, the core content consists of qualitatively treating speed, distance and time, but as an extension the students can cover the equations of motion.

Tasmania seems by far the most advanced: the students are expected to use more advanced equations of motion to predict the behaviour of objects. The situations also include negative acceleration and motion under gravity. The curriculum suggests experiments with ticker timers and motion detectors.

Thus, looking at all the curricula, the likely minimum position of students finishing Year 10 is that they would know about:

- speed,

- distance,

- acceleration,

- and be able to use the equations $v = s/t, a = (v - u)/t$.

4.2.1.3   Year 12 knowledge

The Year 12 curricula contain rather more detail than those for Year 10. The topics covered under kinematics, however, are broadly the same among the states and territories. Sentiments from the Queensland curriculum form a useful guiding principle (Queensland Government; Queensland Studies Authority, 2007):

> Motion is common to most of our everyday experiences. This is formalised mathematically in kinematics, which is the study of how objects move. Students should be reminded that the types of motion are highly idealised and may seem to have little to do with the real world as we observe it. However, it is essential that students first investigate these simple and idealised motions and their descriptions to obtain a firm understanding of the basis of kinematics. Once this goal has been achieved, they are in a position to apply their knowledge to the more complex real-world situations, and study phenomena in the quantum realm, which is outside our everyday experiences.

The Northern Territory follows the South Australian curriculum for the senior years. This curriculum requires students to know about motion in one and two dimensions in Year 11, and projectile motion in Year 12. The key ideas listed for projectile motion include: vertical and horizontal components of velocity; time of flight, range and maximum height; and the effect of air resistance. The suggested application for projectiles is sport (Senior Secondary Assessment Board of South Australia, 2008).

In the ACT all physics students are required to learn about motion, including using graphs and relevant experimental equipment. It suggests that non-linear motion such as projectile motion may be included (BSSS Australian Captial Territory, 2005).

The Victorian curriculum mentions very similar topics to the ACT, including being able to analyse motion "graphically, numerically and algebraically" including projectile motion and experimental data (Victorian Curriculum and Assessment Authority, 2004).

The Queensland curriculum again talks about using experimental data and graphs to understand motion, but also mentions using vectors. It lists the equations of motion and

includes projectile motion (Queensland Government; Queensland Studies Authority, 2007).

The Tasmanian, Western Australian and NSW senior curricula are virtually identical in the area of motion and go into some detail on the matter. The Tasmanian curriculum requires students to know about displacement and distance, speed and average velocity and acceleration. Students should be able to construct $s - t$, $v - t$ and $a - t$ graphs and be able to obtain information from the area under the graphs and the gradients. Motion under gravity is also mentioned in the context of constant acceleration problems, including terminal speed and projectile motion (Tasmanian Secondary Assessment Board, 2004).

The extra component mentioned by the Western Australian curriculum is that students are expected to be able to work with one and two dimensional vectors (Curriculum Council, Government of Western Australia, 2008a, 2008b). The NSW curriculum wants students to also be able to: distinguish between scalar and vector quantities in equations; be able to plan and chose equipment for experiments in motion; and describe relative motion (Board of Studies NSW, 2007).

4.2.1.4   Summary – the finishing point

The following common requirements of the Year 12 curricula are apparent. Since there is very little detail in the Victorian and ACT curricula, it is assumed that they would cover these topics:

- knowledge of displacement vs distance,

- knowledge of speed vs velocity,

- average speed and velocity: speed=distance/time (average), velocity=displacement/time (average),

- knowledge of acceleration and how to calculate it: $a = (v - u)/t$,

- determination of the preceding quantities from graphs and/or experimental data,

- uniformly accelerated motion including motion under gravity:
  $s = 1/2(u + v)t, s = ut + 1/2at^2, s = (v^2 + u^2)/2a$,

- projectile motion,

  – components of velocity (vectors),

   – time of flight, range, maximum height.

4.2.2   Bridging the Gap

From Sections 4.2.1.2 and 4.2.1.4 it is possible determine what knowledge is needed to bridge the gap between what students already know by the time they finish Year 10, and what they are expected to know by the end of Year 12. This knowledge is:

- displacement is like distance, but is a vector and can be positive or negative,

- velocity is like speed, but to calculate it you need displacement rather than distance; relative velocities,

- acceleration (including acceleration due to gravity),

- projectile motion, and that vectors can be broken up into components

- vectors, that they have magnitude and direction,

- how to interpret graphs in terms of gradient and area under the graph to get useful quantities.

This should also be compared to the NQE curriculum which says "kinematics in one and two dimensions including projectile motion" will be covered in the exams (Australian Science Olympiads, 2005).

With this in mind, common student problems in these areas of kinematics are investigated in the next section.

4.2.3   Student difficulties with kinematics

Most of the difficulties students have with kinematics were identified during the 1980s during a period of intense research conceptual change teaching (see Section 2.4.1). These and other difficulties students have in the areas listed in the previous section are discussed in the following sections.

4.2.3.1   Distance/Displacement

Arons (1990, p. 21) says that the first step in any kinematics instruction is to make sure students understand 'position' and 'clock reading'. This is because, in kinematics, there are several equations that have the same symbol t meaning either an arbitrary time

interval or time measured from zero, and the symbol d (or s) for measuring position, changes in position or distance travelled.

4.2.3.2 Speed/Velocity

Trowbridge & McDermott (1980) investigated student problems with speed and velocity. They found that, at the start of a physics course, students thought that speed had something to do with distance and time, but was not specifically the *ratio*. They found, through showing demonstrations, that students often believed that two objects had the same speed when they were in the same position. Some students rationalised this by comparing it to overtaking on the motorway, saying that cars have the same speed 'for a while' when overtaking. In another demonstrations, students said that when one object was in front of another it must be going faster.

Halloun & Hestenes (1985a) list a taxonomy of common-sense kinematics concepts students have. They say students do not differentiate between an 'instant of time' and an 'interval of time' because an 'instant' to some students just means a very short period of time. This can lead to further problems with differentiating average velocity from instantaneous velocity.

4.2.3.3 Acceleration

Arons (1990, p. 28) says that students, when asked to give a simple description of acceleration, will say "how fast it goes", and then proceed to give the same answer when asked about velocity.

Trowbridge & McDermott (1981) also researched student understanding of acceleration using similar methods to Trowbridge & McDermott (1980). Demonstrations were shown in which students were asked to say whether two objects had the same acceleration. In most cases, students responded that the objects would have the same acceleration when they had the same speed. The reason for this, state Trowbridge & McDermott (1981), is that students do not fully understand the expression for acceleration: $a = \Delta v / \Delta t$. They *say* 'change in velocity over time' but they do not mean 'change in velocity divided by time'. In some cases students do not understand the difference between an instantaneous velocity and an average velocity, and when to use each for calculating acceleration.

4.2.3.4   Projectile Motion

Trowbridge & McDermott (1981) also investigated student difficulties with projectile motion. Students have difficulty grasping that for projectiles, the acceleration is constant (and in one direction) but the velocity changes all the time. A further issue occurs when the object reaches the top of its flight: students often think that the acceleration at this point is momentarily zero because the direction of the object has changed. Arons (1990) agrees, saying that students have difficulty believing that at this point the velocity is zero but the acceleration is not zero. Arons says this is because using the phrase "coming to rest for an instant" in students' minds means the object stops for a finite moment, in which case the acceleration actually would be zero.

It is not just modern students who have difficulties with projectile motion. The 'impetus' theory was used in the 14th Century to explain projectile motion (Halloun & Hestenes, 1985a) and students today sometimes use a similar explanation. The impetus theory says that objects, when thrown or shoved, gain some kind of 'motive power' that keeps them moving, even though the thrower is no longer in contact with the object.

When considering objects dropped from a moving platform, McCloskey (1983) says that students often get confused by the frame of reference and believe the object falls vertically. This is only true if the situation is viewed in a reference frame which is moving with the platform. If the reference frame is stationary then the object follows a parabolic path.

Hecht & Bertamini (2000) investigated student understanding of ballistic motion which includes, for example, cannonballs fired from a cannon or a ball being thrown. They found that students believed the greatest speed along a trajectory of an object being projected was somewhere near the middle of the trajectory, instead of right at the start (or right at the end) when the ball left the hand of the thrower (or returned to it).

Secondly Hecht & Bertamini (2000) asked students to point out the most 'natural' looking trajectory from a series of realistic and unrealistic drawings. Noting that wind and drag can produce trajectories that are not symmetrical, students still chose semi-circular and sinusoidal (from 0 to π) paths as looking natural, along with parabolic paths.

4.2.3.5   Vectors

Aguirre (1988) found students have difficulties with vector components of velocity. In particular they tend to believe that in projectile motion, the two components of velocity

act sequentially – one has to wear off before the other can act. Another difficulty noted in terms of vectors and projectiles was that students believed the time taken to move along the curved path of a projectile was different to the time taken for the object to fall vertically only, because of there were two velocities influencing the object. Students also had trouble predicting what would happen to the magnitude of one component velocity if another orthogonal velocity was introduced.

4.2.3.6   Graphs

Arons (1990, p. 24) says that students often do not connect the shape of a graph with the actual motion of the object it is describing. The main difficulty students have with graphs in kinematics is the tendency for them to draw graphs that look like the motion, despite being able to correctly verbally describe the motion (Goldberg & Anderson, 1989).

Also, notes Goldberg & Anderson (1989), negative velocities in graphs cause problems for students. Students could not grasp the concept of negative velocity or the graph crossing the time-axis meaning the instantaneous velocity was zero. This is likely due to students thinking of *speed* instead of *velocity* which has direction and magnitude.

Another issue with graphs, found by Bliss & Ogborn (1988), is that some students tend to think of $v - t$ graphs as distance-time graphs. A particular difficulty with $v - t$ graphs for students was drawing a graph for a stationary object as time passed.

Peters (1982) got students to draw graphs of motion ($s - t$ and $v - t$) for an experiment set up in the classroom. Students exhibited difficulties showing speeding up and slowing down, and realising that the $v - t$ is simply a graph of the gradient of the $s - t$ graph. The realisation that a reversal of direction meant a change in the sign of the velocity was also uncommon. McDermott, Rosenquist, & van Zee (1987) noted similar difficulties in an experiment where students were asked to take data needed to draw a $v - t$ graph: students often could not decide what data to take, or what to do with it once they had it. Peters (1982) also noted that confusion occurs between graphs of one and two dimensional motion once both concepts have been introduced.

McDermott et al. (1987) says that students often do not know what 'features' to read from a graph, such as whether to use the co-ordinates of a point, the rise, the run, or the slope of the line, and that curved graphs are harder to interpret than straight line graphs. Students will look at the 'height' of the graph instead of the change in slope of a graph, because the height is the more obvious feature. Using the area under a $v - t$ graph to find displacement is also problematic for students as they find it hard to see how 'counting squares' could result in a linear quantity. They may not know which squares they are

supposed to be counting, or how to work out the displacement associated with one square, or that above the axis represents positive displacement and below the axis is negative displacement.

Furthermore, McDermott et al. (1987) notes, students do not generally draw negative velocity correctly, putting a kink in the graph instead of crossing it at the $v = 0$ axis for a velocity reversal. Finally, being able to draw a correct $a - t$ graph is a challenge for students, especially when an object "slows down, turns around and then speeds up in the opposite direction".

McDermott et al. (1987) says that when students are confronted with a set of related $s - t$, $v - t$ and $a - t$ graphs they find it hard to believe that they all can represent the same motion, even though their shapes are very different.

4.2.3.7   Summary of difficulties

The following is a summary of the previous section concerning common student difficulties with kinematics. Students have difficulty with:

- The meaning of 'instant of time',

- differentiation between position, change in position, distance travelled,

- believing same position means same speed,

- the difference between instantaneous and average velocity,

- believing same speed means same acceleration,

- the speed/acceleration at the points on the trajectory of a projectile,

- the speed/acceleration at the top of flight of a vertically thrown object,

- the shape of the trajectory of a projectile,

- the affect (or otherwise) of components of velocity on each other,

- graphing negative velocity,

- sketching a motion graph of a demonstration or experiment,

- knowing what features to read from a graph,

- working out the area under a graph.

With these difficulties in mind, some currently available resources in kinematics are discussed in the next section.

4.2.4   Current resources in Kinematics

In this section a selection of resources currently available to Australian high school teachers is reviewed. Many of the resources available on the internet are in the form of animations or Java Applets but these resources are not appropriate for this study as they rely on the availability of computers. Also not included in this section are the multitude of standard physics demonstrations and experiments that can be found in several places on the internet. Some of the most useful resources, however, were found in the journal *The Physics Teacher*.

4.2.4.1   Vectors

Instructional Research Lab: UCLA Physics (n.d.-a) has a demonstration of vector addition using two toy bulldozers and a cart or trolley. One bulldozer is put on the cart and set in motion, and the other is used to push the cart across a piece of butchers paper. The initial and final positions of the bulldozers are marked and the resulting vectors are drawn on the board.

4.2.4.2   Time, distance, speed

The website comPADRE (2007) gives an example of a demonstration in kinematics where students predict which toy car will win a race. This, they say, allows student to learn about time, position and speed. The objects have a constant speed, and the class agrees on this fact to start with. Then, before performing any demonstrations, the teacher asks the students to work out which car will win the race. The students discuss what they would need to know or measure in order to answer the question. It is up to the teacher whether to provide the speeds and distance to students, or whether to let them measure it themselves, and express their confidence in their measurements. The students discuss their ideas and find out different ideas from the class on how to make the measurements. Alternatives to a simple race is for the class to work out how much of a head start (or handicap) one car needs so they finish at the same time, or to work out where the cars would collide if they were moving towards each other.

Forrest (1999) describes a class experiment where the aim is to work out when to drop an egg from a tower so that it hits the teacher on their head. The physics involved is

simply working out how far the teacher walks in the time it takes for the egg to drop. Forrest reports that this activity was found to be fun, and memorable, and that students learned to appreciate the usefulness of formulae. The experiment involves group work, and a write up afterwards where students discuss what worked and what did not. There is also the possibility of discussing sources of error e.g. reaction time or wind effects that would contribute to the egg missing the target. Forrest says that this experiment is better performed outdoors (giving the students a change of scenery) and that normally only about half the eggs hit the teacher.

An experiment using 'Hollywood Physics' to introduce the topic of speed is described in Dennis (2006). He uses the scene in the movie *Forrest Gump* where Forrest as a child is running from bullies then the scene merges to him as an adult running to score a touchdown in a game of American Football. The question asked of the students is 'which Forrest is faster?'. Dennis says that this can be attempted even before the students have come across the concept of 'speed', as it will come naturally to the students in the course of the exercise. It is possible to easily measure adult-Forrest's speed as the football field has distances marked on it. Students have to do experiments to determine stride length in order to find child-Forrest's speed. It is possible that this movie will be too old and 'uncool' for students in 2008, so other movies could be found to perform this experiment on (see Section 4.2.4.6).

Jackson, Laws, & Franklin (2003, p. A-76) have a suggestion for an extended activity on the concepts of velocity and average velocity. The activity is centred around the discovery in 1978 of fossilised hominid footprints, and the students are asked to work out, based on the measurements of the spacing of the footprints, the speed of the walker and how far they would have been able to walk in a day. This activity could be extended, or be part of the broader theme of 'dinosaurs' that is popular with students (see Section 2.5), or incorporated into some kind of geography lesson.

4.2.4.3   Acceleration

Colicchia, Zollman, Wiesner, & Sen (2008) have an interesting suggestion for an acceleration application and experiment. In this experiment students can build, or use, a model of a head and upper-spine to replicate whiplash in a human neck as a result of a car accident. The students record the simulated rear-end collision using a digital camera and plot distance the head moves against time, and derive the acceleration vs time graph using software. Colicchia et al. say that this shows an important application of physics to car safety. This activity could be extended to incorporate a headrest and then students

could see the difference in the acceleration of the head. In this way, the activity may appeal to female students because of the 'helping people' aspect, and to the male students with a 'crashing' aspect. The topics covered in the experiment could include the biomechanics of the spine and it could provide a lead-in to forces and Newton's Laws. The use of a computer to analyse the data may not be essential.

4.2.4.4 Graphs

A suggestion by Sathe (1979) relates to the interpretation of the area under a $v - t$ graph. As was noted in Section 4.2.3.6, some students have difficulty seeing how an 'area' can correspond to a (linear) 'distance'. So Sathe draws a simple $v - t$ graph on the board, and then takes a sheet of notepaper with equally spaced lines, holds it so that the lines are vertical, and cuts the paper so it is the same shape as the graph. The students are then told the distance between each line is Δt (infinitesimal time). Then the teacher cuts the 'graph' along the lines and lays the strips out onto the table end-to-end. Then students can see that the line of paper is 'infinitesimally thin', but represents a distance.

Doherty (2004) suggests that an $s - t$ graph can be more easily seen by performing the following experiment. A person sits on a skateboard (or equivalent), and another person has five beanbags. The first person is pulled along on the skateboard at a constant speed. A third person with a stopwatch calls out the seconds. The bean-bag holder drops a bean-bag next to the skateboard every second for five seconds. The distances between bean-bags can be measured and a graph plotted. This experiment is described in terms of forces but could be adapted for a simple motion experiment.

4.2.4.5 Projectiles

The National Science Foundation (2003, p. 16) reports on a program, aimed at female students, in which science principles are presented through sport. But instead of learning about the sport in the classroom, the students actually learn how to hit a tennis ball or golf ball or play basketball, at the same time as learning the science of trajectories and range.

Bartlett (1984) has an suggestion for homework related to projectiles and sport, although this is reasonably specific to the USA. In American Football, there are distance lines marked on the field, and using these and a stopwatch, students can time how long a ball is in the air, and how far it is thrown (see also the *Forrest Gump* experiment described in Section 4.2.4.2) . This experiment is best performed in pairs (one to watch

the distance and one to time), or the game can be recorded and played back frame by frame. The students are asked to find the initial velocity (including direction) and the maximum elevation reached by the ball. Bartlett says further to this experiment, students could record their uncertainties and work out the acceleration of the ball (and later, the force on it). The experiment could also be applied to other sports where the distance information was available.

Walker & Syed (2008) apply projectile motion to a real life tragedy. A Siberian Tiger jumped out of its enclosure at the San Francisco Zoo and killed a teenager. This exercise uses projectile motion to find the minimum velocity the tiger would have needed to have to escape from its enclosure, and thus determine whether the enclosure was adequate. This is a relatively complicated calculation involving differentiation and minimisation which would probably stretch a Year 12 group, but it could possibly be adapted to make it a less difficult problem.

A way to treat projectile motion without using trigonometric functions is outlined in Mohazzabi & Kohneh (2005). This procedure can be used to find the location of the projectile at any point, including finding the range and maximum range. This treatment could be useful to include as an alternative to the standard trigonometric treatment.

Instructional Research Lab: UCLA Physics (n.d.-b) has an interesting suggestion for a demonstration of projectile motion using a water stream. The water stream is projected at an angle and a stick with rulers hanging off it at intervals is hung over the stream (at the same initial angle). The rulers aid the class and the teacher to make measurements at various points in the trajectory, and see clearly the angle that gives the maximum range. The author says that this demonstration appeals to students due to the possibility of the teacher getting wet.

Tao (1987) wrote a book on the physics of traffic accident investigation. The book contains several examples relevant to kinematics. In one exercise students work out how long it took for a boy to walk on a pedestrian crossing to the point where he was knocked down by a car (p. 28). In the section on projectile motion students can work out the speed of the car on impact from the distance of debris from the car, or from the landing point of the car if went down a slope (p. 74). This latter exercise also has an extension where students have to deal with projectiles launched at an angle and landing at a lower height than where they started (p. 77). These exercises could easily be turned into a scaled-down laboratory activity.

4.2.4.6   A bit of everything

Baird (n.d.) has a set of student resources on kinematics that are one or two pages long and explain various topics in entertaining ways. For example, in describing the classic 'monkey and hunter' question, the author makes up a big silly story around a legend of a monkey terrorising a village. This story would appeal to boys, but perhaps not girls. Overall however, these resources are still rather like a classic textbook, but with more humour.

Dennis (2002) discusses the general idea of using Hollywood films as a classroom aid. The advantage, he says, is that films are familiar terrain for students, and that they are curious to see whether physics has any relevance to real life. He says it is also useful for students with low maths skills. Dennis suggests avoiding the big finale action scenes as they generally do not contain much reality, and instead suggests focussing on scenes where "nature takes its course", or scenes with on-screen measurements such as speedometers (*Back to the Future*), or a character describing motion (*The Fugitive*). Dennis suggests using films more recent than 15 years old, but to include all genres including science fiction. Another example given is in the movie *Speed*, where students learning about projectile motion can work out whether the bus is likely to be able to make the jump across the gap in the freeway.

Lasry & Christin (2006) suggests using magic in the classroom to engage students in a topic. They say that students should make predictions about the outcome of a 'trick' so they "develop a vested interest in the outcome (*"will I be right?"*)", and when they get it wrong (because it's a magic trick) they are more likely to learn something. The suggested tricks given in Lasry & Christin do not relate to kinematics unfortunately.

4.3   Can a resource be designed that is relevant and adequate?

The final research question is: 'Can a resource be designed that is relevant and adequate?' ASI requested that the resources not be not lesson plans but instead activities that could be turned into lessons. These activities would be at different levels of difficulty, and would have subsidiary activities such as background, homework and demonstrations associated with them.

The following two resources were therefore created:

1. *Survival Physics* – an unlikely tale of deserts and jungles.

2. *Traffic Physics* – all about traffic safety and stunts.

Copies of these resources can be found in Appendix A.

Chapter 5

Conclusions

5.1   Summary of the study

This study was concerned with the creation of resources for high school physics teachers at the request of the organisation Australian Science Innovations (ASI). Through the Australian Science Olympiads, ASI selects students to represent Australia at the International Science Olympiads. This is a competition for Year 11 students around the world in physics, chemistry and biology. The created resources were to be linked with the Australian Science Olympiads in an effort to attract more students to enter the selection process for the Australian team.

Three research questions were identified, which, when answered would lead to the creation of the resources. These questions were:

1. What do I need to consider when designing an adequate resource?

2. What areas of the state and territory curricula are relevant?

3. Can a resource be designed that is relevant and adequate?

5.2   What to consider when designing an adequate resource?

To design an adequate resource, the following were considered:

- The skills students needed to be successful physics Olympians

- The knowledge emphases currently prominent in Australian schools

- Learning theories that have been found to work in the classroom

- What makes science appealing to students, especially female students

- The 'nuts and bolts' of resource design

First, it was found that the important skills for being successful in the International Olympiads were: problem solving; an understanding of physics concepts; and experimental skills and techniques.

Next, the main knowledge emphases for school curricula were discussed. It was found that three emphases were evident. The first was the need to provide students with the pure scientific knowledge that would allow them to go on to do further study. The second was scientific literacy, or teaching students knowledge that would be useful for understanding social issues that had a science aspect to them, such as genetically modified crops or global warming. The third emphasis was the Nature of Science which aims to provide students with a background in how science works and an understanding of the processes behind science. This was found to be related to scientific literacy as it also attempts to give students enough knowledge to usefully discuss science issues in the future. The Nature of Science was found to be an acceptable compromise between learning knowledge and having an enjoyable science experience and so was chosen as the focus for the study.

Following this, different learning theories were explored. The first was the conceptual change theory which was found to be not just about replacing student misconceptions with the correct concept but about restructuring students' knowledge. It was found that conceptual change was hard to teach for, and often did not work.

Context-based learning was investigated next. This technique involves putting science learning in a social or local-issue context. It was found that although this technique was popular with students it did not result in much science knowledge being learned.

Inquiry-based learning was the last theory examined. This aims to show students where science results come from, including the process of science, which leads to a better understanding by the student. This technique was found to be heavily student-centred making it harder for teachers to make the class productive. The need for large amounts of data to facilitate this learning was also found to be a disadvantage.

How to make science appealing for students was discussed next. It was found that to make science appealing to female students, avoiding the use of male-biased language was important. Including positive references to female scientists, allowing students to

spend more time on experiments and fostering a cooperative classroom environment were all vital to encourage female students. Another way to make science appealing to both male and female students was to help them manage their border crossing from a non-science way of thinking into the culture of science. Finally, incorporating practical work into lessons was found to be important as this is a popular activity for students. It was found, however, that for practical work to be useful the students must be able to see the relevance of it.

Lastly, the literature concerning the 'nuts and bolts' of resource design was reviewed. It was found that teachers preferred their resources to be in print format and for the resources to be modifiable. The language used needed to be suitable for all abilities of student. Teachers were also found to be reluctant or generally unable to incorporate computer based activities into the classroom and so it was concluded that the resources created for this study should avoid this need.

5.3   What areas of the state and territory curricula are relevant?

To find the relevant areas of the curricula, all state and territory science curricula in Australia were obtained and the common ground among all of them was found. From this, one common area of physics was chosen to be the topic of the resources. An investigation of student difficulties in the chosen area of physics, and a brief investigation into currently available resources in that area was also undertaken.

The common area of the science curriculum was found to be kinematics. The knowledge students needed to bridge the gap between their Year 10 knowledge and their Year 12 knowledge was found to include concepts such as projectile motion, the difference between displacement and distance, and the use of vectors.

Student difficulties with kinematics were investigated next and it was found that there was a range of commonly reported problems. These included the inability to grasp the difference between instantaneous velocity and average velocity, working out the speed and acceleration at different points on the trajectory of a projectile, and difficulties graphing negative velocity.

Following this, a selection of currently available resources were discussed in order to provide some ideas for the creation of the resources for this study.

It was noted that ASI requested that the resources not be lesson plans but instead

activities that could be turned into lessons. These activities would be at different levels of difficulty, and would have subsidiary activities such as background, homework and demonstrations associated with them.

5.4 Can a resource be designed that is relevant and adequate?

Two sets of resources were created: *Survival Physics* and *Traffic Physics*.

The designed resources contain two components: a guide for the teacher, and worksheets for the students. In order for the resources to be widely used, the teacher guide was set out in such a way that a teacher could just pick it up and use it. Leaving open the possibility of teacher modification of the resources was then a challenge but a compromise solution was found: different topics started on a new page in the student worksheets, meaning the teacher could use each section individually if desired.

The teacher resources set out the general curriculum topic of the resource and the intended learning outcomes at the beginning, as well as the motivation for students using the resource. The front section also includes the reasons these activities were chosen, for example, because they are likely to appeal to female students, or that they cover a certain common difficulty in the topic. The main body of the resource contains the different activities clearly set apart from each other. The body also contains the questions (and answers) that form part of the student worksheet.

The aesthetics of the resources were also considered carefully. The teacher resources were designed so they were uncluttered and easy to follow. Colour was used but is not integral to the design, so that printing the resource in black and white would not cause problems. The student worksheets do not generally contain spaces for students to write their answers for two reasons: the first is that the students are likely to be in Year 11 or above and should no longer need the comfort of writing on question sheets; secondly, the resources are more likely to be used again if the teacher can collect clean worksheets at the end of the lesson. The teacher resources were designed so there was plenty of white space in which the teachers could make notes or add comments.

The resources were made using the Adobe® programs InDesign® and Photoshop®. InDesign® was used to create PDF documents, and while this prevents teachers from directly editing the resources for their own use, it did ensure the resource design was professional in appearance.

Overall, the resources incorporated much of the teaching of this study and satisfy the request made by ASI that resources be created that are relevant, engaging, and useful and will lead teachers to enter more students in the Olympiads.

5.5 Limitations

The resources created for this study were most significantly limited in number and scope by the size of the study. It would have been nearly impossible to incorporate every aspect of teaching and learning research, every aspect of making science fun, and every aspect of good design into just two resources.

The fact that there was also no possibility of the resources being evaluated by teachers was another significant limitation. Had the resources been shown to teachers for evaluation, it would have likely meant some that activities would have been removed, some extended and some changed. The resulting resources would then have been even better tailored to Australian science teachers.

5.6 Recommendations for further work

A future study should certainly include an evaluation of the resources. At the very least this evaluation should ask teachers whether they would use the resources in the current format, whether the difficulty of the questions is suitable for the students they teach, and whether the instructions and solutions given were adequate.

This study provides a template for the future creation of resources for ASI. The literature has been researched fully, and the most up to date views on teaching and learning methods have been found. A future study would need to find other common topics in the physics curricula of Australia and research the student difficulties in those areas. This could also be done in chemistry and biology, leading to the creation of a suite of resources for distribution to schools throughout Australia, all advertising the Olympiads and the fun of science.

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Appendix A

The Resources

This appendix contains the two resources created for this study. They are presented as an image: in their original format they are designed to be printed one page to a sheet of A4.

1. Survival Physics

   (a) Teacher Edition

   (b) Student Edition

2. Traffic Physics

   (a) Teacher Edition

   (b) Student Edition

Survival
Physics

Introduction

- This resource is centered around an unlikely story of being lost in the desert, tracking footprints, catching a tiger and putting it in a zoo.

- This resource covers the curriculum topics of:
  - The difference between distance and displacement
  - The difference between speed and velocity
  - Vectors
  - Projectiles
  - Experimental skills

- The level of difficulty of the individual activities varies from very easy (*What is speed?*) to complex (*How to contain a tiger*).

- After completing this resource, students will have a real-world grounding in these curriculum topics. They will be able to perform calculations involving speed, distance, time, vectors, and projectiles. They will have designed and carried out several experiments and will have an appreciation of factors affecting the outcome of those experiments. They will have applied their physics knowledge creatively.

- In accordance with research in science teaching, this resource contains an example of a female scientist (Mary Leakey), non-physics applications (tracking, zoo design), creativity (story writing), experiments including pre- and post-lab work (tracking, catching the tiger), helping people (zoo design), movie physics (*The Fugitive*), and 'border crossings' where students learn concepts using their own language (tracking).

- Motivation for students:

  "In this resource you will learn tracking and how to catch a tiger, among other useful skills!"

* NOTE: copies of the video material are not required to complete any activity.

Contents

Note:
■ Student questions in the accompanying worksheets are in boxes like this.

What is speed?

To give students an easy reminder of the idea of speed, the following questions may be useful:

■ **What is the fastest thing you've seen moving? Do you know its speed?**

Aeroplane in the sky: 1000 km/h
Car: 100 km/h
Shuttle launch: 5500km/h two minutes after launch[1]
A ray of light (did you *see* it though?): 1×10^9 km/h (or 3×10^8 m/s)

■ **What is the slowest thing you've ever seen? Do you know its speed?**

A snail moving[2]: 0.05 km/h
Grass growing: guesstimate in summer 1×10^{-7} km/h (2cm/week)
Someone walking: 5 km/h
Hair growing: 2×10^{-8} km/h (6 inches/ year)
Continents moving: 2×10^{-9} km/h (2cm/year)[3]

■ **What do you think might be the fastest/slowest things in the universe?**

FASTEST: speed of light: 1×10^9 km/h (or 3×10^8 m/s)
SLOWEST: macroscopically: something that is not moving (speed=zero). Atomic level: anything that has been cooled to absolute zero (-273ºC). At this temperature there is still some motion due to *zero point energy,* but there isn't much! This is quantum physics.

A discussion of "order of magnitude", appropriate units, or scientific notation may also be useful here.

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1 See NASA http://www.nasa.gov/lb/facts/Space/space_facts_archives.html
2 http://hypertextbook.com/facts/AngieYee.shtml
3 http://hypertextbook.com/facts/ZhenHuang.shtml

Tracking your walking speed

We now come to the start of the 'unlikely story' that forms the backbone of this resource. It is not essential to use this story of course! A sketch map is useful for the later section on vectors. Here is an example:
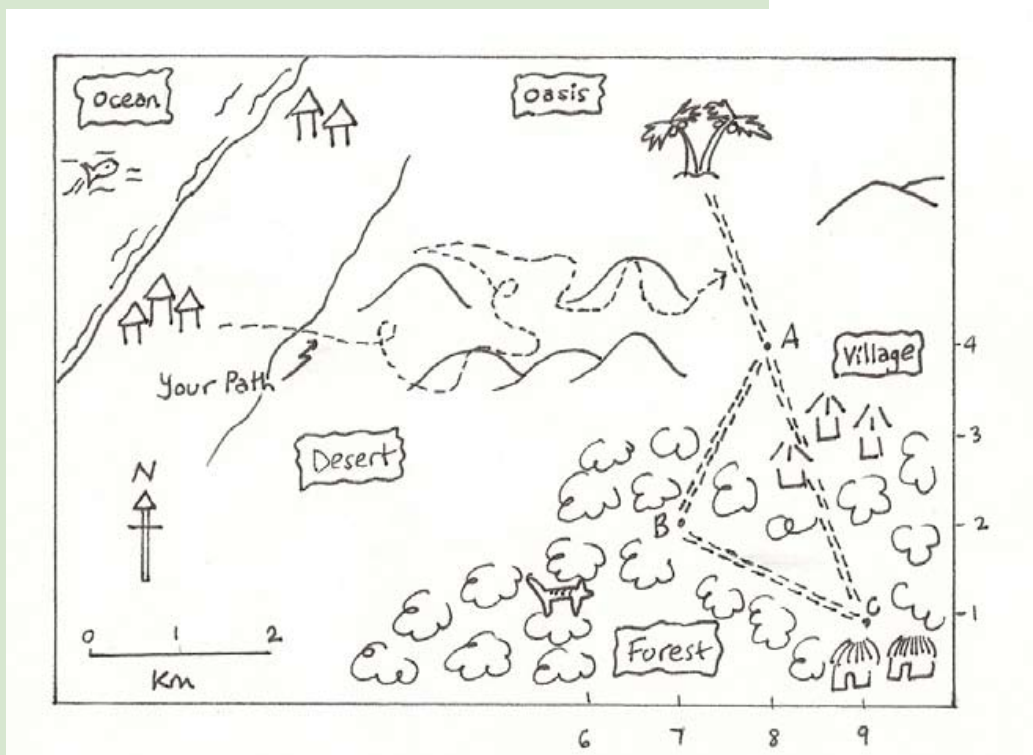
The story goes…

You're lost in the desert (don't ask me why). You see footprints crossing your path. You suppose they are human because of their shape. You want to know how fast they are walking to see if you could catch up with them.

Some history can be introduced here.

Mary Leakey and Richard Hay discovered the first fossilised human-like (hominid) footprints in 1978. They were found in an old volcanic lava bed in the Laetoli region of Tanzania, Africa[4]. The largest trail of prints was about 25m long, and the average dimensions of the prints were 18.5cm x 8.8cm. The average stride length was 38.7cm.

4 Nature, Volume 278, p317-323, 22 March 1979

Survival Physics

The following are suggestions for questions and activities for students:

Speed

■ Go outside and find some soft soil/clay. Volunteer to make some footprints. Alternatively paint your feet and make footprints on some butchers' paper. For extra fun, get more than one person to walk, and get others to decipher the tracks.

■ Compare the measurements of the Laetoli tracks with your footprints. What can you say about the Laetoli tracks?

The student tracks should be bigger in size and stride length than Laetoli (depending on the height of the students). The Laetoli were likely to be shorter than modern humans… unless the tracks were made by a child? Discuss the possibilities.

■ Can you work out your walking speed? Do the same for the Laetoli footprints.

To do this, the students would have to time how long it takes them to walk the few footsteps they made and calculate the speed from this. Then they should try to replicate the shorter stride length and work out the speed of the hominids.
Over 3m, one self-timing of normal stride length gave 3.5s, resulting in a speed (=distance/time) of 0.85m/s. For the Laetoli footprints, walking with a stride length of about 40cm over 3m took 6.9s, resulting in a speed of 0.43 m/s.

Imagine these people have been walking all day, on and off. Sometimes they might stop for a rest. You have just calculated their instantaneous speed because it was measured over a very short distance compared to the whole day's walking.

■ What would be their average speed if they walked on average for half an hour, then stopped for half an hour? Is it the same as instantaneous speed?

Effectively by doubling the 'time' part of the calculation in the previous question, this will lead to the answer being half the speed. It should not be the same as instantaneous speed.

Further to this, the students could walk over longer distances (e.g. on a running track) to get a better estimate of speed. This is an opportunity to introduce good experimental practice.

MaryLeakey(1913-1996)wasone of the foremost archaeologists of the 20th Century. During her pre-teenage years she lived in France with her parents and went on archaeological digs with a family friend. As a teenager she didn't enjoy the convent school where she was enrolled, so left at 13.
  When she was 17 she started to write to archaeologists asking to accompany them on digs. She was accepted by one and it was through her brilliant drawings that she became part of the culture of archaeology.
  She married another archaeologist and they spent many years in Africa on digs, where Mary found the oldest (at the time) human-ancestor skull. Over the years she also found another hominid skull (a different human-ancestor), and the Laetoli tracks.[5]
  Her lack of a university degree never stopped her! Her autobiography is called Disclosing the Past.

5 http://www.utexas.edu/courses/wilson/ant304/biography/arybios97/dentebio.html

SurVival Physics

Distance

The wind is blowing the tracks away in the time it took to work all this out…

■ **How far away could the owners of the mystery tracks be? What do you need to assume to make a good estimate?**

Since the wind is blowing the tracks away, guess that the people would have maybe an hour's head start. The students need to assume that the people have been walking at the 'instantaneous speed' all the time. The instantaneous speed will give the maximum range, as long as the people keep on the same path. In an hour they would be (distance = speed x time): 0.85 x (60x60) = 3km away.

■ **How far could they walk in one day?**

Distance = 'instantaneous speed' x time (e.g. 8hrs). For my calculation distance = 0.85 x (8x60x60) = 24480 m = 24km.

This exercise could also be used to discuss estimation and its limitations.

Vectors, distance and displacement

Of course, they probably didn't just walk in exactly a straight line.

Look at the map (North is marked, and there is a scale): some possible trails for the people who made the footprints are marked.

■ **If they did a dog-leg around a village, what would be the distance they walked? What would be the displacement?**

On the map, write down vector positions (ordered pairs) for the start, end and elbow of the diversion, i.e.,

Start: (8, 4)
Elbow: (7, 2)
End: (9, 1)

Using the diagram on the next page:

This sort of information is useful for geographers to understand how ancient settlements were formed. With no other form of transport (except possibly by river), limits can be placed on which communities were likely to be in contact, and how culture spread and networks were formed.

An example here is the vast number of Australian aboriginal languages spoken. Aboriginal settlements are so far apart (when you are walking) that little interaction would have occurred over their history and so a common language was not necessary.

Walking distance also affects the size of the community because how far people can walk puts limits on the amount of food that can be gathered.

NOTE: distance and displacement in one-dimension should be covered before this section is attempted.

Survival Physics

$$A^2 = 1^2 + 2^2$$
$$A = \sqrt{1^2 + 2^2} = 2.2\text{km}$$

So...

$$A_x = A\cos\theta_A$$
$$\theta_A = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$
$$= \tan^{-1}\left(\frac{2}{1}\right)$$
$$= 63°$$
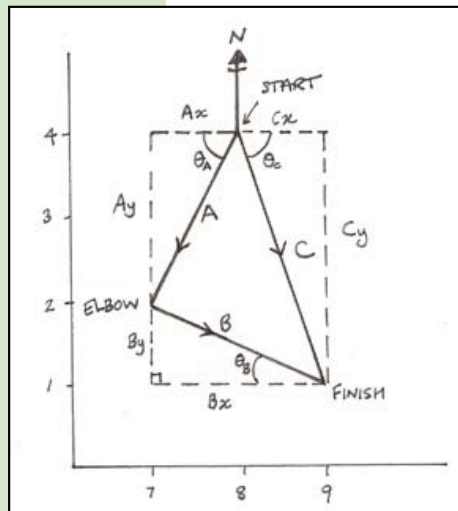
The displacement A is 2.2km, 207° from North.
Similarly the displacement B is 2.2km, 155° from North.

The distance around the dog-leg is 4.4 km.

Now to work out the displacement between start and finish:

$$C^2 = 1^2 + 3^2$$
$$C = \sqrt{1^2 + 3^2} = 3.2\text{km}$$

$$\text{angle from North} = \theta_C + 90° = \tan^{-1}\left(\frac{C_y}{C_x}\right) + 90°$$
$$= \tan^{-1}\left(\frac{3}{1}\right) + 90°$$
$$= 161°$$

The displacement from start to finish is 3.2km, 161° from North.

The distance C is 3.2km.

Distance and displacement mean different things!

■ Check your answer using a piece of string and the scale on the map!

■ In your own words, write down the difference between distance and displacement.

Survival Physics

Distance is the entire distance travelled; displacement is measured as the crow flies and you have to specify the direction.

At this point, reminding students of the formal definitions of distance and displacement is necessary. They will probably be quite close with their 'own words' definition, but may not mention *scalars* or *vectors*.

<u>Scalar:</u> a quantity with magnitude (size) but no associated direction (e.g. distance, speed)
<u>Vector:</u> a quantity with magnitude and direction (e.g. displacement, velocity)

> ■ When might the distinction between distance and displacement be important in general? Discuss among your friends, and then report back to the class.

The difference would be important if you were working out how much fuel or water you needed to get somewhere (distance); how much time you had to get to a certain place e.g. between camps (distance); if you were firing a rocket there, or hang-gliding there, or sighting a landmark (displacement).

> ■ What can you now say about the velocity of the owners of the mystery tracks (remember it has a direction too)?

The students should realise that they can work out the direction of the tracks by looking at the shape of the footprints.

The velocity of the people making the tracks on the map is 0.85 m/s (calculated earlier from the students' walking speed) in the direction 161° from North (the angle from North of the line going from the start to the finish).

On the run

■ Watch this scene from the movie **The Fugitive** (1993).

In this scene, the hero Richard Kimble (played by Harrison Ford) has just escaped from custody in a train/bus crash. The US Marshall Sam Gerard (played by Tommy Lee Jones) is on his trail.

The scene starts at about 20 minutes into the movie, and is over by 23m 30s. There is some bad language in this segment.[6]

> At the scene of the crash, Marshal Gerard says:
>
> "Listen up ladies and gentlemen!
>
> Our fugitive has been on the run for 90 minutes. The average foot speed over uneven ground barring injury is 4 miles an hour. That gives us a radius of 6 miles…
>
> … check-points go up at 15 miles."

■ Why do the checkpoints go up at a much larger radius than his predicted distance?

He may run, he may be fitter than average, he may reach smooth ground, he may get transport etc. Students can discuss this. Also consider the disadvantages of wide checkpoints: the wider the radius the larger the area inside the checkpoints is to search. The area is proportional to the square of the radius.

■ Make estimates of your walking and running speed on smooth ground? What about rough ground?

Students could do this on the sports field: time how long it takes to walk/run 100m on the athletics track. If you have a cross-country running trail of known distance, students can use this.
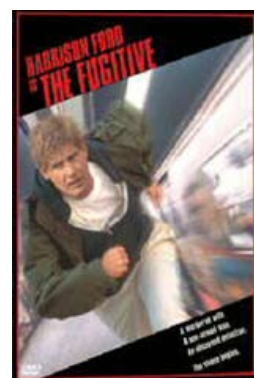
This is what trackers do in real life. In aboriginal culture, tracking is very important as it was traditionally used in hunting and the search for water. There are some details on this on the Culture and Recreation website of the Australian Government. A quote from this website:[7]

"Trackers also need to know whether tracks are fresh, otherwise they might be wasting their hunting time. At the end of a day, however, a good hunter needs to be able to find his way home using the shortest route possible - not in the tedious zigzag way he tracked his prey. This acute sense of direction is inseparable from acute powers of observation and good memory."

6 Image from Warner Bros: http://whv.warnerbros.com/WHVPORTAL/Portal/product.jsp?OID=27946
7 http://www.cultureandrecreation.gov.au/articles/indigenous/trackers/

Survival Physics

How to catch a tiger/teacher

Now you find yourself in a forest, having followed the footprints there. You get scared because you can hear a big animal moving about, so you find a big rock and climb a tree with it. You see it's a tiger!

But wait! The tiger appears to be injured. You don't want to leave it there to get angrier and more injured, so you decide to trap it and arrange for it to be taken to a zoo. First though, you need to stop it.

It's walking in the direction of your tree! You have a rock, and some physics knowledge…

> NOTE: basic equations of motion should be covered before this section is attempted.

A tiger-catching experiment

■ **Instead of a tiger and a rock, you have a teacher and some eggs. Your tree is the bandstand, or an upstairs window of your school. The eggs are your rock. Your task is to drop an egg to hit the teacher squarely on the head.**

The students must calculate what position the teacher needs to be in when they release the egg. This experiment can be delivered to students in stages, or left to the students to work out the procedure. It would probably be best as a team exercise. The original designer of the experiment reports that less than half of the eggs usually hit him, and even fewer hit him on the head.[8] The height needs to be about 6-10m to differentiate between correct calculations and being lucky. A pre-lab exercise could consist of a reminder of the relevant formulae. The following is the detailed procedure:

■ **How high is your tree (window/bandstand)? Describe how you found this out.**

Examples: really long measuring tape, asked someone, trigonometry.

■ **How long does it take for the rock (egg) to drop this distance? (Show your working)**

This can be done on paper (to connect the formulae with the activity) or students can experiment (perhaps after they have done a first calculation). The following calculation is done with a height of 10m, $g = 10m/s^2$, and where $v_0 = 0$:

---

8 Forrest, D (1999), 'Raw eggs – moving target', The Physics Teacher, 37(6), 371-372.

Teacher Edition

Survival Physics

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

$$t = \sqrt{\frac{2\Delta x}{a}} = \sqrt{\frac{2 \times 10}{10}} = 1.4\text{s}$$

■ How far does the tiger (teacher) walk in the time it takes for the rock (egg) to fall? Experiment and describe your procedure.

Constant walking speed here is important! The students should get the teacher to walk at a constant speed for the given time and measure the distance. Improving on this procedure, the students could get the teacher to walk for double/triple the time and divide the answer appropriately, or take multiple measurements.

■ Set up your mark on the ground and work out your plan, then do the experiment! Only one shot per team.

The teacher can wear a raincoat!

■ Write about how well you were able to stop the tiger. What else did you need to take into account? What is the largest source of error and how could you account for it if you did the experiment again?

Factors: reaction-time, wind, parallax error (seeing when the teacher reaches the mark), air resistance. Largest factor: reaction-time
Redoing: include reaction time when measuring how far the teacher walks in the egg-falling-time e.g. by pushing the mark back by a calculated amount.

If time permits and no-one hit the teacher, perhaps the experiment could be repeated taking these factors into account, so there is satisfying closure for the students.

How to contain a tiger

So, after many adventures on the high seas along the way, you get the tiger back to the zoo, and it has started to recover from its injuries (including the rock-induced one). You need to build an enclosure for the tiger now.

NOTE: projectile motion should be covered before this section is attempted.

■ **What sort of things do you need to consider? Discuss with your neighbour and report back to class.**

How fast a tiger can run, how high it can jump, how easily it can climb. Also considerations of the conditions tigers like to live in, and what provides good viewing for zoo visitors.

This section is based on an incident at San Francisco Zoo in 2007 where a Siberian tiger jumped out of its enclosure and killed a teenager.[9]

■ **The dimensions of the tiger enclosure at San Francisco Zoo are listed below. Your task is to work out if they are adequate.**

Wall height = y = 3.8m
Moat width = w = 10m
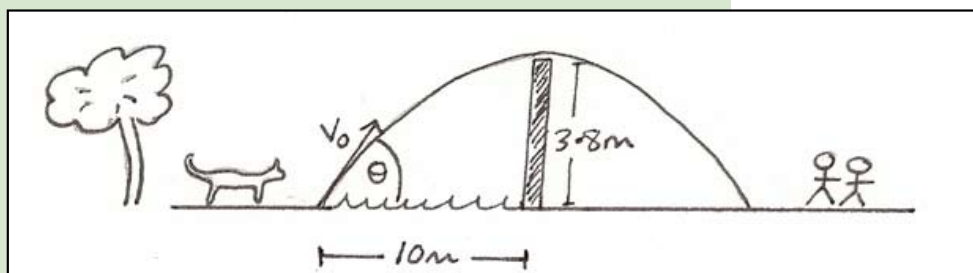
(Diagram not to scale…) This calculation is based on a preprint of a paper on the database arXiv.[10] In the calculation described in the paper, the velocity and launch angle are unknowns and the expression for v_0 is minimised using calculus to give the minimum velocity the tiger needs to just clear the wall. This calculation may be too advanced for Year 11 and 12 students. Instead, in this resource, a simpler calculation is performed. The following information can be found:

Range (x); initial horizontal velocity (v_{0x}); initial vertical velocity (v_{0y}); resultant velocity (v_0); time of flight (t).

9 See a news report here http://www.news.com.au/heraldsun/story/0,21985,22978198-663,00.html
10 http://arxiv.org/ arXiv:0801.4407v1 [physics.soc-ph] 29 Jan 2008

Survival Physics

■ What is the minimum distance the tiger needs to jump (i.e. the range, x)?

This is just double the width of the moat, assuming the tiger just clears the wall using the minimum effort.

$$x = 2w = 20\text{m}$$

■ What is the velocity required to make the jump? Note down any assumptions you make about the launch angle.

Since we're looking at the minimum velocity needed to escape, we can assume the angle of launch is 45°. In that case, the minimum velocity needed to get a range of 20m can be worked out using the range equation:

$$
\begin{aligned}
x &= \frac{v_0^2 \sin 2\theta}{g} \\
v_0 &= \sqrt{\frac{xg}{\sin 2\theta}} \\
&= \sqrt{\frac{20 \times 10}{\sin(2 \times 45)}} = 14\text{m/s}
\end{aligned}
$$

Converting to km/h gives: 50 km/h. A commonly reported Siberian tiger speed is 50 mph over short distances (80 km/h).[11] The tiger could go fast enough, but will it have jumped high enough?

■ What are the initial vertical and horizontal velocities of the tiger?

$$
\begin{aligned}
v_{0x} &= v_0 \cos \theta \\
&= 14 \times \cos 45 \\
&= 10\text{m/s}
\end{aligned}
\qquad
\begin{aligned}
v_{0y} &= v_0 \sin \theta \\
&= 14 \times \sin 45 \\
&= 10\text{m/s}
\end{aligned}
$$

These are the same. This is something interesting to note about the angle that gives the maximum range.

■ You made an assumption about the launch angle. Do you think a tiger could jump at that angle?

The minimum angle the tiger would have to jump at to get out is going to be greater than 20° (using trigonometry to make a triangle of base 10m and height 3.8m). It would probably be able to do 45°.

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11 http://www.siberiantigers.org/faq.html

Survival
Physics

■ Is the vertical velocity enough for the tiger to clear the fence?

To answer this question we need to work out the maximum height of the trajectory with this vertical velocity.

$$
\begin{aligned}
v_y^2 &= v_{0y}^2 - 2gy \\
0 &= v_{0y}^2 - 2gy_m \\
y_m &= \frac{v_{0y}^2}{2g} = \frac{10^2}{2 \times 10} = 5\text{m}
\end{aligned}
$$

Since this height is greater than the height of the wall (3.8m) the tiger should be able to clear the fence.

Therefore we can say that we agree that the enclosure was not good enough to contain the tiger.

■ Discuss how the enclosure could be improved to ensure the safety of the public.

The moat could be made bigger, the wall higher, put a roof on it.

More detailed discussions about the exact trajectory, the combinations of wall height and moat width (to limiting cases) could be discussed. How high does the wall need to be with no moat? What about if there was just a moat? (Can tigers swim?). What about if the tiger started in a tree and jumped from there? Would the tiger just need to get a paw to the top of the fence to get out? Lateral thinking could be encouraged to make things more interesting.

Your story

So, the story went:

"You're lost in the desert (don't ask me why). You see footprints crossing your path. You suppose they are human because of their shape. You want to know how fast they are walking to see if you could catch up with them.

Now you find yourself in a forest, having followed the footprints there. You now get scared because you can hear a big animal moving about, so you find a big rock and climb a tree with it. You see it's a tiger!

But wait! The tiger appears to be injured. You don't want to leave it there to get angrier and more injured, so you decide to trap it and arrange for it to be taken to a zoo. First though, you need to stop it.

It's walking in the direction of your tree! You have a rock, and some physics knowledge…

So, after many adventures on the high seas along the way, you get the tiger back to the zoo, and it has started to recover from its injuries (including the rock-induced one). You need to build an enclosure for the tiger now."

■ Can you write a better short-story than this? You can either write one to go around the exercises you have done, or write a general story. Either way the physics must be correct!

A story which included the correct physics for three separate situations (eg involving speed, distance, projectile motion etc) would be awarded the highest grade.

Survival Physics

What is speed?

Answer the following questions, and don't forget to write down the source of your results if you looked in a book or on the internet.

■ What is the fastest thing you've seen moving? Do you know its speed?

■ What is the slowest thing you've ever seen? Do you know its speed?

■ What do you think might be the fastest/slowest things in the universe?

STUDENT EDITION:
Physics   Years 10-12

Survival Physics

Inside you will learn tracking and how to catch a tiger, among other useful skills!

Contents

- What is speed?
- Tracking your walking speed
- On the run
- How to catch a tiger/teacher
- How to contain a tiger
- Your story

Tracking your walking speed

You're lost in the desert (don't ask me why). You see footprints crossing your path. You suppose they are human because of their shape. You want to know how fast they are walking to see if you could catch up with them.
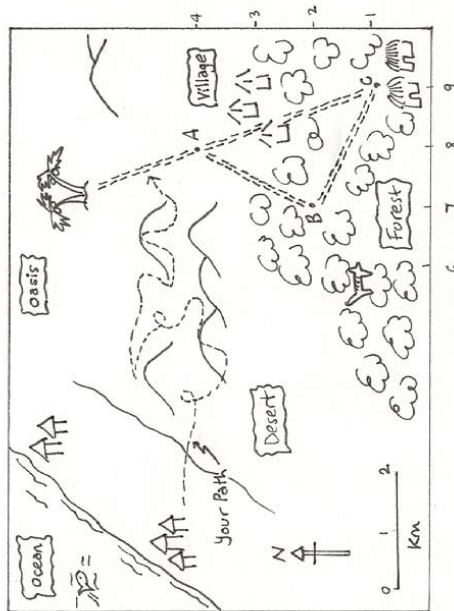
Mary Leakey and Richard Hay discovered the first fossilised human-like (hominid) footprints in 1978. They were found in an old volcanic lava bed in the Laetoli region of Tanzania, Africa. The largest trail of prints was about 25m long, and the average dimensions of the prints were 18.5cm x 8.8cm. The average stride length was 38.7cm.

Did You Know?

Mary Leakey (1913-1996) was one of the foremost archaeologists of the 20th Century. During her pre-teenage years she lived in France with her parents and went on an archaeological digs with a family friend. As a teenager she didn't enjoy the convent school where she was enrolled, so left at 13.

When she was 17 she started to write to archaeologists asking to accompany them on digs. She was accepted by one and it was through her brilliant drawings that she became part of the culture of archaeology.

She married another archaeologist and they spent many years in Africa on digs, where Mary found the oldest (at the time) human-ancestor skull. Over the years she also found another hominid skull (a different human-ancestor), and the Laetoli tracks.

Her lack of a university degree never stopped her! Her autobiography is called Disclosing the Past.

Speed

- Go outside and find some soft soil/clay. Volunteer to make some footprints. Alternatively paint your feet and make footprints on some butchers paper. For extra fun, get more than one person to walk, and get others to decipher the tracks.

- Compare the measurements of the Laetoli tracks with your footprints. What can you say about the Laetoli tracks?

- Can you work out your walking speed? Do the same for the Laetoli footprints.

Imagine these people have been walking all day, on and off. Sometimes they might stop for a rest. You have just calculated their instantaneous speed because it was measured over a very short distance compared to the whole day's walking.

- What would be their average speed if they walked on average for half an hour, then stopped for half an hour? Is it the same as instantaneous speed?

Survival Physics

Distance

"The wind is blowing the tracks away in the time it took to work all this out..."

- How far away could the owners of the mystery tracks be? What do you need to assume to make a good estimate?

- How far could they walk in one day?

Did You Know?

This sort of information is useful for geographers to understand how ancient settlements were formed. With no other form of transport (except possibly by river), limits can be placed on which communities were likely to be in contact, and how culture spread and networks were formed.

An example here is the vast number of Australian aboriginal languages spoken. Aboriginal settlements are so far apart (when you are walking) that little interaction would have occurred over their history and so a common language was not necessary.

Walking distance also affects the size of the community because how far people can walk puts limits on the amount of food that can be gathered.

Vectors, distance and displacement

Of course, they probably didn't just walk in exactly a straight line.

Look at the map (North is marked, and there is a scale); some possible trails for the people who made the footprints are marked.
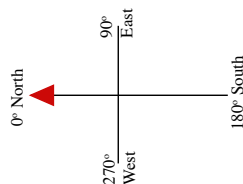
- If they did a dog-leg around a village, what would be the distance they walked? What would be the displacement?

- In your own words, write down the difference between distance and displacement.

- When might the distinction between distance and displacement be important in general? Discuss among your friends, and then report back to the class.

- What can you now say about the velocity of the owners of the mystery tracks (remember it has a direction too)?

0° North
90° East
180° South
270° West

Check your answer using a piece of string and the scale on the map!

Survival Physics

On the run

- Watch this scene from the movie **The Fugitive** (1993).

In this scene, the hero Richard Kimble (played by Harrison Ford) has just escaped from custody in a train/bus crash. The US Marshall Sam Gerard (played by Tommy Lee Jones) is on his trail.[1]

At the scene of the crash, Marshal Gerard says:

"Listen up ladies and gentlemen!

Our fugitive has been on the run for 90 minutes. The average foot speed over uneven ground barring injury is 4 miles an hour. That gives us a radius of 6 miles...

... check-points go up at 15 miles."

- Why do the checkpoints go up at a much larger radius than his predicted distance?

- Make estimates of your walking and running speed on smooth ground? What about rough ground?

Did You Know?

This is what trackers do in real life. In aboriginal culture, tracking is very important as it was traditionally used in hunting and the search for water. There are some details on this on the Culture and Recreation website of the Australian Government. A quote from this website:[2]

"Trackers also need to know whether tracks are fresh, otherwise they might be wasting their hunting time. At the end of a day, however, a good hunter needs to be able to find his way home using the shortest route possible - not in the tedious zigzag way he tracked his prey. This acute sense of direction is inseparable from acute powers of observation and good memory."

1 Image from Warner Bros: http://whv.warnerbros.com/WHVPORTAL/Portal/product.jsp?OID=27946
2 http://www.cultureandrecreation.gov.au/articles/indigenous/trackers/

97

Survival Physics

How to catch a tiger/teacher

Now you find yourself in a forest, having followed the footprints there. You now get scared because you can hear a big animal moving about, so you find a big rock and climb a tree with it. You see it's a tiger!

But wait! The tiger appears to be injured. You don't want to leave it there to get angrier and more injured, so you decide to trap it and arrange for it to be taken to a zoo. First though, you need to stop it.

It's walking in the direction of your tree! You have a rock, and some physics knowledge....

A tiger-catching experiment

■ Instead of a tiger and a rock, you have a teacher and some eggs. Your tree is the bandstand, or an upstairs window of your school. The eggs are your rock. Your task is to drop an egg to hit the teacher squarely on the head.

Here's a suggested method but you can use your own!

■ How high is your tree (window/bandstand)? Describe how you found this out.

■ How long does it take for the rock (egg) to drop this distance? (Show your working)

■ How far does the tiger (teacher) walk in the time it takes for the rock (egg) to fall? Experiment and describe your procedure.

■ Set up your mark on the ground and work out your plan, then do the experiment! Only one shot per team.

■ Write about how well you were able to stop the tiger. What else did you need to take into account? What is the largest source of error and how could you account for it if you did the experiment again?


Survival Physics

How to contain a tiger

So, after many adventures on the high seas along the way, you get the tiger back to the zoo, and it has started to recover from its injuries (including the rock-induced one). You need to build an enclosure for the tiger now.

■ What sort of things do you need to consider? Discuss with your neighbour and report back to class.

■ The dimensions of the tiger enclosure at San Francisco Zoo are listed below. Your task is to work out if they are adequate.

Wall height = y = 3.8m
Moat width = w = 10m
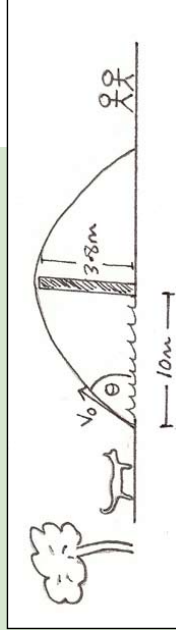
> *This section is based on an incident at San Francisco Zoo in 2007 where a Siberian tiger jumped out of its enclosure and killed a teenager.*

■ What is the minimum distance the tiger needs to jump (i.e. the range, x)?

■ What is the velocity required to make the jump? Note down any assumptions you make about the launch angle.

■ What are the initial vertical and horizontal velocities of the tiger?

■ You made an assumption about the launch angle. Do you think a tiger could jump at that angle?

■ Is the vertical velocity enough for the tiger to clear the fence?

> *A commonly reported Siberian tiger speed is 50 mph over short distances (80 km/h)*

■ Discuss how the enclosure could be improved to ensure the safety of the public.

Survival Physics

"Your story"

Your story

So, the story went:

"You're lost in the desert (don't ask me why). You see footprints crossing your path. You suppose they are human because of their shape. You want to know how fast they are walking to see if you could catch up with them.
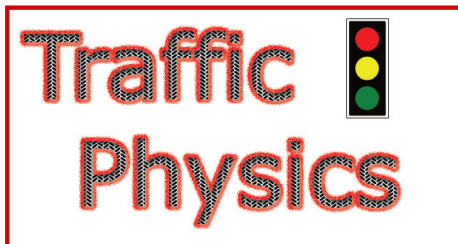
Now you find yourself in a forest, having followed the footprints there. You now get scared because you can hear a big animal moving about, so you find a big rock and climb a tree with it. You see it's a tiger!

But wait! The tiger appears to be injured. You don't want to leave it there to get angrier and more injured, so you decide to trap it and arrange for it to be taken to a zoo. First though, you need to stop it.

It's walking in the direction of your tree! You have a rock, and some physics knowledge...

So, after many adventures on the high seas along the way, you get the tiger back to the zoo, and it has started to recover from its injuries (including the rock-induced one). You need to build an enclosure for the tiger now."

■ Can you write a better short-story than this? You can either write one to go around the exercises you have done, or write a general story. Either way the physics must be correct!

Introduction

- This resource is a mixture of crazy and caution: there are stunts from movies and TV, and there are lessons in crashes and how to survive them.

- This resource covers the curriculum topics of
  Projectile motion
  Kinematics graphs

- On completing this resource, students will have a thorough understanding of projectile motion. They will have encountered it in unusual situations, meaning they should have a deeper appreciation for the techniques used to solve problems. There are graph-sketching activities for projectile motion. Students also have the opportunity to practice their experimental skills through designing, carrying out and evaluating the results of their own investigations.

- In accordance with research in science teaching, this resource contains a local application (crash data), movie/TV physics (*Speed* and *TopGear*), a science communication activity (advertising for head restraints), a medical application (whiplash), an experiment (*TopGear* stunt) and an activity involving helping people (head restraints).

- Motivation for students:
  "Learn about car stunts involving 100m jumps, how to foil the bad guy and ways to prevent injury in car crashes"

* NOTE: copies of the video material are not required to complete any activity.

Contents

- Flick a coin or two
- Bus jumping
- Ski-jumping in a Mini
- When things go wrong
- Crash safety
- Spread the word

Note:
■ Student questions in the accompanying worksheets are in boxes like this.

Traffic Physics

Flick a coin or two

This is a short introduction to the concept of the independence of horizontal and vertical components of projectile motion.

NOTE: Projectile motion should be covered before this section is attempted

Projectile motion is defined as motion where only gravity acts.

REMEMBER: gravity acts vertically.

■ Think of things that affect how far you can make a projectile go (the range).

These include: the angle at which you launch the projectile and its initial velocity. And for the more lateral thinkers, the strength of gravity will affect the range – the smaller it is (e.g. on the Moon), the larger the range.

■ Get two coins (e.g. 5c pieces) and a plastic ruler that is a bit bendy. Find a place with a bench top and a hard floor. Set up the coins and ruler like this:

Hold one end still, and flick the other to knock both coins at the same time.

■ Listen! Do the coins hit the ground at the same time or different times?
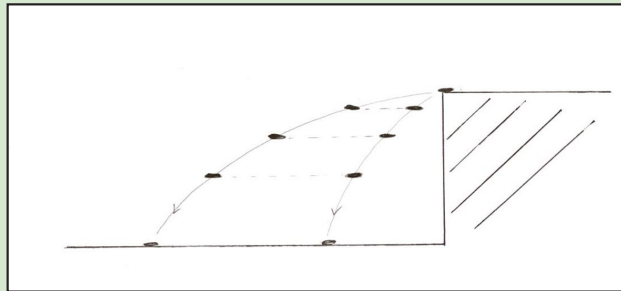
■ What is going on?

Traffic Physics

'Flick a coin or two'

Both coins should hit the ground at the same time, and one should hit the ground further away from the starting point than the other.
• Both coins started at the same height and fell the same vertical distance
• Both coins were given an initial horizontal velocity only.

The independence of components of motion: the time it took the coins to fall vertically is independent of how far they travelled horizontally.

Traffic Physics

Bus jumping

In the movie **Speed** (1994) the hero, Jack Traven (played by Keanu Reeves), is stuck on a bus that must stay above 50mph at all times, otherwise it will explode.

At this point in the movie the bus is travelling along a new, unopened section of freeway in Los Angeles. Unfortunately, as the bus gets to a freeway interchange, Jack is informed that there is a gap in the bridge!

NOTE: Projectile motion should be covered before this section is attempted

The segment starts 59 minutes into the movie and finishes by 64m 30s. There is some strong language at the beginning of the section but is over by 60m 30s.[1]

Officer: Sir, we have a serious problem.
Chief: What?
Officer: This freeway isn't finished.
Chief: What are you talking about?
Officer: The aerial unit … about 3 miles ahead, there's a section missing.
Chief: How big is the section?
Officer: 50 feet, at least.
Jack: It's an interchange, there might be an incline – floor it!

As the bus approaches the jump, you can clearly see the road is flat, however. The last view of the speedometer before the jump shows the bus is going at 67mph (= 29m/s).

■ Based on the information the film, could the bus have made the jump?

The first thing to note is that since there was no ramp, the bus is essentially falling. We can work out how far it fell vertically in the time it covered the 50ft.

Firstly, how long did it take to cover 50 ft horizontally?

$$
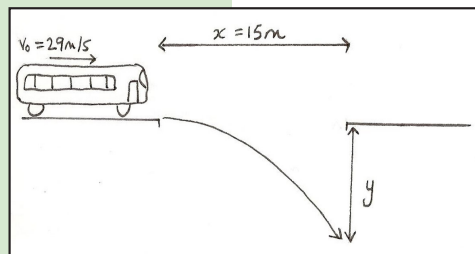\begin{aligned}
x &= v_0 t \\
t &= \frac{x}{v_0} = \frac{15}{29} = 0.5\text{s}
\end{aligned}
$$

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1 Original Website: 20th Century Fox http://www.foxhome.com/speed/index_frames.html. Image from allmovie. com (http://www.allmovie.com/cg/avg.dll?p=avg&sql=1:131239~T0).

Traffic Physics

Secondly, how far did the bus fall in that time? Define downwards as the positive direction:

$$y = \frac{1}{2}gt^2 = \frac{1}{2} \times 10 \times 0.5^2 = 1.25\text{m}$$

Since it fell 1.25m it would not make the jump, but instead probably crash into the edge of the freeway.

■ **How narrow would the gap need to be for the bus to make the jump?**

This is a conceptual question: the gap would need to be essentially non-existent since there is no ramp. From this we can conclude that the only way the bus will get over the jump is if there is a ramp at an appropriate angle.

■ **What angle ramp would make the jump possible based on this data?**
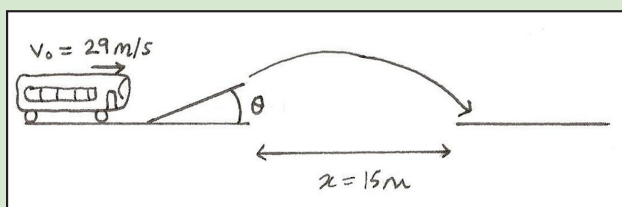
The range equation (used when initial and final heights are equal), this can be used to calculate the angle.

$$
\begin{aligned}
x &= \frac{v_0^2 \sin 2\theta}{g} \\
\frac{xg}{v_0^2} &= \sin 2\theta \\
\sin^{-1}\left(\frac{xg}{v_0^2}\right) &= 2\theta \\
\theta &= \frac{1}{2}\sin^{-1}\left(\frac{15 \times 10}{29^2}\right) = 5°
\end{aligned}
$$

There is a short explanation of this on You-Tube.[2]

---

2 http://www.youtube.com/watch?v=9tEAMLOupKs

**Traffic
Physics**

The Internet Movie Database[3] has some more details about the jump:

> "A special bus was used for the bus jump scene. This bus was modified so that it could reach a speed of 70 mph and it was equipped with powerful shock absorbers. The driver seat was moved back 15 feet so that if something went wrong the driver wasn't ejected from the bus. The seat itself was a suspension mechanism between the ceiling and the bus floor to avoid the driver from suffering spinal compression on impact.
>
> For the bus jump sequence, a ramp was built. The bus was started from about 1 mile back and accelerated towards the ramp. When it hit the ramp it had reached a speed of 61 mph. The bus travelled 109 feet and its front wheels reached an altitude of 20 feet from the ground, which was higher than anyone had anticipated. Because of this, the cameras were not placed correctly and the top front part of the bus goes out of the frame when the bus reaches the maximum point of the jump."

■ **On the basis of the IMDB data, at what angle was the ramp?**

Note 61mph = 98 km/h = 27 m/s, 109ft = 33m, 20ft = 6m.
Use the range equation again to get a ramp angle of 13°.

$$\theta = \frac{1}{2}\sin^{-1}\left(\frac{33 \times 10}{27^2}\right) = 13°$$

■ **Does this agree with the maximum reported height of the front wheels of the bus? If not, why not?**

Work out the vertical velocity (v_{0y}). If $\theta = 13°$, then

$$v_{0y} = v_0 \sin 13 = 27 \times \sin 13 = 6\text{m/s}$$

Work out the maximum height (y_m). This occurs when the vertical velocity is zero, so

$$
\begin{aligned}
v_y^2 &= v_{0y}^2 - 2gy \\
0 &= v_{0y}^2 - 2gy_m \\
y_m &= \frac{v_{0y}^2}{2g} = \frac{6^2}{2 \times 10} = 2\text{m}
\end{aligned}
$$

3 http://www.imdb.com/title/tt0111257/trivia

Traffic
Physics

As you can see, this is not the same as the reported value of 6m. The reason it's not the same is because the 6m measurement is of the front wheels. From the film you can see the front wheels are higher than the back wheels – the bus tilted well back during the jump. If the bus was 12m long (40ft) then for the front wheels to be 6m up, and the back wheels to be 2m up, it would mean the bus was tilted at 18°, which is slightly more than the ramp angle. (tan θ = (6-2)/12).

The reason for the discrepancy in the angle could be simply a reflection of the uncertainty in the data. Students could discuss this.

■ How fast was the bus going when it landed?

A conceptual question – the students don't need to use formulae. The answer is: in theory the same speed as when it took off. Air resistance would have a minor effect.

■ Can you think of any other films that have improbable car jumps or something similar?

Set as homework, use ideas for next year's class.

Ski-jumping in a Mini

In the BBC TV show[4] **TopGear**'s Winter Olympics special episode, the team decides to fire an old Mini down a ski jump to see if it can go further than a human ski-jumper. (Available as a separate DVD, and a condensed version of the segment is online[5]).

NOTE: Projectile motion should be covered before this section is attempted

The ski jump is Lysgårdsbakken in Lillehammer, Norway, where the 1994 Winter Olympics were held.[6]

Some data on the ski-jump, useful for the rest of the exercise, is listed below:[7]

Hill Size:	HS 138
K-Point:	123 m
Hill record:	145.0 m (Espen Rian NOR, 2006-12-03, NC)
Official hill record:	143.0 m (Gregor Schlierenzauer AUT, 2008-03-07, WC)
Summer hill record:	140.5 m (Anders Jacobsen NOR & Thomas Lobben NOR, 2007-10-14)
Length of inrun:	102.7 m
Length of takeoff:	6.9 m
Height of takeoff:	3.7 m
Angle of takeoff:	11.0°
Speed:	approx. 92.9 km/h
Landing angle:	34.6°

4 http://www.bbc.co.uk/topgear/
5 http://www.topgear.com/au/videos/mini-ski-jump/
6 Image from http://www.topgear.com/content/timetoburn/sections/galleries/other/winter_olympics/01/
7 http://www.skisprungschanzen.com/e_index.htm?/nor/nore_lillehammer.htm

Traffic Physics

More data can be obtained from looking at a still from when the skier makes the jump, which shows the angle of the slope at the top is about 25°. The distance the skier reaches is never told, so we'll assume he makes it to the K-point, which is the "par" distance in ski-jumping for any particular jump.[8]

More information on the sport of ski jumping can be found on the BBC website.[9]

The segment starts 47 minutes into the show, and finishes at 57 minutes. The last few minutes of the show, where a human-driven snowmobile is sent down the ski jump, is worth watching!

This is the conversation the team has when they are trying to work out how to beat the skier:

Jeremy Clarkson: So let's work this out: a Mini does 0-60 in what?
Richard Hammond: 14 seconds.
James May: Hang on, that's not going to be very relevant though is it, 'cause you're not going to get any grip off the tyres – all you've got up there is gravity.
JC: Ooh I know, gravity is a cruel and unpredictable mistress, so…
JM: Well, no it isn't, it's a constant all over the world. Look, this is quite simple arithmetically… it's v=u+at, we know what acceleration due to gravity is – it's 9.8 m/s². But that's weight component down a plane 'cause it's on a slope. So we need to get the mass of the car, and we need to know the angle of the slope and then we need to work out also the angle when it gets to the lip where it jumps off, and that will give us v, then it will follow a sort of parabolic trajectory and we should be able to then calculate the exact point where the car comes and meets the snow…

■ Listen to James May's explanation of the problem – is he right, or his he just trying to sound clever?

They don't need to know the mass of the car until later when working out the rocket power required, but they do need to know the angles. It will follow a parabolic trajectory (not a "sort-of parabolic" trajectory) and in theory, they should be able to calculate where it lands.

He is not completely correct about gravity being a constant all over the world, though. The strength of gravity varies slightly in different parts of the world. The GRACE satellite[10] has made detailed measurements of Earth's gravity and has mapped the variations. To find out the local strength of gravity use the following equation:[11]

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8 http://www.skijumpingcentral.com/scoring.htm
8 http://news.bbc.co.uk/sport2/hi/other_sports/winter_sports/sport_guides/4492616.stm
10 Homepage http://www.csr.utexas.edu/grace/
11 From http://www.npl.co.uk/server.php?show=ConWebDoc.1393

Traffic Physics

$$g = 9.780327(1 + 0.0053024\sin^2 L - 0.0000058\sin^2 2L) - 3.086 \times 10^{-6} H\,\text{m/s}^{-2}$$

where:
L = latitude
H = height in metres above sea level

Example

Using Google Earth, Canberra's latitude is about 35°, and elevation is about 570m, so

g= 9.790327 x (1+0.0053024 x sin²(35) - 0.0000058 x sin²(2x35)) - (3.086 × 10⁻⁶) x 570
 = 9.798 m/s²

At this point the presenters go off to work out a plan.

Richard Hammond then asks the question:

"Is gravity going to be enough to get the car down the ramp and beat the skier?"

■ What's the answer?

If you pause the tape immediately after this question has been asked, it will allow the students to work out the answer before they are told it.

At this point you could leave the students to stew for a while and play with formulae, but if they are prepared appropriately then they will realise that ignoring friction and air resistance all objects will reach the same speed at the bottom of the slope, as the acceleration *g* is independent of mass.
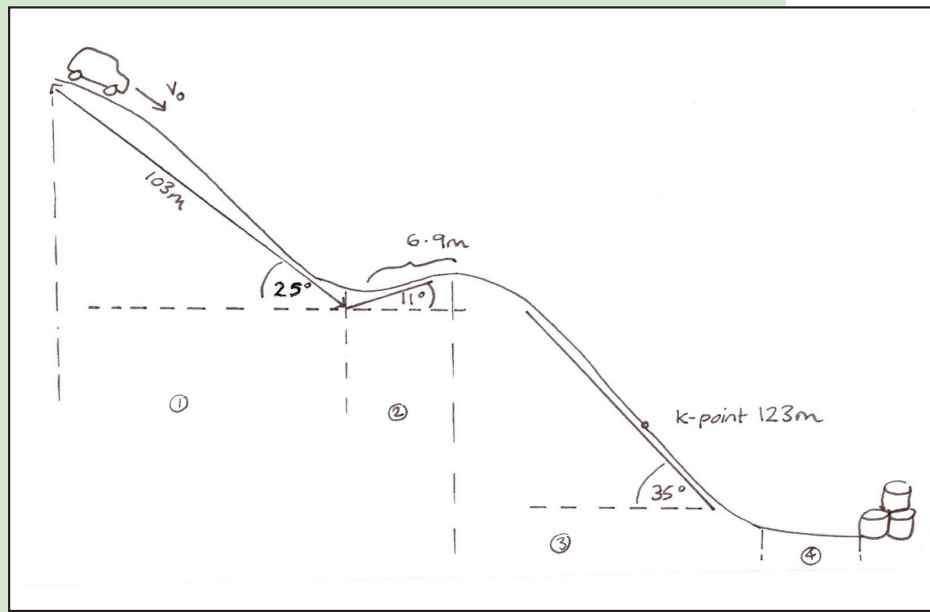
What will make the difference is the air resistance and friction of the Mini compared with the skier. Qualitatively it is easy to see that the Mini will be slower than the skier.

So the answer to Richard's question is: 'No' – un-pause the tape to hear James agree!
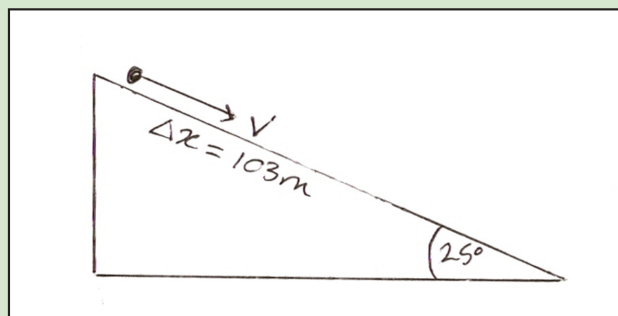
Traffic Physics

■ What is the theoretical maximum distance anything (including the Mini) can jump on this ski-jump?

The answer to this question can be divided into stages if required:

■ How fast does the Mini go down the initial ramp?

Approximate the slope to be at a constant angle.

This is an inclined plane problem. We know gravity acts vertically, and we want to know the component of acceleration due to gravity that acts in the direction the car is going – i.e. down the slope.

Traffic Physics

We need to define the 'normal' direction – that which is perpendicular to the slope.
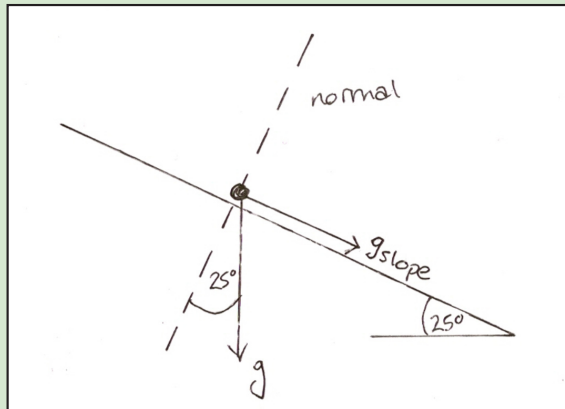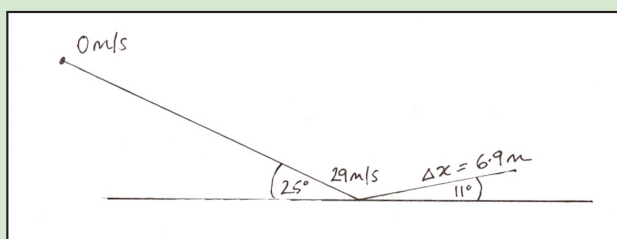

The acceleration of the Mini down the slope is

$$
\begin{aligned}
g_{\text{slope}} &= g\sin\theta \\
&= 10\sin 25 \\
&= 4.2\text{m/s}^2
\end{aligned}
$$

So the velocity of the car at the bottom of the initial ramp is

$$
\begin{aligned}
v^2 &= v_0^2 + 2g_{\text{slope}}\Delta x \\
v &= \sqrt{0^2 + (2\times 4.2\times 103)} \\
&= 29\text{m/s}
\end{aligned}
$$

which is 104 km/h or 65 mph.

■ **Given the length of the launch ramp, work out how fast the car is going at the end of the ramp.**

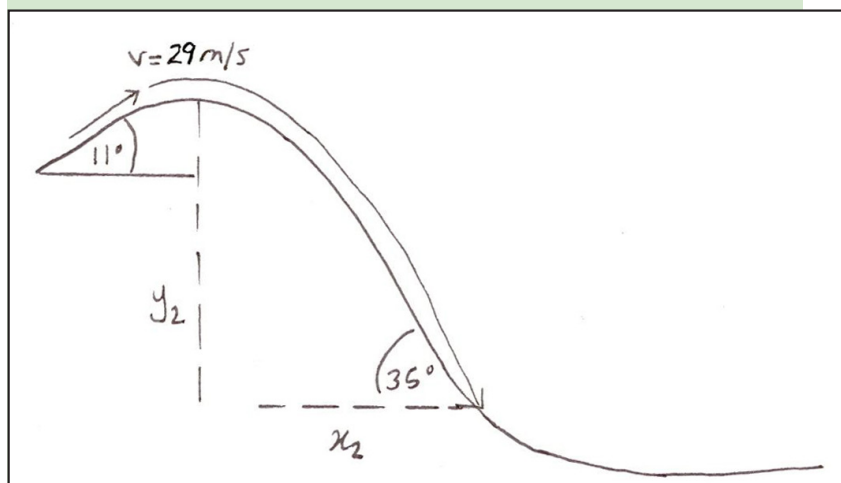Because the Mini is going against gravity, *g* is negative

Traffic Physics

$$g_{\text{slope}} = -g\sin\theta$$
$$= -10\sin 11$$
$$= -1.9\text{m/s}^2$$

So the velocity is

$$v^2 = v_0^2 + 2g_{\text{slope}}\Delta x$$
$$v = \sqrt{29^2 + (2 \times -1.9 \times 6.9)}$$
$$= 28.5\text{m/s}$$
$$= 29\text{m/s}$$

Basically, the Mini does not lose speed on the launch ramp. This is the whole point of the ramp being so short!

■ How far does the Mini then go on the jump?

From the diagram and using $v_{ix} = v\cos\theta$, and $v_{iy} = v\sin\theta$, we can see that the components of the velocity at the end of the take-off ramp are $v_{ix} = 28$ m/s and $v_{iy} = 5.5$ m/s. We can solve for the distance using simultaneous equations. So,

$$x_2 = v_{ix}t = 28t$$

$$-y_2 = v_{iy}t + \frac{1}{2}(-g)t^2$$
$$= 5.5t + \frac{1}{2}(-g)t^2$$

Traffic Physics

But we also know, from trigonometry on the landing ramp, that

$$\begin{aligned} \tan 35 &= \frac{y_2}{x_2} \\ y_2 &= x_2 \tan 35 \\ &= 28t \times \tan 35 = 19.6t \end{aligned}$$

By adding the two expressions for y_2 we can eliminate it from the problem:

$$\begin{aligned} y_2 &= 19.6t \\ -y_2 &= 5.5t - \frac{1}{2}gt^2 \\ 0 &= 25.1t - \frac{1}{2}gt^2 \\ 0 &= t(25.1 - \frac{1}{2}gt) \end{aligned}$$

There are two solutions to this equation, $t = 0$ or

$$t = \frac{25.1}{\frac{1}{2}g} = 5.0s$$

So the horizontal range is

$$x_2 = v_{ix}t = 28 \times 5.0 = 140m$$

And the distance down the hypotenuse is

$$\begin{aligned} \cos 35 &= \frac{140}{z} \\ z &= \frac{140}{\cos 35} = 170m \end{aligned}$$

So the theoretical maximum distance possible to jump, based on the data available or estimated, is 170m. Check the answer: this is larger than the "par" 123m K-point for this jump, and is also larger than the record for the jump of 143m. Two possible reasons for the overestimate compared to the "par" distance are:
- the angle of the initial ramp is an estimate, and
- the initial ramp might not be at a constant angle all the way down.

Repeating the latter part of the calculation using the speed given in the table on p8 (92.9 km/h or 26 m/s), the distance of the jump is 143m which is close to the various records.

Further discussion on how skiers minimise friction and air resistance could take place here.
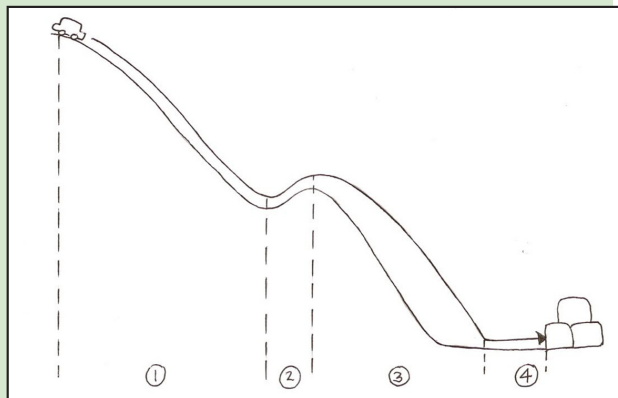
Traffic
Physics

'Ski-jumping in a Mini'

■ Using the profile of the ski jump below, sketch a velocity-time graphs for both
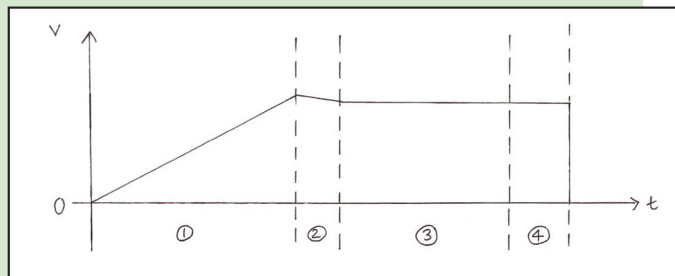
- the horizontal component, and
- the vertical component

of motion of the Mini from the top of the jump to when it crashes into the barrier at the bottom.
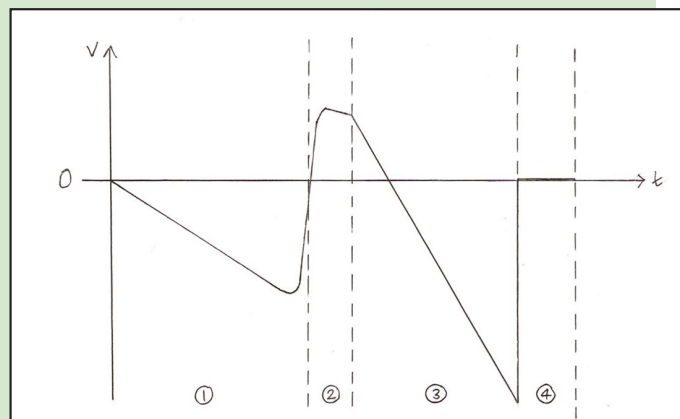
Define the positive direction for velocity as "up".

Horizontal Velocity

Vertical Velocity

Traffic 🚦
Physics

Students need to think here. What is the initial velocity for both components? It is zero. Divide the slope into four parts.

At the start of <u>section 1</u> both components are zero. Then both components start to increase as the car moves down the slope.

As the slope bottoms out, the Mini's horizontal velocity doesn't change much, but its vertical velocity starts to change from being in the negative direction (i.e. down) to the positive direction (i.e. up) as the Mini moves up the launch ramp in <u>section 2</u>. At the bottom of the launch ramp the vertical velocity is instantaneously zero. The Mini is only on the ramp for a short time before it enters projectile motion in <u>section 3</u>.

While the Mini is undergoing projectile motion the horizontal velocity is constant. The Mini's vertical velocity starts to decrease until it is zero at the top of its flight. The Mini accelerates downwards at a constant rate (i.e. $g = 9.8$ m/s^2).

When the Mini hits horizontal ground in <u>section 4</u> the horizontal velocity stays as it was in section 3 without increasing or decreasing, while the vertical velocity becomes zero.

■ Can you replicate the mini jump using a toy car and a scale model of the jump? (Probably 1m:1cm scale)

■ What differences do you need to consider with the scale model?

The toy car is not powered; the air resistance/friction is relatively more significant.

Traffic Physics

When things go wrong

It is important for investigators to know the details of traffic accidents so they can work out the cause - if it was something wrong with the car or the road, or if the driver was at fault. Traffic accident investigators may want to know how fast the car or cars were going. One way for them to do this is to use their knowledge of projectile motion. In a crash, debris from the car is often projected out. By measuring the distance of this debris from the car, the car's speed at the time of the crash can be found.

The local police force may be able to provide some real data from their crash investigators.

■ You are riding in the tray of your mate's ute when the driver loses control and crashes into a low wall at 80 km/h. How far are you projected out of the ute?
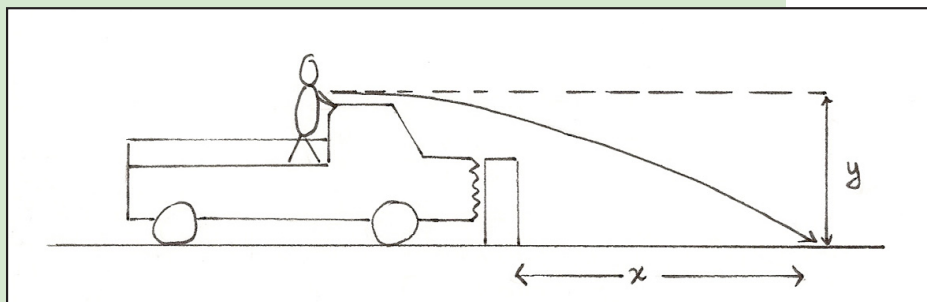
The students will need to estimate the height of their centre of mass in the ute (use y = 1m).

Horizontally (equation 1)

$$t = \frac{x}{v}$$

Vertically (equation 2)

$$y = ut + \frac{1}{2}at^2$$
$$y = 0 + \frac{1}{2}gt^2$$

Substitute equation 1 into equation 2:

$$y = \frac{1}{2}g\left(\frac{x^2}{v^2}\right)$$

$$\frac{2yv^2}{g} = x^2$$

$$x = \sqrt{\frac{2yv^2}{g}}$$

$$= \sqrt{2 \times \frac{1}{10} \times 22^2} = 10\text{m}$$

■ **What else might you need to take into account?**

We have calculated the minimum distance because air resistance has not been taken into account.

The students could do an experiment along these lines where they use something on wheels (such as a toy car, a skateboard, an office chair) carrying some rice, ball bearings or a soccer ball. The wheeled object is crashed into something and students measure the distance covered by the projectiles to work out the speed of the wheeled object.

Traffic Physics

Crash safety

Whiplash injury is a special problem with car accidents and usually occurs after a rear-end collision. In such a collision the effect is the same as if the person were shoved hard in the middle of the back. The head snaps backwards relative to the body, and then, because it is still attached to the body, it "catches up" with the body and snaps forwards.

This can cause severe neck injuries, including causing ligaments, muscles and tendons to be stretched beyond their normal range of movement, as well as muscle tears and detached ligaments.

Head restraints were introduced to help prevent whiplash injuries but modern cars have a whole range of additional safety features including more rigid seats and airbags. Head restraints should be positioned at least as high as eye level, and as close to the back of the head as possible.

■ If you have a car at home, check the position of the head restraints (take a photo?).

- How easy is it to move them?
- Can you get them into the correct position for the main driver?
- Did the main driver know about the correct position of head restraints?
- How did they know?

Discuss your findings with the class.

A class discussion on the varying positions of head restraints and whether they are moveable should occur. The class should talk about why newer cars have easier-to-move head restraints (modern safety features), why they think the drivers did or did not know about the correct positioning – if they did, where did they get the information from? What was an effective message on head restraints that causes people to adjust their cars?

Traffic Physics

Spread the word

■ Write a brochure, newspaper ad, or make a presentation that explains the importance of headrests and why they need to be in the right position. You will need to do some research on the topic.

■ Look at current information available to the public – is it easy to understand/convincing?

■ Put it in the school newspaper or test it out on your family.

Hints and tips for convincing the public:

·   The general public will not respond to formulae of any kind – do not use them!
·   No technical terms or unexplained acronyms should be used.
·   What is the most important piece of information you want people to get from your brochure/ad/presentation? – focus on this.
·   Small, digestible pieces of information are best.
·   Good pictures or diagrams are useful – but graphs are not!

Traffic Physics 🚦

STUDENT
EDITION:
Physics
Years 10-12

Learn about car stunts involving 100m jumps, how to foil the bad guy and ways to prevent injury in car crashes

Contents

Traffic Physics 🚦

Flick a coin or two

Projectile motion is defined as motion where only gravity acts.

REMEMBER: gravity acts vertically.

■ Think of things that affect how far you can make a projectile go (the range).

■ Get two coins (e.g. 5c pieces) and a plastic ruler that is a bit bendy. Find a place with a bench top and a hard floor. Set up the coins and ruler like this:

Hold one end still, and flick the other to knock both coins at the same time.

■ Listen! Do the coins hit the ground at the same time or different times?

■ What is going on?

> **Important!**
> Horizontal and vertical components of projectile motion are independent.

Bus jumping

In the movie **Speed** (1994)[1] the hero, Jack Traven (played by Keanu Reeves), is stuck on a bus that must stay above 50mph at all times, otherwise it will explode. At this point in the movie the bus is travelling along a new, unopened section of freeway in Los Angeles. Unfortunately, as the bus gets to a freeway interchange, Jack is informed that there is a gap in the bridge!

> **Officer:** Sir, we have a serious problem.
> **Chief:** What?
> **Officer:** This freeway isn't finished.
> **Chief:** What are you talking about?
> **Officer:** The aerial unit ... about 3 miles ahead, there's a section missing.
> **Chief:** How big is the section?
> **Officer:** 50 feet, at least.
> **Jack:** It's an interchange, there might be an incline – floor it!

As the bus approaches the jump, you can clearly see the road is flat, however. The last view of the speedometer before the jump shows the bus is going at 67mph (= 29m/s).

- Based on the information the film, could the bus have made the jump?
- How narrow would the gap need to be for the bus to make the jump?
- What angle ramp would make the jump possible based on this data?

The Internet Movie Database[2] has some more details about the jump:

> "A special bus was used for the bus jump scene. This bus was modified so that it could reach a speed of 70 mph and it was equipped with powerful shock absorbers. The driver seat was moved back 15 feet so that if something went wrong the driver wasn't ejected from the bus. The seat itself was a suspension mechanism between the ceiling and the bus floor to avoid the driver from suffering spinal compression on impact.
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Find the IMDB at
http://www.imdb.com/

- On the basis of the IMDB data, at what angle was the ramp?
- Does this agree with the maximum reported height of the front wheels of the bus? If not, why not?
- How fast was the bus going when it landed?

- Can you think of any other films that have improbable car jumps or something similar?

121

Ski-jumping in a Mini

In the BBC TV show[3] *TopGear*'s Winter Olympics special episode, the team decides to fire an old Mini down a ski jump to see if it can go further than a human ski-jumper.

The ski jump is Lysgårdsbakken in Lillehammer, Norway, where the 1994 Winter Olympics were held.[4]

Some data on the ski-jump, useful for the rest of the exercise, is listed below:[5]

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Height of takeoff:	3.7 m
Angle of takeoff:	11.0°
Speed:	approx. 92.9 km/h
Landing angle:	34.6°

3 http://www.bbc.co.uk/topgear/
4 Image from http://www.topgear.com/content/timetoburn/sections/galleries/other/winter_olympics01/
5 http://www.skisprungschanzen.com/e_index.htm?/nor/nor_lillehammer.htm

More data can be obtained from looking at a still from when the skier makes the jump, which shows the angle of the slope at the top is about 25°. The distance the skier reaches is never told, so we'll assume he makes it to the K-point, which is the "par" distance in ski-jumping for any particular jump.[6]

This is the conversation the team has when they are trying to work out how to beat the skier:

Jeremy Clarkson: So let's work this out: a Mini does 0-60 in what?

Richard Hammond: 14 seconds.

James May: Hang on, that's not going to be very relevant though is it, 'cause you're not going to get any grip off the tyres – all you've got up there is gravity.

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■ Listen to James May's explanation of the problem – is he right, or his he just trying to sound clever?

At this point the presenters go off to work out a plan.

Richard Hammond then asks the question:

"Is gravity going to be enough to get the car down the ramp and beat the skier?"

■ What's the answer?

6 http://www.skijumpingcentral.com/scoring.htm

Traffic Physics

Define the positive direction for velocity as "up".
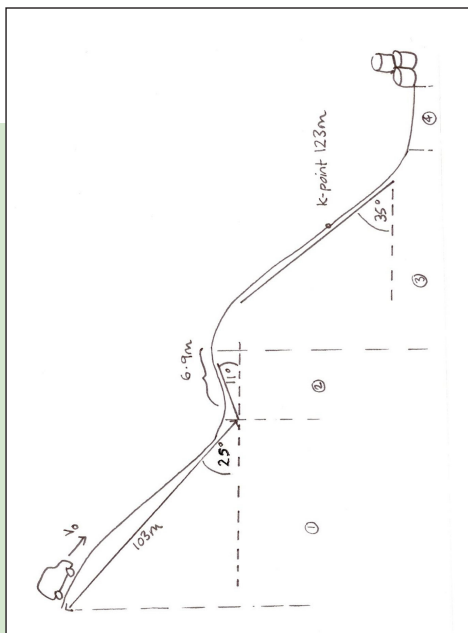
Follow these steps to answer the question:

- How fast does the Mini go down the initial ramp?

- Given the length of the launch ramp, work out how fast the car is going at the end of the ramp.

- How far does the Mini then go on the jump?

- Using the profile of the ski jump below, sketch a velocity-time graphs for both
  - the horizontal component, and
  - the vertical component

  of motion of the Mini from the top of the jump to when it crashes into the barrier at the bottom.
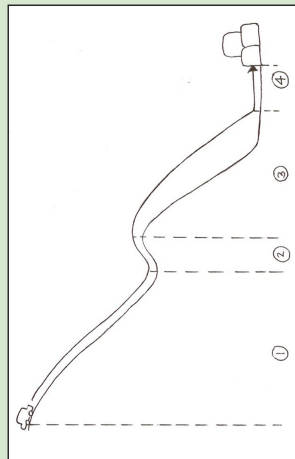
An Experiment

- Can you replicate the mini jump using a toy car and a scale model of the jump? (Probably 1m:1cm scale)

- What differences do you need to consider with the scale model?

Traffic Physics

- What is the theoretical maximum distance anything (including the Mini) can jump on this ski-jump?

123

Traffic Physics
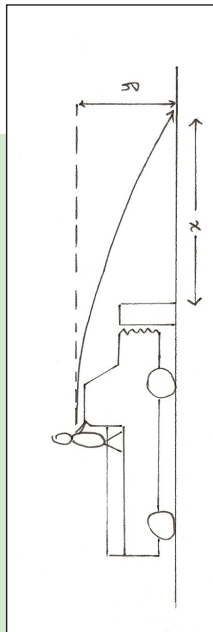
Crash safety

Whiplash injury is a special problem with car accidents and usually occurs after a rear-end collision. In such a collision the effect is the same as if the person were shoved hard in the middle of the back. The head snaps backwards relative to the body, and then, because it is still attached to the body, it "catches up" with the body and snaps forwards.

This can cause severe neck injuries, including causing ligaments, muscles and tendons to be stretched beyond their normal range of movement, as well as muscle tears and detached ligaments.

Head restraints were introduced to help prevent whiplash injuries but modern cars have a whole range of additional safety features including more rigid seats and airbags. Head restraints should be positioned at least as high as eye level, and as close to the back of the head as possible.

■ If you have a car at home, check the position of the head restraints (take a photo).
· How easy is it to move them?
· Can you get them into the correct position for the main driver?
· Did the main driver know about the correct position of head restraints?
· How did they know?

Discuss your findings with the class.

Traffic Physics

When things go wrong

It is important for investigators to know the details of traffic accidents so they can work out the cause - if it was something wrong with the car or the road, or if the driver was at fault. Traffic accident investigators may want to know how fast the car or cars were going. One way for them to do this is to use their knowledge of projectile motion. In a crash, debris from the car is often projected out. By measuring the distance of this debris from the car, the car's speed at the time of the crash can be found.

■ You are riding in the tray of your mate's ute when the driver loses control and crashes into a low wall at 80 km/h. How far are you projected out of the ute?

■ What else might you need to take into account?

124

Appendix B

International Physics Olympiads 2007: Questions

This appendix contains copies of the 2007 International Physics Olympiads questions as discussed in Section 2.2 (International Physics Olympiads, 2008b).

1. Green Question

2. Orange Question

3. Blue Question

4. Pink Question

Experimental Problem

Determination of energy band gap of semiconductor thin films

I. Introduction

Semiconductors can be roughly characterized as materials whose electronic properties fall somewhere between those of conductors and insulators. To understand semiconductor electronic properties, one can start with the *photoelectric effect* as a well-known phenomenon. The photoelectric effect is a quantum electronic phenomenon, in which photoelectrons are emitted from the matter through the absorption of sufficient energy from electromagnetic radiation (i.e. photons). The minimum energy which is required for the emission of an electron from a metal by light irradiation (*photoelectron*) is defined as *"work function"*. Thus, only photons with a frequency ν higher than a characteristic threshold, i.e. with an energy $h\nu$ (h is the Planck's constant) more than the material's work function, are able to knock out the photoelectrons.
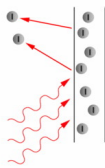
Figure 1. An illustration of photoelectron emission from a metal plate: The incoming photon should have an energy which is more than the work function of the material.

In fact, the concept of work function in the photoelectric process is similar to the concept of the energy band gap of a semiconducting material. In solid state physics, the band gap E_g is the energy difference between the top of the valence band and the bottom of the conduction band of insulators and semiconductors. The valence band is completely filled with electrons, while the conduction band is empty however electrons can go from the valence band to the conduction band if they acquire sufficient energy (at least equal to the band gap energy).The semiconductor's conductivity strongly depends on its energy band gap.
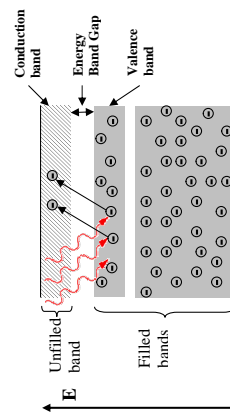
Figure 2. Energy band scheme for a semiconductor.

Band gap engineering is the process of controlling or altering the band gap of a material by controlling the composition of certain semiconductor alloys. Recently, it has been shown that by changing the nanostructure of a semiconductor it is possible to manipulate its band gap.

In this experiment, we are going to obtain the energy band gap of a thin-film semiconductor containing nano-particle chains of iron oxide (Fe$_2$O$_3$) by using an optical method. To measure the band gap, we study the optical absorption properties of the transparent film using its optical transmission spectrum. As a rough statement, the absorption spectra shows a sharp increase when the energy of the incident photons equals to the energy band gap.

II. Experimental Setup
You will find the following items on your desk:
1. A large white box containing a spectrometer with a halogen lamp.
2. A small box containing a sample, a glass substrate, a sample-holder, a grating, and a photoresistor.
3. A multimeter.
4. A calculator.
5. A ruler.
6. A card with a hole punched in its center.
7. A set of blank labels.

The spectrometer contains a goniometer with a precision of 5′. The Halogen lamp acts as the source of radiation and is installed onto the fixed arm of the spectrometer (for detailed information see the enclosed "Description of Apparatus").

The small box contains the following items:
1. A sample-holder with two windows: a glass substrate coated with Fe$_2$O$_3$ film mounted on one window and an uncoated glass substrate mounted on the other.
2. A photoresistor mounted on its holder, which acts as a light detector.
3. A transparent diffraction grating (600 line/mm).

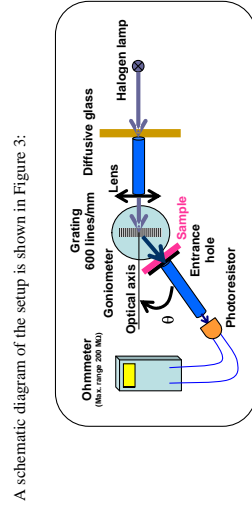**Note:** *Avoid touching the surface of any component in the small box!*

A schematic diagram of the setup is shown in Figure 3:

Figure 3. Schematic diagram of the experimental setup.

III. Methods

To obtain the transmission of a film at each wavelength, $T_{film}(\lambda)$, one can use the following formula:

$$T_{film}(\lambda) = I_{film}(\lambda)/I_{glass}(\lambda) \quad (1)$$

where I_{film} and I_{glass} are respectively the intensity of the light transmitted from the coated glass substrate, and the intensity of the light transmitted from the uncoated glass slide. The value of I can be measured using a light detector such as a photoresistor. In a photoresistor, the electrical resistance decreases when the intensity of the incident light increases. Here, the value of I can be determined from the following relation:

$$I(\lambda) = C(\lambda)R^{-1} \quad (2)$$

where R is the electrical resistance of the photoresistor, C is a λ-dependent coefficient.

The transparent grating on the spectrometer diffracts different wavelengths of light into different angles. Therefore, to study the variations of T as a function of λ, it is enough to change the angle of the photoresistor (θ') with respect to the optical axis (defined as the direction of the incident light beam on the grating), as shown in Figure 4.

From the principal equation of a diffraction grating:

$$n\lambda = d[\sin(\theta' - \theta_o) + \sin\theta_0] \quad (3)$$

one can obtain the angle θ' corresponding to a particular λ: n is an integer number representing the order of diffraction, d is the period of the grating, and θ_o is the angle the normal vector to the surface of grating makes with the optical axis (see Fig. 4). (In this experiment we shall try to place the grating perpendicular to the optical axis making $\theta_o = 0$, but since this cannot be achieved with perfect precision the error associated with this adjustment will be measured in task 1-e.)
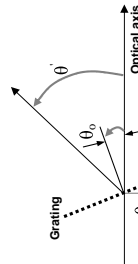
Figure 4. Definition of the angles involved in Equation 3.

Experimentally it has been shown that for photon energies slightly larger than the band gap energy, the following relation holds:

$$\alpha h\nu = A(h\nu - E_g)^\eta \quad (4)$$

where α is the absorption coefficient of the film, A is a constant that depends on the film's material, and η is the constant determined by the absorption mechanism of the film's material and structure. Transmission is related to the value of α through the well-known absorption relation:

3

$$T_{film} = \exp(-\alpha t) \quad (5)$$

where t is thickness of the film.

IV. Tasks:

0. *Your apparatus and sample box (small box containing the sample holder) are marked with numbers. Write down the **Apparatus number** and **Sample number** in their appropriate boxes, in the answer sheet.*

1. Adjustments and Measurements:

1-a	Check the vernier scale and report the maximum precision ($\Delta\theta$).	0.1 pt

Note: Magnifying glasses are available on request.

Step1:
To start the experiment, turn on the Halogen lamp to warm up. It would be better not to turn off the lamp during the experiment. Since the halogen lamp heats up during the experiment, please be careful not to touch it.

Place the lamp as far from the lens as possible, this will give you a parallel light beam.

We are going to make a rough zero-adjustment of the goniometer without utilizing the photoresistor. Unlock the rotatable arm with screw 18 (underneath the arm), and visually align the rotatable arm with the optical axis. Now, firmly lock the rotatable arm with screw 18. Unlock the vernier with screw 9 and rotate the stage to 0 on the vernier scale. Now firmly lock the vernier with screw 9 and use the vernier fine-adjustment screw (screw 10) to set the zero of the vernier scale. Place the grating inside its holder. Rotate the grating's stage until the diffraction grating is roughly perpendicular to the optical axis. Place the card with a hole in front of the light source and position the hole such that a beam of light is incident on the grating. Carefully rotate the grating so that the spot of reflected light falls onto the hole. Then the reflected light beam coincides with the incident beam. Now lock the grating's stage by tightening screw 12.

1-b	By measuring the distance between the hole and the grating, estimate the precision of this adjustment ($\Delta\theta_1$).	0.3 pt
	Now, by rotating the rotatable arm, determine and report the range of angles for which the first-order diffraction of visible light (from blue to red) is observed.	0.2 pt

Step 2:
Now, install the photoresistor at the end of the rotatable arm. To align the system optically, by using the photoresistor, loosen the screw 18, and slightly turn the rotatable arm so that the photoresistor shows a minimum resistance. For fine positioning, firmly lock screw 18, and use the fine adjustment screw of the rotatable arm.

4

GREEN — 38th International Physics Olympiad, Isfahan–Iran, July 2007

answer only on your direct readings of the ohmmeter.

Step 4:
The precision obtained so far is still limited since it is impossible to align the rotatable arm with the optical axis and/or position the grating perpendicular to the optical axis with 100% precision. So we still need to find the asymmetry of the measured transmission at both sides of the optical axis (resulting from the deviation of the normal to the grating surface from the optical axis (θ_o)).
To measure this asymmetry, follow these steps:

| 1-e | First, measure T_{film} at $\theta = -20°$. Then, obtain values for T_{film} at some other angles around $+20°$. Complete Table 1e (you can use the values obtained in Table 1d). | 0.6 pt |
| | Draw T_{film} versus θ and visually draw a curve. | 0.6 pt |

On your curve find the angle γ for which the value of T_{film} is equal to the T_{film} that you measured at $\theta = -20°$ ($\gamma \equiv \theta|_{T_{film}=T_{film}(-20°)}$). Denote the difference of this angle with $+20°$ as δ, in other words:

$$\delta = \gamma - 20° \qquad (6)$$

| 1-e | Report the value of δ in the specified box. | 0.2 pt |

Then for the first-order diffraction, Eq. (3) can be simplified as follows:

$$\lambda = d \sin(\theta - \delta/2), \qquad (7)$$

where θ is the angle read on the goniometer.

2. Calculations:

2-a	Use Eq. (7) to express $\Delta\lambda$ in terms of the errors of the other parameters (assume d is exact and there is no error is associated with it). Also using Eqs. (1), (2), and (5), express ΔT_{film} in terms of R and ΔR.	0.6 pt
2-b	Report the range of values of $\Delta\lambda$ over the region of first-order diffraction.	0.3 pt
2-c	Based on the measured parameters in Task 1, complete Table 2c for each θ. Note that the wavelength should be calculated using Eq. (7).	2.4 pt
2-d	Plot R_{glass}^{-1} and R_{film}^{-1} as a function of wavelength together on the same diagram. Note that on the basis of Eq. (2) behaviors of R_{glass}^{-1} and R_{film}^{-1} can reasonably give us an indication of the way I_{glass} and I_{film} behave, respectively.	1.5 pt
	In Table 2d, report the wavelengths at which R_{glass} and R_{film} attain their minimum values.	0.4 pt

GREEN — 38th International Physics Olympiad, Isfahan–Iran, July 2007

Use the vernier fine-adjustment screw to set the zero of the vernier scale.

1-c	Report the measured minimum resistance value ($R_{min}^{(0)}$).	0.1 pt
	Your zero-adjustment is more accurate now, report the precision of this new adjustment ($\Delta\varphi_o$).	0.1 pt
	Note: $\Delta\varphi_o$ is the error in this alignment i.e. it is a measure of misalignment of the rotatable arm and the optical axis.	

Hint: After this task you should tighten the fixing screws of the vernier. Moreover, tighten the screw of the photoresistor holder to fix it and do not remove it during the experiment.

Step 3:
Move the rotatable arm to the region of the first-order diffraction. Find the angle at which the resistance of the photoresistor is minimum (maximum light intensity). Using the balancing screws, you can slightly change the *tilt* of the grating's stage, to achieve an even lower resistance value.

| 1-c | Report the minimum value of the observed resistance ($R_{min}^{(1)}$) in its appropriate box. | 0.1 pt |

It is now necessary to check the perpendicularity of the grating for zero adjustment, again. For this you must use the reflection-coincidence method of Step 1.

Important: From here onwards carry out the experiment in dark (close the cover).

Measurements: Screw the sample-holder onto the rotatable arm. Before you start the measurements, examine the appearance of your semiconductor film (sample). Place the sample in front of the entrance hole S_1 on the rotatable arm such that a uniformly coated part of the sample covers the hole. To make sure that every time you will be working with the same part of the sample make proper markings on the sample holder and the rotatable arm with blank labels.

Attention: At higher resistance measurements it is necessary to allow the photoresistor to relax, therefore for each measurement in this range wait 3 to 4 minutes before recording your measurement.

| 1-d | Measure the resistance of the photoresistor for the uncoated glass substrate and the glass substrate coated with semiconductor layer as a function of the angle θ (the value read by the goniometer for the angle between the photoresistor and your specified optical axis). Then fill in Table 1d. Note that you need at least 20 data points in the range you found in Step 1b. Carry out your measurement using the appropriate range of your ohmmeter. | 2.0 pt |
| | Consider the error associated with each data point. Base your | 1.0 pt |

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| 2-e | For the semiconductor layer (sample) plot T_{film} as a function of wavelength. This quantity also represents the variation of the film transmission in terms of wavelength. | 1.0 pt |

3. Data analysis:

By substituting $\eta = 1/2$ and $A = 0.071$ $((eV)^{1/2}/nm)$ in Eq. (4) one can find values for E_g and t in units of eV and nm, respectively. This will be accomplished by plotting a suitable diagram in an $x - y$ coordinate system and doing an extrapolation in the region satisfying this equation.

| 3-a | By assuming $x = h\nu$ and $y = (\alpha t h\nu)^2$ and by using your measurements in Task 1, fill in Table 3a for wavelengths around 530 nm and higher. Express your results (x and y) with the correct number of significant figures (digits), based on the estimation of the error on one single data point.
Note that $h\nu$ should be calculated in units of eV and wavelength in units of nm. Write the unit of each variable between the parentheses in the top row of the table. | 2.4 pt |

| 3-b | Plot y versus x.
Note that the y parameter corresponds to the absorption of the film. Fit a line to the points in the linear region around 530 nm.
Specify the region where Eq. (4) is satisfied, by reporting the values of the smallest and the largest x-coordinates for the data points to which you fit the line. | 2.6 pt |

| 3-c | Call the slope of this line m, and find an expression for the film thickness (t) and its error (Δt) in terms of m and A (consider A to have no error). | 0.5 pt |

| 3-d | Obtain the values of E_g and t and their associated errors in units of eV and nm, respectively. Fill in Table 3d. | 3.0 pt |

❖ Some useful physical constants required for your analysis:

- Speed of the light: $c = 3.00 \times 10^8$ m/s
- Plank's constant: $h = 6.63 \times 10^{-34}$ J.s
- Electron charge: $e = 1.60 \times 10^{-19}$ C

ORANGE — 38th International Physics Olympiad, Isfahan–Iran, July 2007

In this problem we deal with a simplified model of accelerometers designed to activate the safety air bags of automobiles during a collision. We would like to build an electromechanical system in such a way that when the acceleration exceeds a certain limit, one of the electrical parameters of the system such as the voltage at a certain point of the circuit will exceed a threshold and the air bag will be activated as a result.

Note: Ignore gravity in this problem.

1. Consider a capacitor with parallel plates as in Figure 1. The area of each plate in the capacitor is A and the distance between the two plates is d. The distance between the two plates is much smaller than the dimensions of the plates. One of these plates is in contact with a wall through a spring with a spring constant k, and the other plate is fixed. When the distance between the plates is d the spring is neither compressed nor stretched, in other words no force is exerted on the spring in this state. Assume that the permittivity of the air between the plates is that of free vacuum ε_0. The capacitance corresponding to this distance between the plates of the capacitor is $C_0 = \varepsilon_0 A/d$. We put charges $+Q$ and $-Q$ on the plates and let the system achieve mechanical equilibrium.
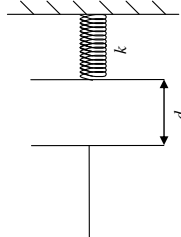
Figure 1

| 1.1 | Calculate the electrical force, F_E, exerted by the plates on each other. | 0.8 |

| 1.2 | Let x be the displacement of the plate connected to the spring. Find x. | 0.6 |

| 1.3 | In this state, what is the electrical potential difference V between the plates of the capacitor in terms of Q, A, d, k? | 0.4 |

| 1.4 | Let C be the capacitance of the capacitor, defined as the ratio of charge to potential difference. Find C/C_0 as a function of Q, A, d and k. | 0.3 |

| 1.5 | What is the total energy, U, stored in the system in terms of Q, A, d and k? | 0.6 |

Figure 2, shows a mass M which is attached to a conducting plate with negligible mass and also to two springs having identical spring constants k. The conducting plate can move back and forth in the space between two fixed conducting plates. All these plates are similar and have the same area A. Thus these three plates constitute two capacitors. As shown in Figure 2, the fixed plates are connected to the given potentials V and $-V$, and the middle plate is connected

through a two-state switch to the ground. The wire connected to the movable plate does not disturb the motion of the plate and the three plates will always remain parallel. When the whole complex is not being accelerated, the distance from each fixed plate to the movable plate is d which is much smaller than the dimensions of the plates. The thickness of the movable plate can be ignored.
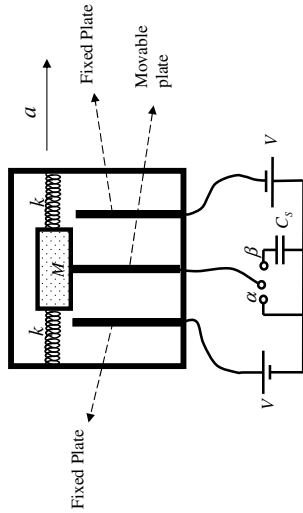

Figure 2

The switch can be in either one of the two states α and β. Assume that the capacitor complex is being accelerated along with the automobile, and the acceleration is constant. Assume that during this constant acceleration the spring does not oscillate and all components of this complex capacitor are in their equilibrium positions, i.e. they do not move with respect to each other, and hence with respect to the automobile.

Due to the acceleration, the movable plate will be displaced a certain amount x from the middle of the two fixed plates.

2 Consider the case where the switch is in state α i.e. the movable plate is connected to the ground through a wire, then

2.1	Find the charge on each capacitor as a function of x.	0.4
2.2	Find the net electrical force on the movable plate, F_E, as a function of x.	0.4
2.3	Assume $d \gg x$ and terms of order x^2 can be ignored compared to terms of order d^2. Simplify the answer to the previous part.	0.2
2.4	Write the total force on the movable plate (the sum of the electrical and the spring forces) as $-k_{eff}x$ and give the form of k_{eff}.	0.7
2.5	Express the constant acceleration a as a function of x.	0.4

3 Now assume that the switch is in state β i.e. the movable plate is connected to the ground through a capacitor, the capacitance of which is C_S (there is no initial charge on the capacitors). If the movable plate is displaced by an amount x from its central position,

3.1	Find V_S the electrical potential difference across the capacitor C_S as a function of x.	1.5
3.2	Again assume that $d \gg x$ and ignore terms of order x^2 compared to terms of order d^2. Simplify your answer to the previous part.	0.2

4 We would like to adjust the parameters in the problem such that the air bag will not be activated in normal braking but opens fast enough during a collision to prevent the driver's head from colliding with the windshield or the steering wheel. As you have seen in Part 2, the force exerted on the movable plate by the springs and the electrical charges can be represented as that of a spring with an effective spring constant k_{eff}. The whole capacitor complex is similar to a *mass and spring* system of mass M and spring constant k_{eff} under the influence of a constant acceleration a, which in this problem is the acceleration of the automobile.

Note: In this part of the problem, the assumption that the mass and spring are in equilibrium under a constant acceleration and hence are fixed relative to the automobile, no longer holds.

Ignore friction and consider the following numerical values for the parameters of the problem:

$d =1.0$cm. $\quad A = 2.5\times10^{-2}$ m^2, $\quad k = 4.2\times10^3$ N/m. $\quad \varepsilon_0 = 8.85\times10^{-12}$ C^2/Nm^2, $V =12$V, $M = 0.15$kg.

4.1	Using this data, find the ratio of the electrical force you calculated in section 2.3 to the force of the springs and show that one can ignore the electrical forces compared to the spring forces.	0.6

Although we did not calculate the electrical forces for the case when the switch is in the state β, it can be shown that in this situation, quite similarly, the electrical forces are as small and can be ignored.

4.2	If the automobile while traveling with a constant velocity, suddenly brakes with a constant acceleration a, what is the maximum displacement of the movable plate? Give your answer in parameter.	0.6

Assume that the switch is in state β and the system has been designed such that when the electrical voltage across the capacitor reaches $V_S = 0.15$V, the air bag is activated. We would like the air bag not to be activated during normal braking when the automobile's acceleration is less than the acceleration of gravity $g = 9.8m/s^2$, but be activated otherwise.

4.3	How much should C_S be for this purpose?	0.6

ORANGE 38th International Physics Olympiad
Isfahan-Iran, July 2007

We would like to find out if the air bag will be activated fast enough to prevent the driver's head from hitting the windshield or the steering wheel. Assume that as a result of collision, the automobile experiences a deceleration equal to g but the driver's head keeps moving at a constant speed.

| 4.4 | By estimating the distance between the driver's head and the steering wheel, find the time t_1 it takes before the driver's head hits the steering wheel. | 0.8 |

| 4.5 | Find the time t_2 before the air bag is activated and compare it to t_1. Is the air bag activated in time? Assume that airbag opens instantaneously. | 0.9 |

BLUE 38th International Physics Olympiad
Isfahan-Iran, July 2007

In physics, whenever we have an equality relation, both sides of the equation should be of the same type i.e. they must have the same dimensions. For example you cannot have a situation where the quantity on the right-hand side of the equation represents a length and the quantity on the left-hand side represents a time interval. Using this fact, sometimes one can nearly deduce the form of a physical relation without solving the problem analytically. For example if we were asked to find the time it takes for an object to fall from a height of h under the influence of a constant gravitational acceleration g, we could argue that one only needs to build a quantity representing a time interval, using the quantities g and h and the only possible way of doing this is $T = a(h/g)^{1/2}$. Notice that this solution includes an as yet undetermined coefficient a which is *dimensionless* and thus cannot be determined, using this method. This coefficient can be a number such as 1, 1/2, $\sqrt{3}$, π, or any other real number. This method of deducing physical relations is called *dimensional analysis*. In dimensional analysis the dimensionless coefficients are not important and we do not need to write them. Fortunately in most physical problems these coefficients are of the order of 1 and eliminating them does not change the order of magnitude of the physical quantities. Therefore, by applying the dimensional analysis to the above problem, one obtains $T = (h/g)^{1/2}$.

Generally, the dimensions of a physical quantity are written in terms of the dimensions of four fundamental quantities: M (mass), L (length), T (time), and K (temperature). The dimensions of an arbitrary quantity, x is denoted by $[x]$. As an example, to express the dimensions of velocity v, kinetic energy E_k, and heat capacity C_V we write: $[v] = LT^{-1}$, $[E_k] = ML^2T^{-2}$, $[C_V] = ML^2T^{-2}K^{-1}$.

1 Fundamental Constants and Dimensional Analysis

| 1.1 | Find the dimensions of *the fundamental constants*, i.e. the Planck's constant, h, the speed of light, c, the universal constant of gravitation, G, and the Boltzmann constant, k_B, in terms of the dimensions of length, mass, time, and temperature. | 0.8 |

The Stefan-Boltzmann law states that the black body emissive power which is the total energy radiated per unit surface area of a black body in unit time is equal to $\sigma\theta^4$ where σ is the Stefan-Boltzmann's constant and θ is the absolute temperature of the black body.

| 1.2 | Determine the dimensions of the Stefan-Boltzmann's constant in terms of the dimensions of length, mass, time, and temperature. | 0.5 |

The Stefan-Boltzmann's constant is not a fundamental constant and one can write it in terms of fundamental constants i.e. one can write $\sigma = a\, h^\alpha c^\beta G^\gamma k_B^\delta$. In this relation a is a dimensionless parameter of the order of 1. As mentioned before, the exact value of a is not significant from our viewpoint, so we will set it equal to 1.

| 1.3 | Find α, β, γ, and δ using dimensional analysis. | 1.0 |

BLUE 38th International Physics Olympiad
Isfahan-Iran, July 2007

2 Physics of Black Holes

In this part of the problem, we would like to find out some properties of black holes using dimensional analysis. According to a certain theorem in physics known as the *no hair theorem*, all the characteristics of the black hole which we are considering in this problem depend only on the mass of the black hole. One characteristic of a black hole is the area of its *event horizon*. Roughly speaking, the event horizon is the boundary of the black hole. Inside this boundary, the gravity is so strong that even light cannot emerge from the region enclosed by the boundary.

We would like to find a relation between the mass of a black hole, m, and the area of its event horizon, A. This area depends on the mass of the black hole, the speed of light, and the universal constant of gravitation. As in 1.3 we shall write $A = G^\alpha c^\beta m^\gamma$.

| 2.1 | Use dimensional analysis to find α, β, and γ. | 0.8 |

From the result of 2.1 it becomes clear that the area of the event horizon of a black hole increases with its mass. From a classical point of view, nothing comes out of a black hole and therefore in all physical processes the area of the event horizon can only increase. In analogy with the second law of thermodynamics, Bekenstein proposed to assign entropy, S, to a black hole, proportional to the area of its event horizon i.e. $S = \eta A$. This conjecture has been made more plausible using other arguments.

| 2.2 | Use the thermodynamic definition of entropy $dS = dQ/\theta$ to find the dimensions of entropy. dQ is the exchanged heat and θ is the absolute temperature of the system. | 0.2 |

| 2.3 | As in 1.3, express the dimensioned constant η as a function of the fundamental constants h, c, G, and k_B. | 1.1 |

Do not use dimensional analysis for the rest of problem, but you may use the results you have obtained in previous sections.

3 Hawking Radiation

With a semi-quantum mechanical approach, Hawking argued that contrary to the classical point of view, black holes emit radiation similar to the radiation of a black body at a temperature which is called the *Hawking temperature*.

| 3.1 | Use $E = mc^2$, which gives the energy of the black hole in terms of its mass, and the laws of thermodynamics to express the Hawking temperature θ_H of a black hole in terms of its mass and the fundamental constants. Assume that the black hole does no work on its surroundings. | 0.8 |

| 3.2 | The mass of an isolated black hole will thus change because of the Hawking radiation. Use Stefan-Boltzmann's law to find the dependence of this rate of change on the Hawking temperature of the black hole, θ_H and express it in terms of mass of the black hole and the fundamental constants. | 0.7 |

BLUE 38th International Physics Olympiad
Isfahan-Iran, July 2007

| 3.3 | Find the time t^*, that it takes an isolated black hole of mass m to evaporate completely i.e. to lose all its mass. | 1.1 |

From the viewpoint of thermodynamics, black holes exhibit certain exotic behaviors. For example the heat capacity of a black hole is negative.

| 3.4 | Find the heat capacity of a black hole of mass m. | 0.6 |

4 Black Holes and the Cosmic Background Radiation

Consider a black hole exposed to the cosmic background radiation. The cosmic background radiation is a black body radiation with a temperature θ_B which fills the entire universe. An object with a total area A will thus receive an energy equal to $\sigma \theta_B^4 \times A$ per unit time. A black hole, therefore, loses energy through Hawking radiation and gains energy from the cosmic background radiation.

| 4.1 | Find the rate of change of a black hole's mass, in terms of the mass of the black hole, the temperature of the cosmic background radiation, and the fundamental constants. | 0.8 |

| 4.2 | At a certain mass, m^*, this rate of change will vanish. Find m^* and express it in terms of θ_B and the fundamental constants. | 0.4 |

| 4.3 | Use your answer to 4.2 to substitute for θ_B in your answer to part 4.1 and express the rate of change of the mass of a black hole in terms of m, m^*, and the fundamental constants. | 0.2 |

| 4.4 | Find the Hawking temperature of a black hole at thermal equilibrium with cosmic background radiation. | 0.4 |

| 4.5 | Is the equilibrium stable or unstable? Why? (Express your answer mathematically) | 0.6 |

Two stars rotating around their center of mass form a binary star system. Almost half of the stars in our galaxy are binary star systems. It is not easy to realize the binary nature of most of these star systems from Earth, since the distance between the two stars is much less than their distance from us and thus the stars cannot be resolved with telescopes. Therefore, we have to use either photometry or spectrometry to observe the variations in the intensity or the spectrum of a particular star to find out whether it is a binary system or not.

Photometry of Binary Stars

If we are exactly on the plane of motion of the two stars, then one star will occult (pass in front of) the other star at certain times and the intensity of the whole system will vary with time from our observation point. These binary systems are called ecliptic binaries.

1   Assume that two stars are moving on circular orbits around their common center of mass with a constant angular speed ω and we are exactly on the plane of motion of the binary system. Also assume that the surface temperatures of the stars are T_1 and T_2 ($T_1 > T_2$), and the corresponding radii are R_1 and R_2 ($R_1 > R_2$), respectively. The total intensity of light, measured on Earth, is plotted in Figure 1 as a function of time. Careful measurements indicate that the intensities of the incident light from the stars corresponding to the minima are respectively 90 and 63 percent of the maximum intensity, I_0, received from both stars ($I_0 = 4.8\times10^{-9}$ W/m^2). The vertical axis in Figure 1 shows the ratio I/I_0 and the horizontal axis is marked in days.
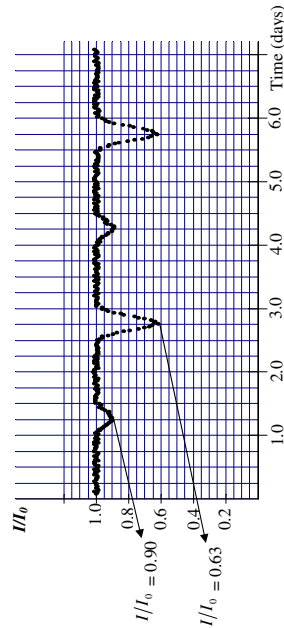

Figure 1. The relative intensity received from the binary star system as a function of time. The vertical axis has been scaled by $I_0 = 4.8\times10^{-9}$ W/m^2. Time is given in days.

| 1.1 | Find the period of the orbital motion. Give your answer in **seconds** up to two significant digits. What is the angular frequency of the system in **rad/sec**? | 0.8 |

To a good approximation, the receiving radiation from a star is a uniform black body radiation from a flat disc with a radius equal to the radius of the star. Therefore, the power received from the star is proportional to AT^4 where A is area of the disc and T is the surface temperature of the star.

| 1.2 | Use the diagram in Figure 1 to find the ratios T_1/T_2 and R_1/R_2. | 1.6 |

Spectrometry of Binary Systems

In this section, we are going to calculate the astronomical properties of a binary star by using experimental spectrometric data of the binary system.

Atoms absorb or emit radiation at their certain characteristic wavelengths. Consequently, the observed spectrum of a star contains *absorption lines* due to the atoms in the star's atmosphere. Sodium has a characteristic yellow line spectrum (D$_1$ line) with a wavelength 5895.9Å (10 Å = 1 nm). We examine the absorption spectrum of atomic Sodium at this wavelength for the binary system of the previous section. The spectrum of the light that we receive from the binary star is Doppler-shifted, because the stars are moving with respect to us. Each star has a different speed. Accordingly the absorption wavelength for each star will be shifted by a different amount. Highly accurate wavelength measurements are required to observe the Doppler shift since the speed of the stars is much less than the speed of light. The speed of the center of mass of the binary system we consider in this problem is much smaller than the orbital velocities of the stars. Hence all the Doppler shifts can be attributed to the orbital velocity of the stars. Table 1 shows the measured spectrum of the stars in the binary system we have observed.

Table 1: Absorption spectrum of the binary star system for the Sodium D$_1$ line

t/days	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4
λ_1 (Å)	5897.5	5897.7	5897.7	5896.2	5895.1	5894.3	5894.1	5894.6
λ_2 (Å)	5893.1	5892.8	5893.7	5896.2	5897.3	5898.7	5899.0	5898.1

t/days	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8
λ_1 (Å)	5895.6	5896.7	5897.3	5897.7	5897.2	5896.2	5895.0	5894.3
λ_2 (Å)	5896.4	5894.5	5893.1	5892.8	5893.7	5896.2	5897.4	5898.7

(*Note:* There is no need to make a graph of the data in this table)

2   Using Table 1,

| 2.1 | Let v_1 and v_2 be the orbital velocity of each star. Find v_1 and v_2. The speed of light $c = 3.0\times10^8$ m/s. Ignore all relativistic effects. | 1.8 |

| 2.2 | Find the mass ratio of the stars (m_1/m_2). | 0.7 |

| 2.3 | Let r_1 and r_2 be the distances of each star from their center of mass. Find r_1 and r_2. | 0.8 |

| 2.4 | Let r be the distance between the stars. Find r. | 0.2 |

| 3 | The gravitational force is the only force acting between the stars. | |

| 3.1 | Find the mass of each star up to one significant digit. The universal gravitational constant $G = 6.7\times10^{-11}$ m^{3}kg^{-1}s^{-2}. | 1.2 |

General Characteristics of Stars

4   Most of the stars generate energy through the same mechanism. Because of this, there is an empirical relation between their mass, M, and their luminosity, L, which is the total radiant power of the star. This relation could be written in the form $L/L_{Sun} = (M/M_{Sun})^{\alpha}$. Here, $M_{Sun} = 2.0\times10^{30}$ kg is the solar mass and, $L_{Sun} = 3.9\times10^{26}$ W is the solar luminosity. This relation is shown in a log-log diagram in Figure 2.
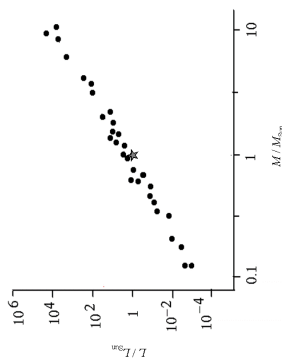

Figure 2. The luminosity of a star versus its mass varies as a power law. The diagram is log-log. The star-symbol represents Sun with a mass of 2.0×10^{30} kg and luminosity of 3.9×10^{26} W.

| 4.1 | Find α up to one significant digit. | 0.6 |

| 4.2 | Let L_1 and L_2 be the luminosity of the stars in the binary system studied in the previous sections. Find L_1 and L_2. | 0.6 |

| 4.3 | What is the distance, d, of the star system from us in light years? To find the distance you can use the diagram of Figure 1. One light year is the distance light travels in one year. | 0.9 |

| 4.4 | What is the maximum angular distance, θ, between the stars from our observation point? | 0.4 |

| 4.5 | What is the smallest aperture size for an optical telescope, D, that can resolve these two stars? | 0.4 |

Appendix C

Curricula: Years 10-12

This appendix contains the relevant parts of the Australian state and territory Years 10-12 curricula. These were discussed in Section 4.2. The header of each page indicates which state or territory the curriculum page belongs to, and whether it is the junior or senior curriculum.

<u>Junior</u>

1. Northern Territory (Department of Education, Employment and Training, Northern Territory Government, 2008)

2. Australian Capital Territory (Curriculum Renewal Taskforce, 2008)

3. Victoria (Victorian Curriculum and Assessment Authority, 2002)

4. South Australia (Government of South Australia, 2001)

5. Queensland (Queensland School Curriculum Council, 1999)

6. Western Australia (Department of Education and Training, Government of Western Australia, 2008b)

7. New South Wales (Board of Studies NSW, 2003)

8. Tasmania (Department of Education, Tasmania, 2007)

<u>NQE</u>

1. ASI: National Qualifying Exam (Australian Science Olympiads, 2005)

Senior

1. Australian Capital Territory (BSSS Australian Captial Territory, 2005)

2. Victoria (Victorian Curriculum and Assessment Authority, 2004)

3. South Australia (Senior Secondary Assessment Board of South Australia, 2008)

4. Queensland (Queensland Government; Queensland Studies Authority, 2007)

5. Western Australia (Yr11) (Curriculum Council, Government of Western Australia, 2008a)

6. Western Australia (Yr12) (Curriculum Council, Government of Western Australia, 2008b)

7. New South Wales (Board of Studies NSW, 2007)

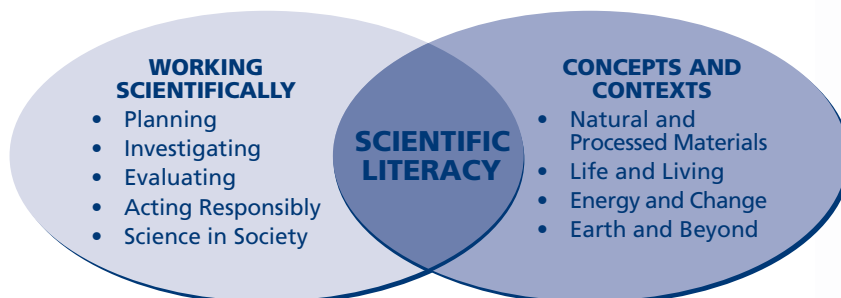8. Tasmania (Tasmanian Secondary Assessment Board, 2004)

- **Natural and Processed Materials**
    - the properties and structure of materials are inter-related
    - patterns of interaction between materials can be identified and used to predict and control further interactions
    - the uses of material are determined by their properties, some of which can be changed.
- **Life and Living**
    - the characteristics of living things and its functioning are inter-related
    - evolutionary processes have given rise to a diversity of living things which can be grouped according to their characteristics
    - environments are dynamic and have living and non-living components which interact.
- **Energy and Change**
    - the forces acting on objects influence their motion, shape, behaviour and energy
    - in interactions and changes, energy is transferred and transformed but not created or destroyed
    - there are different ways of obtaining and utilising energy and these have different consequences.
- **Earth and Beyond**
    - the Earth, solar systems and universe are dynamic systems
    - events on Earth, in the solar systems and in the universe occur on different scales of time and space
    - iving things use the resources of the Earth, solar system and universe to meet their needs and wants and these have different consequences

These elements can be informed by local material (issues or problems), learner needs and cultural contexts, enabling topics and pedagogy to be culturally relevant and providing the opportunity to involve local experts. This in turn will facilitate rich inquiry into different knowledge systems as well as foster collaboration, mutual understanding and respect.

The two strands are inter-related, working together to develop the scientific literacy of learners. When the strands are integrated in this way learners
- investigate and communicate in and about science
- investigate scientific contexts and concepts that are relevant and meaningful to them and their society, in a responsible way
- investigate scientific concepts in a range of contexts to question, extend or amend their personal constructions of scientific understandings and processes.

Figure 1: Inter-relationship between the two strands

WORKING SCIENTIFICALLY
- Planning
- Investigating
- Evaluating
- Acting Responsibly
- Science in Society

SCIENTIFIC LITERACY

CONCEPTS AND CONTEXTS
- Natural and Processed Materials
- Life and Living
- Energy and Change
- Earth and Beyond

Science

Introduction

Learning Areas

Every chance to learn

Later adolescence
Band of development

Essential content

In the later adolescence band of development, students have opportunities to understand and learn about:

Science as a human endeavour

19.LA.1 current issues that involve implications of research or applications of science (e.g. Human Genome project)

19.LA.2 instances in which progress in science can be affected by and influence social issues and priorities (e.g. water purification, alternative energy sources, space exploration, ethics of biotechnology)

19.LA.3 scientific advances that challenged understandings and practices in science and everyday life (e.g. causes of disease)

19.LA.4 how contemporary scientists often draw on concepts and processes across scientific disciplines in multi-disciplinary teams and how science can provide rewarding careers

19.LA.5 how people of diverse cultures have contributed to and shaped the development of science

Energy and force

19.LA.6 effects of several forces on the motion and energy of objects

19.LA.7 how and why the movement of energy (e.g. light and sound) varies according to the medium through which it moves and conservation of energy when it is transformed and transferred

Matter

19.LA.8 scientific models and terms to explain the properties of materials, the changes materials undergo and the conservation of matter

19.LA.9 explanations of physical and chemical changes in terms of types and arrangements of particles (e.g. atoms, molecules, elements, compounds)

19.LA.10 factors that affect chemical changes (e.g. factors that affect rate) and applications in everyday situations

Living things

19.LA.11 how an organism's body systems interact to meet its needs

19.LA.12 the theory of evolution by natural selection to explain the diversity of living things and how inherited characteristics are passed from parent to offspring

19.LA.13 scientific concepts and models to explain the interdependence of populations of organisms and the environment, and to predict the consequences of changes to an ecosystem

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Curriculum framework for ACT schools

Later adolescence
Band of development

Earth and space

19.LA.14 scientific theories of the origin of the universe

19.LA.15 the theory of plate tectonics to explain global patterns of geological activity (e.g. earthquake and volcanic zones)

19.LA.16 causes and consequences of global atmospheric changes resulting from natural and human activity (e.g. climate change).

In the later adolescence band of development, students have opportunities to learn to:

19.LA.17 examine, question and consider scientific ideas, concepts and theories

19.LA.18 analyse and synthesise information, and use scientific models and terms to explain properties and interrelationships and to predict change in phenomena and systems

19.LA.19 apply scientific knowledge in exploring and constructing views around ethical and social issues relating to science (e.g. genetic modification, stem cell research, animal testing of products, nuclear energy)

19.LA.20 select laboratory equipment appropriate to an investigation and use it safely and correctly.

Markers of progress

By the end of the later adolescence band of development, students apply scientific knowledge to explain phenomena, interrelationships and processes. They analyse and synthesise information to explain causes and predict effects of change in physical and biological systems. They understand that scientific knowledge is continually changing and explain how particular scientific theories developed on the basis of new evidence. They use scientific knowledge to justify their opinions or question claims made about scientific matters and to evaluate information presented as science. They evaluate the impacts of particular scientific advances on society.

Science

Level 6: Physical science

View Learning Outcomes | Learning Outcomes and Indicators

Curriculum Focus

Students use contexts of direct relevance to their lives to investigate and experience a wide range of physical phenomena related to light, electricity and motion. They take accurate measurements and apply quantitative calculations to their observations and data. They describe refraction, absorption and polarisation of light, and relate these behaviours to technological and artistic applications. They learn that the same principles can explain the operation of simple optical devices, such as a periscope or reading glasses, and more complex devices, such as cameras and telescopes. They identify basic electronic components and describe the role of these components in the operation of electronic devices. They use simple circuits to observe the operation of electronic and electrical components and the effects of combining components. They describe the link between electricity and magnetism and the operation of electromagnetic devices. They explain the combined action of different forces on objects in familiar situations. They describe formal relationships between force, mass, acceleration and velocity, using quantitative data. They apply these relationships to examples from contexts, such as transport, sport and recreation. They learn about new technological developments and the benefits and disadvantages associated with these developments.

Examples of contexts and learning activities

- use a light box to investigate the path of light through lenses
- observe images formed by lenses and relate these to everyday applications, such as magnifiers, cameras and eyes
- deduce the arrangement of switches in an electronic 'black box' which models a logic gate
- connect a diode and a resistor in a simple circuit and observe the direction of current in the diode
- build or dismantle a simple electric motor and investigate the conditions under which it works best
- explain the structure and operation of an electromagnet
- make, explain and evaluate the operation of a simple optical instrument, for example, a kaleidoscope, periscope or telescope
- investigate the effect of viewing the liquid crystal screen of a calculator through a polarising material
- explain the movement of an aircraft as the result of interactions between lift, weight, thrust and drag
- use a ticker timer or datalogger to obtain a record of the motion of a laboratory trolley rolling down an incline and analyse the tape to produce a graph of the motion
- use a computer timing package or a probe linked to a graphics calculator to measure the acceleration of a cart being pulled by different forces to infer the relationship between force and acceleration
- link the relationship between stopping distance and speed to issues of speed limits and road safety.

Skills, processes and procedures

Students will be able to:

- use electrical and electronic components, such as diodes, light emitting diodes (LEDs), light dependent resistors (LDRs), resistors, transistors, capacitors, batteries, buzzers, microphones, speakers and electric motors
- use ammeters, voltmeters and multimeters, light boxes, lenses, prisms, color filters, laboratory power supplies, digital laboratory balances, spring balances, ticker timers, motion detectors and dataloggers
- form hypotheses and devise and carry out experiments, controlling relevant variables and evaluating experimental design
- use appropriate units for all measured and derived quantities, such as resistance, force and acceleration
- use scientific and graphics calculators to record and process numerical data obtained in investigations
- use a spreadsheet to organise data and calculations from an investigation
- identify trends and patterns in numerical data.

http://www.sacsa.sa.edu.au/index_fsrc.asp?t=CB

Science

Strand: energy systems

Students in the Senior Years conceptualise the ideas of force and energy, and their application to current and future problems. [F] [T] They use relevant everyday contexts to investigate and experience a wide range of physical phenomena related to light, electricity and motion. [Id] [T] They apply principles of energy conservation and work energy, and develop expressions for common energy forms. [T] [C] They use and appraise new technologies and the benefits and disadvantages associated with these developments. [In] [T] [KC7] They participate in discussion, make decisions and take action on global scientific issues such as disposal of nuclear waste. [Id] [C] [KC2]

Following are the Key Ideas that comprise the energy systems strand.

Key Idea: Students critique key methods of energy conversion and energy use, and compare the extent of currently known sources with projected future needs. They identify changes necessary for sustainable energy transformation and use. [F] [In] [T] [KC1]

This includes such learning as:

- planning and investigating the production of electricity (by moving wires in magnetic fields) and the methods used to produce electricity in power stations [T] [KC3] [KC6]
- exploring the distribution and use of electricity circuits and concepts such as voltage, currents and resistance (eg through use of virtual circuit simulation) [T] [KC7]
- measuring energy uses (eg the energy required to heat a home or boil a kettle of water) and completing quantitative energy audits for existing and more efficient use by individuals, families, workplaces and communities, using energy usage simulation software [T] [C] [KC1] [KC5] [KC7]
- collaboratively exploring scientific developments through topical issues such as the generation and equitable distribution of electrical energy in the past, today, and in probable and preferred futures [F] [KC6]
- exploring social issues in energy use, and the ways that scientists estimate known and possible energy sources. Students assess the calculation of costs and benefits for diverse groups [F] [In] [KC5] [KC6]
- considering a range of alternative energy sources and energy strategies for different situations [In] [F] [T] [KC6]
- developing their understanding of energy through the design of an energy system for a remote community, and reflecting on the social constructions of the concept of 'remoteness' [In] [T] [KC6]
- applying cost-benefit analyses, and considering sustainability, in decisions about energy products. [F] [C] [KC1] [KC5]

Key Idea: Students apply quantitative relationships between forces, energy and energy transfer in order to explore the properties of the physical world. [In] [T] [KC5] [KC6]

This includes such learning as:

- appreciating that, while friction causes energy dissipation, it is also essential for some forms of motion (eg walking) and for many static situations (eg sitting on a slope). Students plan and investigate instances of increasing and decreasing friction (eg exploring a range of adhesives or lubricants) [T] [KC3] [KC6]
- describing and graphically representing (using multimedia presentations) gravitational, magnetic and electric fields. Students use their understanding to explain such things as gravitational forces on objects on the earth, and those on other planets and the moon [T] [C] [KC2] [KC5]
- planning and carrying out activities to compare sound production and recording, and reproduction of a number of systems, for qualities such as clarity, range of frequency, and modes of recording and delivery [T] [C] [KC1] [KC2] [KC3]
- planning and carrying out activities, including experimental simulations, to investigate the transmission of energy, and how humans detect and respond to energy (eg sound, light) [In] [KC3] [KC6] [KC7]
- identifying forces involved when riding a bicycle, and using other ideas such as velocity, inertia, acceleration and energy to describe its operation [T] [KC6]
- investigating ways of energy transfer (eg conduction, convection, radiation), and carrying out 'fair tests' on various aspects of home insulation and its relation to ecologically sustainable use of energy [In] [T] [C] [KC6]
- planning and carrying out investigations to compare the relative efficiencies and cost of heating the same quantity of water with different fuels, or different ways of utilising the same fuel [T] [C] [KC1] [KC3] [KC5]
- using mathematical representations to calculate the energy associated with objects or the motion of objects, due to the forces exerted on them or the work required to shift them. [T] [C] [KC5]

Strand: energy systems

Standard 4	STANDARD 5	
At Standard 4, towards the end of Year 8, the student:	At Standard 5, towards the end of Year 10, the student:	Year 12 Standards
4.3 Investigates ways of obtaining, transferring and using energy (including from sustainable energy sources and from fossil fuels) for particular purposes. [F] [C] [KC6]	**5.3 Analyses aspects of energy sustainability, including energy resources, energy production and distribution, and challenges for future 'worldwide' uses of energy. [F] [In] [KC1]**	**The Year 12 Standards for science comprise the capabilities of the Essential Learnings demonstrated along with standards from external curriculum.**
Examples of evidence include that the student:	Examples of evidence include that the student:	**External curriculum is quality assured at Year 12 level by the accrediting authority under the Australian Qualifications Framework or equivalent.**
• identifies sources of energy used to heat or cool their home, and measures amounts of energy used [C] [KC1] [KC5]	• uses online sources of information to investigate local, national and global energy resources, production and needs for renewable and non-renewable energies [F] [C] [KC1]	The Essential Learnings are:
• uses information and communication technologies and	• investigates ways of converting various energy forms into more easily usable forms (eg electricity), and the efficiencies and ecological sustainability of such conversions [In] [T] [KC1]	• Futures • Identity • Interdependence • Thinking

Core content	Energy and Change

The forces acting on objects influence their motion, shape, behaviour and energy.

Motion and forces
- floating, sinking, rolling, sliding, falling
- pushing/pulling
- magnetic — attraction and repulsion, north and south poles, magnetic and non-magnetic materials, electromagnets, making magnets
- electrostatic — positive and negative charges
- gravity — on Earth, moon and other planets relative to size
- friction — opposing motion, everyday applications and implications
- balanced/unbalanced forces — forces acting in pairs
- Newton's laws of motion — inertia, F = ma, action and reaction
- speed, velocity, acceleration
- momentum

Motion and energy changes
- kinetic energy
- potential energy — elastic, gravitational, electrical, chemical

Manipulation of forces
- simple machines — levers, pulleys, inclined planes
- mechanical advantage
- efficiency
- perpetual motion

In interactions and changes, energy is transferred and transformed but is not created or destroyed.

Transfer and transformation of energy types
- heat — conduction, convection, radiation, Celsius and Kelvin temperature scales
- sound — vibration, pitch, frequency, volume, echo, travel of sound in solids, liquids and gases
- light — reflection, refraction, diffraction, visible spectrum, ray diagrams
- electrical — static and current, AC-DC, voltage, current, resistance, power, Ohm's law, series and parallel circuits, circuit symbols and diagrams
- potential — elastic, gravitational, electrical, chemical
- kinetic

Conservation of energy

Energy transfers that occur in:
- home
- community
- transport

Energy converters
- efficiency

There are different ways of obtaining and utilising energy and these have different consequences.

Sources of energy
- fossil fuels — coal, oil, gas
- sun — wind energy, photo-electric cells
- geothermal
- hydroelectric
- tidal
- nuclear

Alternative ways of obtaining energy
- solar cells
- solar hot water
- wind turbines

Ways of utilising energy
- coal-fired power stations
- nuclear power stations
- use of fuels in transport
- electric cars

Consequences of energy use
- short-term effects — pollution
- long-term effects — greenhouse effect
- renewable/non-renewable energy sources, long-term sustainability
- design efficiency
- social and cultural patterns of energy use

Organisation of content into year levels is advisory. Teachers will continue to make professional judgements about when to introduce content based on students' prior learning and achievement.

*National Consistency in Curriculum Outcomes, Statement of Learning – Science

Extension content for students working towards **Stage 2 units in Physics or Physical Science**
Motion calculations and Newton's laws • definitions of quantities and units of measurement of velocity, acceleration, force • calculations involving force, mass, acceleration and velocity: $v = \frac{s}{t}$, $a = \frac{v-u}{t}$, F = ma • use Newton's laws of motion to analyse the behaviour of objects.

5

Science Years 7–10 Syllabus

Stage 5

Outcome 5.6: A student applies models, theories and laws to situations involving energy, force and motion.	
Essential Content	
Students learn about:	**Students learn to:**
5.6.1 the wave model	a) identify waves as carriers of energy b) qualitatively describe features of waves including frequency, wavelength and speed c) give examples of different types of radiation that make up the electromagnetic spectrum and identify some of their uses.
5.6.2 Newton's Laws – motion	a) describe qualitatively the relationship between force, mass and acceleration b) explain qualitatively the relationship between distance, speed and time c) relate qualitatively acceleration to a change in speed and/or direction as a result of a net force d) analyse qualitatively common situations involving motion in terms of Newton's Laws.
5.6.3 electrical energy	a) design, construct and draw circuits containing a number of components b) describe voltage, resistance and current using analogies c) describe qualitatively the relationship between voltage, resistance and current d) compare the characteristics and applications of series and parallel circuits.
5.6.4 light energy	a) distinguish between the absorption, reflection and refraction of light and identify everyday situations where each occurs.
5.6.5 nuclear energy	a) identify that energy and particles may be released from the nuclei of atoms.
5.6.6 gravitational force	a) distinguish between the terms 'mass' and 'weight'.

Additional Content is not prerequisite knowledge for following stages but may be used to broaden and deepen students' knowledge, understanding and skills in Stage 4 and/or Stage 5.

Students learn about:	Students learn to:
Wave model	• discuss similarities and differences between transverse and longitudinal wave models • relate the speed of light and the speed of sound to frequency and wavelength • compare different types of radiation making up the electromagnetic spectrum in terms of frequency, wavelength and energy • design and describe ways of enabling or impeding energy transfer by waves • describe quantitatively features of waves including frequency, wavelength and speed using $v = f\lambda$.
Newton's Laws: motion	• explain the difference between speed and velocity • describe the relationships between displacement, time, velocity and acceleration both qualitatively and quantitatively using equations of motion • explain the relationship between velocity and direction of force acting to produce circular motion.
Electrical energy	• explain the relationship between voltage, resistance and current using Ohm's Law.
Light energy	• describe how the structure of the eye allows vision • relate scattering and dispersion of light to everyday occurrences.
Nuclear energy	• discuss similarities and differences between nuclear fission and fusion • explain radioactivity in terms of release of particles and energy.
Gravitational force	• relate qualitatively the force of gravity between two objects to their masses and distance apart.

31

143

Standard five–science as a body of knowledge—energy and force

Students should be provided with learning opportunities that develop their ability to:

Main idea	Stage thirteen	Stage fourteen	Stage fifteen
The behaviour of objects is determined by the forces that act on them	• investigate the effect of several forces on the motion and energy of an object	• use Newton's Laws to explain the behaviour of a variety of objects	• work with established scientific laws and theories to predict the behaviour of objects (e.g. equations of motion) including quantitative calculations
Energy can be transferred and transformed	• recognise that when energy is transformed and transferred it is also conserved • explore how and why the movement of energy (e.g. light, sound) varies according to the medium through which it is transferred	• show an understanding of relevant scientific concepts when describing energy transfers and transformations e.g. kinetic energy, potential energy, electromagnetic spectrum, heat loss	• research, analyse and explain the energy transfers and transformations that occur in some common systems, commenting on their significance e.g. human body, the Earth, the Universe, electricity production, atoms
Humans use energy and this raises ethical and sustainability issues	• research and discuss some uses and the associated advantages and disadvantages of a particular form of energy e.g. nuclear power, X-rays, microwaves, hydro-electricity	• research, analyse and argue the merits of available energy sources and systems, considering issues such as viability, cost, human and environmental impact, sustainability	• analyse the implications (technological, political, social, economic) of current and likely future global energy demand (considering energy resources, energy production and energy distribution), including commenting on preferred futures and sustainability

Possible learning contexts

Drag!* Accident?* What are the implications of our energy choices? What does Newton do for you? Where does your energy go? Should Australia go nuclear? *(* denotes LTAG learning sequence)*

Sample learning activities

The behaviour of objects is determined by the forces that act on them

- drawing and explaining force diagrams that illustrate the various forces that act on a moving object e.g. a car is acted on by force due to friction, force from the engine, force of the road pushing on the car, force of the car on the road (weight / gravity)
- investigating, discussing and explaining that, while friction causes energy dissipation, it is also essential for some forms of motion (e.g. walking) and for many static situations (e.g. sitting on a slope)
- researching coefficients of restitution for various materials and designing an activity to investigate the effects of the varying coefficients on how different types of balls bounce, including at different temperatures
- researching and investigating factors that may affect the injuries obtained in a car crash e.g. air bags, crumpling bumper bars, speed, weather conditions
- discussing and identifying applications of Newton's 1st Law (objects remain at rest or in uniform motion unless a force acts) e.g. What happens to you when a car turns suddenly? Why can you pull a tablecloth out from underneath the dishes?
- investigating the relationship between mass and force and acceleration (Newton's 2nd Law) e.g. using a spring balance to lift objects of different masses then plotting F vs m and identifying a straight line relationship and the acceleration, or use balls of different mass rolling down a ramp then determine acceleration and plot a vs m

- identifying, discussing and explaining applications of Newton's 3rd Law (to every action there is an equal and opposite reaction) e.g. What happens if you are sitting on a computer chair with castors and push someone who is sitting on a similar chair? What happens to an astronaut tightening the bolts on the space station?
- carrying out investigations using rockets (e.g. balloon, water) and explaining the behaviour / effectiveness of different rockets in terms of Newton's Laws
- identifying whether the quantities they are working with are scalar or vector quantities e.g. distance / displacement, mass / weight, speed / velocity
- using a motion detector and datalogger to record the motion of an object
- using ticker timers and trolleys to investigate the equations of motions $s = ut + \frac{1}{2}at^2$, $v = u + at$, $v^2 = u^2 + 2as$
- applying the equations of motion to situations that involve slowing down (negative acceleration) and falling bodies $(a = g = 9.8ms^{-2})$ e.g. determining the acceleration due to gravity by dropping balls from different heights, timing the length of the fall, graphing $s-t^2$, finding the slope of the line and doubling it (graphic calculators / software may be useful)
- watching cartoons such as *Roadrunner* and identifying events that misrepresent what would happen in the real world e.g. roadrunner goes off cliff and continues in straight line before falling, movement of boulders
- viewing a video or setting up an experimental demonstration to show that objects released at the same time fall at the same rate (ignoring air resistance), regardless of their initial horizontal velocity
- use the Learning Federation object, *Accelerate*, to explore Newton's second law of motion

Energy can be transferred and transformed

- understanding the range of the electromagnetic spectrum and some of its applications and impacts e.g. use of sunscreen, medical use of X-rays and gamma rays, comparison of microwaves for cooking with microwaves for transmission of mobile phone signals, how the electromagnetic spectrum is different from sound
- visiting a medical facility or inviting a guest speaker for the purpose of learning about a practical application of electromagnetic radiation
- exploring the characteristics of visible light e.g. using a ray box to investigate the transmission, reflection and refraction of light using various lenses, mirrors and prisms, investigating total internal reflection and discussing its significance in fibre optic cables, carrying out investigations that demonstrate the refraction of light
- making a model eye and investigating defects that may occur and how to correct the image that is produced
- exploring the operation of various optical instruments (e.g. pinhole camera, microscope, telescope), building a working model and researching the instrument's historical development
- investigating heat by looking at the ways in which different materials gain and lose heat energy e.g. Does tea or coffee cool faster? How does the type of cup used affect the cooling rate of a hot drink?
- investigating the effectiveness of water as a heat absorbing medium e.g. water can be heated in a paper cup, water is used to treat burns, water has a global role in moderating temperature
- discussing and explaining conservation of energy through considering the transfer and transformation of energy in systems such as trampolines, tennis and roller-coasters, using formulae to equate potential and kinetic energy
- investigating how a variety of musical instruments produce sound and how players modify the sounds that their instruments produce
- designing a recording studio or restaurant, considering how sounds will be reflected and absorbed
- investigating the roles of components in more advanced electrical circuits e.g. diodes, relays, capacitors
- using *Audacity©* to explore sound and how it can be modified electronically

Humans use energy and this raises ethical and sustainability issues

- researching, coming to a considered opinion and debating whether Australia should switch to nuclear power
- investigating some ways in which humans meet their energy needs in more remote areas e.g. use solar panels to power outback phones and lighthouse beacons
- exploring social issues in energy use and the ways that scientists estimate known and possible energy sources
- using ICT for information to investigate local, national and global energy resources, production and needs
- calculating the costs and benefits of energy production for diverse groups e.g. *On whom does uranium mining impact? On whom does building a wind farm or coal fired power station or hydro scheme impact?*

144

NEALS

PHYSICS NQE SYLLABUS for the Australian Science Olympiads For 2005 NQE.

1. Mechanics
(a) Units and measurement
(b) Kinematics in one and two dimensions including projectile motion
(c) Newton's laws of motion - forces, free body diagrams, equations of motion
(d) Momentum, impulse
(e) Work, energy, power
(f) Conservation of energy
(g) Conservation of linear momentum
(h) Elastic and frictional forces
(i) Centre of mass and conditions for equilibrium,
(j) Circular motion of point masses, centripetal forces
(k) Gravitation, Newton's law of gravitation, work and energy in gravitational fields

2. Oscillations and Waves
(a) Simple harmonic motion
(b) Propagation of waves, transverse and longitudinal waves
(c) Superposition and interference of waves
(d) Snell's law

3. Electric Charges and Fields
(a) Conservation of charge
(b) Electric field diagrams for simple geometries like plates and spheres

4. Electric Current
(a) Current, resistance, Ohm's law
(b) Kirchhoff's laws, work and power of direct currents

5. Thermodynamics
(a) Concepts of gases including pressure, volume, temperature
(b) Heat, energy and heat flow

6. Experimental skills and processes
(a) Graphing
(b) Basic data analysis

The National Qualifying Exam for Physics will draw on knowledge of these topics but may also include questions on any other topic, in which case the basic knowledge required to do the question will be provided in the question text. This is consistent with the International Physics Olympiad examination procedures.

APPENDIX B

The following guide is provided to support course writing in the science disciplines of Chemistry, Physics and Life Sciences, which are taught in all ACT colleges.

CHEMISTRY

In addition to the essential concepts and skills outlined in the Framework, all Chemistry major courses should cover:
- Periodicity
- Atomic structure
- Stoichiometry
- Chemical change
- Solubility
- Organic chemistry
- Rates
- Equilibrium
- Bonding and structure
- Types of reactions
- Acids and bases
- Electrochemistry
- Energy.

Minor courses may be structured from a selection of the above.

Course developers are encouraged to include the historical, biological, physical, environmental, analytical and industrial aspects of chemistry.

PHYSICS

In addition to the essential concepts and skills outlined in the Science Course Framework, all Physics major courses should cover:
- Measurement: SI unit system, uncertainty analysis, graphical techniques, instrumentation
- Vectors
- Motion: linear motion, graphical techniques, instrumentation
- Forces: Newton's Laws, gravity, momentum, machines
- Energy: work, kinetic energy, gravitational / elastic potential energy, power, conservation laws.

The following topics are examples of content that may also be included:
- Waves: types, properties, electromagnetic waves, sound
- Non-linear motion eg circular, projectile and simple harmonic motion
- Fields: comparisons and properties of g, E and B fields
- Electricity, magnetism, electromagnetism: electrostatics, current electricity, permanent magnetism, electromagnetic induction

AREA OF STUDY 1

Motion in one and two dimensions

Newtonian theories give important insights into a range of motions, and contribute towards safety considerations. This study focuses on everyday motion.

Newton's insights into gravity have led to understanding of the motion of the solar system, the achievements of space travel, and satellite technology.

Students will use the Newtonian model in the contexts of transport and safety on Earth, and motion in space. They will use safe and responsible practices when completing experiments and/or investigations.

Outcome 1

On completion of this unit the student should be able to use the Newtonian model in one and two dimensions to describe and explain transport motion and related aspects of safety, and motion in space.

To achieve this outcome the student will draw on knowledge and related skills outlined in area of study 1.

Key knowledge and skills

To achieve this outcome the student should demonstrate the knowledge and skills to:

- explain movement in terms of the Newtonian model and assumptions, including
  - Newton's three laws of motion
  - the absolute nature of space and time;
- apply Newton's laws of motion to situations involving two or more forces acting along a straight line and in two dimensions;
- analyse the uniform circular motion of an object in a horizontal plane;
- analyse the ideal motion of projectiles near the Earth's surface graphically and algebraically, assuming air resistance is negligible;
- analyse relative velocity of objects moving along a straight line and in two dimensions;
- distinguish between stationary (inertial) frames of reference and frames of reference that are moving at constant speed relative to the stationary frame, including Galilean transformations in one dimension between frames of reference;
- analyse impulse, and momentum transfer, in collisions between objects moving along a straight line;
- analyse energy transfer resulting from work done by a constant force in one dimension;
- analyse transfers of energy between kinetic energy, potential energy and other forms of energy for objects that
  - interact with springs that obey Hooke's Law, $F = k(-\Delta x)$
  - undergo elastic and inelastic collisions
  - move from position to position in a changing gravitational field, using only areas under force-distance and field-distance graphs;
- analyse planetary and satellite motion modelled as uniform circular orbital motion in a universal gravitation field, using
  - $a = v^2/r = 4\pi^2 r/T^2$
  - $g = GM/r^2$ and $F = GM_1M_2/r^2$;
- use safe and responsible practices when working with moving objects and equipment.

All models are developed within contexts that are familiar and relevant to students. Ideas about energy transfers and transformations continue to be used. Mathematical models are critically applied during experimental investigation of examples of movement.

Students will use the Newtonian model of movement in the contexts of the historical development of the physics of motion, transport, and games and sports.

They will use safe and responsible practices when completing experiments and/or investigations.

Outcome 1

On completion of this unit the student should be able to describe and explain movement of particles and bodies in terms of Aristotelian, Galilean and Newtonian theories.

To achieve this outcome the student will draw on knowledge and related skills outlined in area of study 1.

Key knowledge and skills

To achieve this outcome the student should demonstrate the knowledge and skills to:

- describe non-uniform and uniform motion along a straight line graphically;
- analyse motion along a straight line graphically, numerically and algebraically;
- describe how changes in movement are caused by the actions of forces;
- model forces as external actions through the centre of mass point of each body;
- explain movement in terms of the Newtonian model and some of its assumptions, including Newton's three laws of motion, forces acting on point particles, and the ideal, frictionless world;
- compare the accounts of the action of forces by Aristotle, Galileo and Newton;
- apply the vector model of forces, including vector addition, vector substraction and components, to readily observable forces including weight, friction and reaction forces;
- model mathematically work as force multiplied by distance for a constant force and as area under a force versus distance graph;
- interpret energy transfers and transformations using an energy conservation model applied to ideas of work, energy and power, including transfers between
  - gravitational potential energy and kinetic energy near the Earth
  - potential energy and kinetic energy in springs;
- apply graphical, numerical and algebraic models to primary data collected during practical investigations of movement;
- use safe and responsible practices when conducting experiments and/or investigations related to motion.

AREA OF STUDY 2

Electricity

Students develop circuit models to analyse electrical phenomena and undertake practical investigations of circuit components. Concepts of electrical safety are developed through the study of safety mechanisms and the effect of current and time on humans. Mathematical models are applied and critically assessed during experimental investigation of DC circuits.

Students will use electrical circuits in the contexts of simple battery operated DC devices, household electricity, and car electrical systems.

They will use safe and responsible practices when completing experiments and/or investigations. For further information, see 'Safety' on page 9.

Detailed example

INVESTIGATE ENERGY SUPPLY

Investigate the heating and cooling rates of similar masses of different materials. Select an appropriate material and model its use in maintaining a more consistent temperature of a room during day and night. Collect appropriate temperature and time data and present a report, including explanations of energy transfer and transformation processes in terms of particles and radiation.

Unit 3

AREA OF STUDY 1: Motion in one and two dimensions

Outcome 1	***Examples of learning activities***
Use the Newtonian model in one and two dimensions to describe and explain transport motion and related aspects of safety, and motion in space.	use data loggers to investigate the displacement, velocity and acceleration of students as they perform long jumps and high jumps
	investigate the relative speeds of carts or air table gliders
	investigate the total momentum before and after various types of collisions between carts or air track gliders
	use student designed crumple zones attached to motion trolleys to investigate inelastic collisions; the speed of the motion trolleys can be measured using ticker timers or dataloggers
	discuss various measures to improve road safety from the point of view of the physics involved
	throw a ball, and by measuring the range and time of flight calculate the initial velocity and maximum height
	model the motion of a car rounding a corner by investigating the relationship between speed and radius for a rubber stopper moving in a circular path on the end of a length of fishing line under constant tension
	use photography or other means to determine the angle of lean of a bicycle rider negotiating a curve of known radius at a constant known speed; compare the measured and calculated angles
	develop a spreadsheet that models the motion of a sky diver approaching terminal velocity
	use a set of bathroom scales in a lift to determine the change in apparent weight and hence the acceleration of the lift
	select data on planets and their moons and use a spreadsheet to investigate gravitational and circular motion relationships

Topic 1: Projectile Motion

A projectile, in the absence of air resistance and moving under the action of a constant gravitational force, has a constant acceleration in the direction of the force. The horizontal component of velocity of such a projectile is constant, and the vertical component changes at a constant rate. The time of flight and the range of the projectile are calculated, and the effect of air resistance on the motion is treated qualitatively. These key ideas are applied to projectiles in sport (e.g. a shot-put).

Key Ideas

Students should know and understand the following.

Intended Student Learning

Students should be able to do the following.

Vertical and Horizontal Components of Velocity

For a projectile, in the absence of air resistance, the:
- horizontal component of velocity is constant;
- acceleration is in the vertical direction and is the same as that of a vertically free-falling object.

Given a multi-image photograph of a projectile, demonstrate that the:
- horizontal component of velocity is constant;
- acceleration is in the vertical direction and is the same as that of a vertically free-falling object.

The horizontal motion and the vertical motion are independent of each other: the constant vertical acceleration is independent of the horizontal speed.

Draw a vector diagram in which the horizontal and vertical components of velocity are added, giving the resultant velocity vector at any instant.

The acceleration of a projectile, in the absence of air resistance, is in the direction of the gravitational force.

Using trigonometric calculations or a scale diagram, calculate, from its horizontal and vertical components, the magnitude and direction of a velocity vector at any instant.

On a diagram showing the path of a projectile, draw vectors to represent the velocity and acceleration of the projectile at any instant.

Determination of the Vertical Component of Velocity

The equations for constant acceleration in one dimension can be used to calculate the vertical component of velocity of a projectile at any instant.

Given the initial velocity of a projectile, calculate the vertical component of velocity at any instant.

Resolution of Velocity into Components

Velocity can be resolved into its horizontal and vertical components at any instant.

Using trigonometric calculations or a scale diagram, resolve a velocity vector into its horizontal and vertical components.

Time of Flight

The time of flight of a projectile is determined by the change in vertical component of velocity and the acceleration.

Calculate the time of flight of a projectile in cases where the final height is the same as the initial height.

24

Key Ideas

Students should know and understand the following.

Intended Student Learning

Students should be able to do the following.

Range

The range of a projectile is calculated by multiplying the horizontal component of velocity and the time of flight.

Using the horizontal component of velocity and the time of flight, calculate the range of a projectile.

For a projectile launched from ground height, find, by using sample calculations or otherwise, the:
- launch angle that results in the maximum range;
- relation between the launch angles that result in the same range.

Maximum Height

The maximum height of a projectile can be calculated from the vertical component of the initial velocity and the acceleration *or* the time of flight and the acceleration.

Using the vertical component of the initial velocity and the acceleration, calculate the maximum height of a projectile.

Using the time of flight and the acceleration, calculate the maximum height of a projectile.

Effect of Air Resistance

Air resistance acts in the opposite direction to the velocity of a projectile at any instant.

Describe how air resistance affects both the horizontal component and the vertical component of velocity, and hence the time of flight and the range, of a projectile.

The magnitude of the force of air resistance on an object depends on the object's shape, size, speed, and surface texture; and on the density of the air.

Compare qualitatively the force of air resistance acting on different objects.

Application: Projectiles in Sport

Describe and explain the effect of the launch height of a projectile (e.g. a shot-put launched from shoulder height) on the maximum range, and the effect of the launch angle for a given height.

Investigate the extent to which air resistance affects various projectiles in sport.

25

PHYSICS | SENIOR SYLLABUS

Radioactivity
- $A = \frac{\Delta N}{\Delta t} = -\lambda N$
  - disintegration or decay constant, λ
  - interpretation of graphs of activity or number of particles with time
  - qualitative treatment of decay law
  - half life: $t_{1/2} = 0.693/\lambda$

• Elementary nuclear reactions in equation form, including fission and fusion
• Calculation of mass defect in atomic mass units and conversion to energy units MeV and MeV per nucleon
• Qualitative treatment of radiation dose (gray, sievert) and effects.

Motion

• Analysis of scalar and vector quantities using algebraic and graphical techniques, e.g. motion, energy, force, momentum
• Problems involving equations for motion, e.g. linear, projectile and circular

$v = st$ $v = u + at$ $s = \tfrac{1}{2}(u+v)t$

$s = ut + \tfrac{1}{2}at^2$ $s = (v^2 + u^2)/2a$ $a_c = v^2/r = 4\pi^2 r/T^2$

Momentum and impulse:
$p = mv(vectorial)$ $Ft = \Delta p(vectorial)$

• Characteristics of transverse and longitudinal waves
• Relationship between speed and wavelength: $v = f\lambda$
• Analysis of reflection, refraction, diffraction
• Analysis of interference, e.g. standing waves, air columns, strings and light, using the following formulas:

path difference = dx_n/L constructive: $d \sin\theta = n\lambda$ destructive: $d \sin\theta = (n-\tfrac{1}{2})\lambda$

• Electrostatics
• Qualitative and quantitative analysis of the semiconductor applications
• Qualitative and quantitative treatment of motors, generators and alternative energy technologies
• EMF proportional to rate of change of magnetic flux

$\phi = BA\cos\theta$ $EMF = BLv$ $EMF = -N\Delta\phi/\Delta t$

• Photoelectric effect (KE vs frequency graph and Planck's Constant)
• Qualitative treatment of α, β and γ radiation; formation, penetrating power and other properties.

PHYSICS | SENIOR SYLLABUS

Organiser 3: Motion

Motion is common to most of our everyday experiences. This is formalised mathematically in kinematics, which is the study of how objects move. Students should be reminded that the types of motion are highly idealised and may seem to have little to do with the real world as we observe it. However, it is essential that students first investigate these simple and idealised motions and their descriptions to obtain a firm understanding of the basis of kinematics. Once this goal has been achieved, they are in a position to apply their knowledge to the more complex real-world situations, and study phenomena in the quantum realm, which is outside our everyday experiences.

Key concept
M1
Motion can be described in different ways.

Key concept
M2
Motion can be analysed in different ways.

Key concept
M3
Motion can be described using various models and modern theories.

Key ideas

M1.1 — Changes in motion result from unbalanced forces.

M1.2 — Scalar, vector and graphical methods can be used, as appropriate, to describe motion.

M1.3 — The collection of data used to describe motion can be accomplished using a range of technologies.

M1.4 — Primary and secondary data can be analysed, manipulated and presented in a variety of formats to provide alternative descriptions of motion.

Key ideas

M2.1 — The relationship between force, mass and acceleration can be analysed qualitatively and quantitatively using algorithms and graphical techniques.

M2.2 — The directional relationship between acceleration and net force can be analysed using vector diagrams.

M2.3 — The laws of conservation of energy and momentum can be used to analyse and describe motion of objects in simple and complex situations.

M2.4 — An understanding of the nature of fields (gravitational, magnetic and electric) and their interactions with matter can be used to analyse and predict the motion of an object.

M2.5 — Relative rates of change are useful measures when analysing the motion of an object.

Key ideas

M3.1 — The propagation of light demonstrates the concepts of wave–particle duality, quantisation of energy and probability waves.

M3.2 — Classical and relativistic theories are used to describe motion in different circumstances.

D409 Physics (Year 11) – 2008

Each of the central ideas must be studied within, or applied to, at least one of the following contexts. At least one context must be selected for detailed investigation.
Student outcomes marked * may be selected and taught as appropriate, depending on context chosen and background and needs of students.

Contexts

> **On your own two feet**
> e.g. forces and energy for walking and running; comparison with skiing and skating; walking on different surfaces; acceleration during a sprint start; impulse from the starting blocks; dives and vertical jumps; trampolines; power developed while running up and down hills or flights of stairs.

or

> **Wheels**
> e.g. bicycles and cars; typical speeds and acceleration; stopping times and distances; speed limits; driving and braking forces and air resistance; tyres, treads and wear; cycling up and down hills; collisions between large and small cars, bikes and pedestrians; fuel consumption by cars; relative energy efficiency of cycling, walking and motoring.

Student outcomes

1. Distinguish between scalar and vector quantities.
2. Add and subtract vectors in one dimension
3. Define 'displacement' and state its SI unit.
4. Distinguish between distance and displacement.
5. Define 'speed' and 'velocity' and state their SI unit.
6. Distinguish between speed and velocity
7. Calculate constant, instantaneous and average speed and velocity from tabulated and graphical data.
8. Define 'acceleration' and state its SI unit.
9. Calculate constant (average) acceleration for motion in one dimension.
10. Draw and interpret graphs of objects moving in one dimension, including the interpretation of slope and area.
11. Solve simple problems, including vertical motion under gravity using the equations:

$$v_{ave} = \frac{s}{t}$$
$$v_{ave} = \frac{u+v}{2}$$
$$a = \frac{v-u}{t}$$

for constant acceleration.

12. Define 'inertia'.
13. Define 'mass' and state its SI unit.
14. Define 'momentum' and state its SI unit.
15. Describe the effects produced by forces.
16. State Newton's First, Second and Third Laws of motion.
17. Explain Newton's First Law of motion and account for its apparent failure due to friction.
18. Define 'force' in terms of Newton's First and Second Laws of motion and state its SI unit.
19. Define 'impulse' as the product of force and time and state its SI unit.

20. Use Newton's Second Law to explain the relationship between impulse and change in momentum.
21. State and explain the law of conservation of momentum.
22. Perform calculations involving momentum and conservation of momentum in one dimension:

$$p = mv$$
$$p_{before} = p_{after}$$
$$Ft = mv - mu$$

23. Explain how Newton's Second Law is used to define the unit of force.
24. Distinguish between mass and weight.
25. Solve simple problems using $F = ma$
26. Identify and explain Newton's Third Law in terms of pairs of forces in physical situations.
27. Use weight = mg to solve simple problems.
28. Draw free body diagrams showing the forces acting on objects from descriptions of real life situations.
29.* Define 'pressure' and state its SI unit.
30.* Describe the movement of fluids using pressure differences.
31.* Solve simple problems using

$$P = \frac{F}{A} \quad \text{and} \quad P = \rho g h$$

32.* List and describe the origin of various energy types.
33. State that when a force moves its point of application in the direction of the force, work is done.
34. State and define the SI unit of work.
35. Solve problems using $W = Fs$
36. Distinguish between work and energy.
37. Explain that a system which has energy can be made to perform useful work.
38.* State and explain that one form of energy may be converted into another form.
39. State the SI unit of energy.
40.* Describe the energy changes that occur during energy transformations.
41. State and explain the principle of conservation of energy.
42.* Explain that all forms of energy tend to degrade into thermal energy and relate this to the fact that the efficiency of mechanical systems is never 100%.
43. Define 'kinetic energy' as energy of motion.
44. Solve problems using the expression:

$$E_k = \frac{1}{2}mv^2$$

45. Define 'potential energy' as energy of position or state.
46. Give examples of potential energy.
47. Solve problems using the expression

$$E_p = mgh$$

for gravitational potential energy.

Student Outcomes

1. Add and resolve vectors in one plane.
2. State the equations of motion and the assumptions made in their derivation

$$a = \frac{v - u}{t}$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

3. Describe qualitatively the motion of a projectile in a uniform gravitational field.
4. Solve problems involving projectiles using the equations of motion and two dimensional vectors (neglect air resistance).
5. Use the terms 'time of flight', 'range' and 'maximum height' in solving projectile motion problems within the chosen context.
6. Describe qualitatively the effects of air resistance on projectile motion.
7. Explain that motion of an object in a circle with a constant speed involves a constant magnitude of acceleration towards the centre.
8. Define and explain the concept of centripetal force.
9. Use $a = \frac{v^2}{r}$ to calculate centripetal acceleration.
10. Use resultant $F = ma = \frac{mv^2}{r}$ to solve problems.
11. Identify the force required to produce circular motion in a variety of simple situations (including gravitational and magnetic fields).
12. Analyse the motion of an object undergoing uniform circular motion in a horizontal plane.
13. Analyse the forces acting when an object undergoes circular motion in a vertical plane.
14. Define the term 'centre of mass'.
15. State Newton's Law of Universal Gravitation.
16. Use Newton's Law of Universal Gravitation to solve simple problems.

$$F = G\,\frac{m_1 m_2}{r^2}$$

17. Use Newton's Law of Universal Gravitation to evaluate the gravitational field 'g' at any point in the vicinity of a large object.

$$g = G\,\frac{M}{R^2}$$

18. State the conditions for a satellite to remain in a stable circular orbit.
19. Perform calculations involving all the parameters of a satellite in circular orbits using

$$F = \frac{mv^2}{r} = G\,\frac{m_1 m_2}{r^2}$$

20 Comprehend and communicate scientific information relevant to the contextual and central ideas of this section.

2.2 Structures and materials

The central ideas for this area of study are listed below:

- conditions for stability
- conditions for equilibrium
- stress, strain, Young's modulus.

Each of the central ideas must be studied within, or applied to, at least one of the following contexts. At least one context must be selected for detailed investigation.

Contexts

Bridges and buildings

e.g. simple suspended and supported structures; open frameworks; bridges (force on pylons, suspension bridges, compression bridges); buildings (arches, flying buttresses, catenary arches, Gothic arches, semi-circular arches, suspended structures); building materials (steel, concrete, glass, aluminium).

or

Human and animal frames

e.g. simple stick model structures; bones (fractures, stresses under compression, greenstick fractures, spinal injuries); muscles (tendons and ligaments); safe lifting practices; prosthetic devices (artificial limbs); physical disabilities.

Student Outcomes

1. Define 'torque' or moment of a force about a point.
2. State the principle of moments.
3. Interpret problems involving moments and perform calculations, including examples where the applied force is not perpendicular to the lever arm, using the relationships

$$M = rF \text{ and } \Sigma M = 0.$$

4. Identify situations where a rigid body is in equilibrium.
5. Perform simple 2-dimensional calculations on a rigid body in equilibrium within the chosen context.
6. State the conditions for stable, unstable, and neutral equilibrium and apply them to simple situations within the chosen context.
7. Define 'stress' and 'strain'.
8. Draw and describe the stress-strain curve for typical brittle and ductile materials.
9. Calculate stress using $\dfrac{F}{A}$ and strain using $\dfrac{\Delta l}{l}$.
10. Explain why the terms 'stress' and 'strain' are used rather than force and extension.
11. Define Young's modulus (Y).
12. Explain the use of tables giving values of Young's modulus for different materials.
13. Within the chosen context perform simple calculations using

$$\frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta l/l} = \text{Young's modulus (Y)}$$

14. Demonstrate familiarity with, and conduct experimental activities related to, these student outcomes.

Physics Stage 6 Syllabus

1. Vehicles do not typically travel at a constant speed

Students learn to:

- identify that a typical journey involves speed changes
- distinguish between the instantaneous and average speed of vehicles and other bodies
- distinguish between scalar and vector quantities in equations
- compare instantaneous and average speed with instantaneous and average velocity
- define average velocity as:

$$v_{av} = \frac{\Delta r}{\Delta t}$$

Students:

- plan, choose equipment or resources for, and perform a first-hand investigation to measure the average speed of an object or a vehicle
- solve problems and analyse information using the formula :

$$v_{av} = \frac{\Delta r}{\Delta t}$$

  where r = displacement

- present information graphically of:
  - displacement vs time
  - velocity vs time

  for objects with uniform and non-uniform linear velocity

31

Physics Stage 6 Syllabus

2. An analysis of the external forces on vehicles helps to understand the effects of acceleration and deceleration

Students learn to:

- describe the motion of one body relative to another
- identify the usefulness of using vector diagrams to assist solving problems
- explain the need for a net external force to act in order to change the velocity of an object
- describe the actions that must be taken for a vehicle to change direction, speed up and slow down
- describe the typical effects of external forces on bodies including:
  - friction between surfaces
  - air resistance
- define average acceleration as:

$$a_{av} = \frac{\Delta v}{\Delta t}$$

  therefore

$$a_{av} = \frac{v - u}{t}$$

- define the terms 'mass' and 'weight' with reference to the effects of gravity
- outline the forces involved in causing a change in the velocity of a vehicle when:
  - coasting with no pressure on the accelerator
  - pressing on the accelerator
  - pressing on the brakes
  - passing over an icy patch on the road
  - climbing and descending hills
  - following a curve in the road
- interpret Newton's Second Law of Motion and relate it to the equation:

$$\sum F = ma$$

- identify the net force in a wide variety of situations involving modes of transport and explain the consequences of the application of that net force in terms of Newton's Second Law of Motion

Students:

- analyse the effects of external forces operating on a vehicle
- gather first-hand information about different situations where acceleration is positive or negative
- plan, choose equipment or resources for and perform a first-hand investigation to demonstrate vector addition and subtraction
- solve problems using vector diagrams to determine resultant velocity, acceleration and force
- plan, choose equipment or resources and perform first-hand investigations to gather data and use available evidence to show the relationship between force, mass and acceleration using suitable apparatus
- solve problems and analyse information using:

$$\sum F = ma$$

  for a range of situations involving modes of transport

- solve problems and analyse information involving

$$F = \frac{mv^2}{r}$$

  for vehicles travelling around curves

32

Physics Stage 6 Syllabus

Students learn to: *Students:*

2. Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth

- describe the trajectory of an object undergoing projectile motion within the Earth's gravitational field in terms of horizontal and vertical components

- describe Galileo's analysis of projectile motion

- explain the concept of escape velocity in terms of the:
  – gravitational constant
  – mass and radius of the planet

- outline Newton's concept of escape velocity

- identify why the term 'g forces' is used to explain the forces acting on an astronaut during launch

- discuss the effect of the Earth's orbital motion and its rotational motion on the launch of a rocket

- analyse the changing acceleration of a rocket during launch in terms of the:
  – Law of Conservation of Momentum
  – forces experienced by astronauts

- analyse the forces involved in uniform circular motion for a range of objects, including satellites orbiting the Earth

- compare qualitatively low Earth and geo-stationary orbits

- define the term orbital velocity and the quantitative and qualitative relationship between orbital velocity, the gravitational constant, mass of the central body, mass of the satellite and the radius of the orbit using Kepler's Law of Periods

- account for the orbital decay of satellites in low Earth orbit

- solve problems and analyse information to calculate the actual velocity of a projectile from its horizontal and vertical components using :

$$v_x^2 = u_x^2$$
$$v = u + at$$
$$v_y^2 = u_y^2 + 2a_y\Delta y$$
$$\Delta x = u_x t$$
$$\Delta y = u_y t + \frac{1}{2}a_y t^2$$

- perform a first-hand investigation, gather information and analyse data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by using simulations, data loggers and computer analysis

- identify data sources, gather, analyse and present information on the contribution of one of the following to the development of space exploration: Tsiolkovsky, Oberth, Goddard, Esnault-Pelterie, O'Neill or von Braun

- solve problems and analyse information to calculate the centripetal force acting on a satellite undergoing uniform circular motion about the Earth using:

$$F = \frac{mv^2}{r}$$

- solve problems and analyse information using:

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$$

4   Physics
        Senior Secondary 5C

EXPANDED SYLLABUS OUTLINE

INTRODUCTION TO PHYSICS

These areas are to be treated as they arise in the course structure

- Observation, description, recording and communicating

- Uncertainty in measurements (*simple treatment only*)

- Graphical representation including significance of slopes of tangents and areas under graphs

- Vectors and scalars (*vectors to any angled analysis*)

- Trigonometrical applications of sine rule, cosine rule and components of vectors.

KNOWLEDGE AND UNDERSTANDING OF NEWTONIAN MECHANICS

Motion

- Displacement and distance

  - Displacement problems to any angled analysis

- Speed and average velocity

  Speed = $\dfrac{\text{distance}}{\text{time}}$ (average)

  velocity: $v_{av} = \dfrac{displacement}{time}$

- Acceleration

  $a = \dfrac{\Delta v}{\Delta t} = \dfrac{v - u}{t}$

- Graphical treatment of accelerated motion

  - construct and interpret constant acceleration cases of s-t graphs, v-t graphs and a-t graphs

  - construct v-t and a-t graphs using data from the slopes of s-t and v-t graphs respectively

  $v = \dfrac{\Delta s}{\Delta t} \quad a = \dfrac{\Delta v}{\Delta t}$

  - calculation of displacement and/or distance from v-t graph

- Uniformly accelerated motion, including vertical motion under gravity

  - equations of motion for constant straight line acceleration, including gravity cases (a_g = 9.8 ms^{-2})

  $s = ut + \dfrac{1}{2}at^2$, v = u + at and v^2 = u^2 +2as

  - terminal velocity

- Projectile motion including projection and landing at different levels and/ or heights

  - determine the vertical and horizontal components of velocity (and hence velocity) at any point of the path

  - time of flight

  - horizontal and vertical displacements

Momentum and Newton's Laws

- Momentum and conservation of momentum

  - momentum (p = mv)

  - applications of the law of conservation of momentum to one and two dimensional problems at any angle.

  $\sum p_i = \sum p_f$