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# **Scientific Representational Fluency:**

## **Defining, Diagnosing, and Developing**

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A thesis submitted in fulfilment of requirements for the degree of

Doctor of Philosophy

School of Physics

The University of Sydney

Australia

2015



This thesis is dedicated to my parents, Margaret and Gary Hill,  
who taught me to be fluent with representations.



# **Statement of originality**

I declare that the research presented here is my own work and has not been submitted to any other institution for the award of a degree.

Matthew Hill,  
September 2015



# Abstract

This thesis advocates the importance of representational fluency in physics education. Multiple representations in science (e.g. graphs, words, equations, and diagrams) has been an area of much interest in physics education research in recent years. Representational fluency, however, is a somewhat novel idea. The thesis argues that this little-used term, representational fluency, is a way to draw together various ideas on how and why the use of multiple representations is important for physics students, educators, and education researchers alike.

Representational fluency is investigated by considering three questions: what is representational fluency; what role does representational fluency play in physics learning; and how can students' development of representational fluency be facilitated?

This thesis explores these questions through the format of an introduction, five journal articles, and a general discussion combining the conclusions of each paper.

The first paper presents the development, use, and publication of a survey to measure representational fluency, the Representational Fluency Survey (RFS), which is the first of such surveys in the literature. The RFS is a seven item survey which involves the participant solving problems that are difficult due to the representations in the question, rather than the level of physics content knowledge.

A second paper illustrates how the RFS is used to further develop our understanding of representational fluency. The RFS allowed diagnosis of significant differences in the levels of representational fluency of different cohorts of students at the University of Sydney and identification of various features of students with a high level of representational fluency. It was found that the representational fluency of students with a higher level of physics learning experience was significantly greater than that of students with a lower level of physics learning experience and the difference was evident even within the first year cohort.

Due to the apparent disparity of levels of representational fluency amongst different cohorts of students at the university, the subsequent three papers relate to research into effective pedagogies that facilitate the development of representational fluency.

A format of presenting direct instruction on a particular physics representation through worksheets and consolidating this knowledge with applied questions was trialled as a possible



method of instruction. It was found to alter the way that students use representations in following questions. This was done in the context of students in their final year of high school.

The format was adapted to suit a university physics course in the structure of a semester-long set of weekly online learning modules designed to introduce students to representations relevant to the upcoming week's lectures. The uptake and effectiveness of online learning modules was investigated first: it was found that university students were willing to participate in the modules and that the modules were of benefit to student engagement as intended in their design.

Therefore, an experiment was conducted with the first year physics students at the University of Sydney. The students were randomly separated into two streams. One stream participated in weekly online learning modules focussed on relevant physics representations, the other stream participated in similar modules which more conventionally focussed on relevant physics concepts.

Using the RFS as a pre-post test, it was found that students participating in the modules on physics representations had the largest learning gains in representational fluency. This demonstrates an effective pedagogical tool to support students in developing their representational fluency. Using an established test of conceptual physics understanding, it was also found that the students from each stream of online learning modules developed conceptual physics knowledge by comparative amounts across the semester.

In these ways, this thesis advocates the importance of representational fluency, through defining, diagnosing, and developing representational fluency of university students.

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of Educational Assessment Australia for assisting me to get access to already published items suitable for re-use in the Representational Fluency Survey (Chapter 2). Items 3 and 4 of the Representational Fluency Survey were originally published as part of the Australasian Schools Science Competition and were used in the publication with permission from Educational Assessment Australia. Furthermore, item 7 of the RFS first appeared in the 2007 Rio Tinto Big Science Competition senior paper.

In the production of this thesis I wish to thank Ian Johnston and Alison Hammond for providing detailed feedback on intellectual ideas and feedback in a proofreading capacity.

To my colleagues and fellow students who I have shared an office with, I thank you for helping me to greatly enjoy this Journey. Thank you Gabriel Nguyen, Alex Yeung, Vicky Tzioumis, Evan Hefer, and Helen Georgiou, who along with many visitors and short term colleagues have been people I could learn from both professionally and personally. My special thanks goes to Helen Georgiou who through her intellect, ideas, and friendship has made sharing an office with her a highlight of my Ph.D.

Finally, and most importantly, I would like to thank my wife Elise for freely giving me this opportunity to pursue research and spend years thinking and exploring physics education. You have supported me through the process and I am very grateful of your love for me. After over five years of marriage where I have been studying the entire time, thank you for putting up with my student ways and for working hard to allow me to go down this path.

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---

Soli Deo gloria

# Included Publications and Attribution

Each chapter in the body of the thesis (Chapters 2-6) are stand-alone, self-contained articles for scientific journals. They are collected together in the one document to form a consistent thesis. The first four have been published (or accepted for publication) in peer reviewed journals. Chapter 5 is a journal article that has been submitted, and is currently under review.

## Chapter 2

Hill, M., Sharma, M. D., O’Byrne, J., & Airey, J. (2014). Developing and evaluating a survey for representational fluency in science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 22(6), 22-42

### *My Contribution*

I conceived the idea of developing a multiple representations survey to be used with university students. I identified a pool of items for the survey, and chose the final seven items after consulting with the Sydney University Physics Education Research Group. I conducted the research and was responsible for analysing the results and for writing the publication. Dr John Airey was responsible for suggesting the use of the word “Fluency” in describing the survey and the results.

## Chapter 3

Hill, M., Sharma, M. D., (2015). Variation in students’ representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the Representational Fluency Survey. *Eurasia Journal of Mathematics, Science & Technology Education*, 11(6)

### *My Contribution*

This chapter used the same data as the publication in Chapter 2. I developed the analysis techniques used in this publication with guidance from Associate Professor Manjula Sharma. I was responsible for analysing the results and for writing the publication.

## **Chapter 4**

Hill, M. & Sharma, M. D. (2015). Research-based worksheets on using multiple representations in science classrooms. *Teaching Science*, 61(3), 37-46.

### *My Contribution*

The idea for this investigation was conceived by Dr John Airey. I developed the materials and carried out the investigation. I was responsible for analysing the results and for writing the publication.

## **Chapter 5**

Hill, M., Sharma, M. D., Xu, Y. (Submitted). Pre-lecture online learning modules in university physics – Student participation, perceptions, and subsequent performance. Manuscript submitted for publication.

### *My Contribution*

I conceived the idea for this investigation. I implemented the modules and collected the results. I directed the analysis which was primarily conducted by Yingying Xu. I was responsible for writing the publication.

## **Chapter 6**

Hill, M., Sharma, M. D., Johnston, H. (2015). How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *Eur. J. Phys.* 36 (2015) 045019.

### *My Contribution*

Associate Professor Manjula Sharma and I collaborated to develop the structure of the quasi-experiment. I created the modules, facilitated their implementation and collected all results. I was responsible for analysing the results and for writing the publication.

## Conference presentations and invited talks

- Hill, M. (2012, August) *Physics education and the standard model of matter*. Year 12 Physics focus day, Barker College, Hornsby.
- Hill, M., Georgiou, H., Sharma, M. D. (2012, September) *Multiple representations provide a way of communicating the outcomes of an inquiry task*. National Forum: Enhancing Learning in Science through Inquiry and Technology, Sydney.
- Hill, M., *Bar graphs of pies, and pie graphs of bars: Representational ability of university science students* (2012, November) Institute for Innovation in Science and Mathematics Education, Career Pathways Seminar, Sydney.
- Hill, M., Sharma, M. D., O'Byrne, J. (2012, December) *Can we test representational ability independent of physics conceptual knowledge?* Talk presented at the Australian Institute of Physics Conference, Sydney.
- Hill, M., Sharma, M. D., (2013, July) *Communicating like a physicist: Teaching physics representations to high school students*. Workshop run at the Conference of the Australian Science Teachers' Association, Melbourne.
- Hill, M., Sharma, M. D., Johnston, H., (2013, September) *Developing Representational Skills through Weekly Online Learning Modules: The impact of teaching multiple representations across a semester of 1st year university physics*. Talk presented at the Australian Conference of Science and Maths Education, Canberra.
- Hill, M. (2013, October) *Developing Representational Skills through Weekly Online Learning Modules: The impact of teaching multiple representations across a semester of 1<sup>st</sup> year university physics*. Talk presented at the Physics Teaching Symposium, School of Physics, the University of Sydney.
- Hill, M., Sharma, M. D., Johnston, H. (2014, July) *Developing representational fluency in undergraduate physics students through weekly online learning modules*. Talk presented at GIREP-MPTL 2014 International Conference, The University of Palermo, Palermo, Italy.
- Hill, M. (2014, October) *How does a scientist view the world? Why representational fluency is a vital skill for scientists*. Invited talk to the University of Sydney's Gifted at Talented Program, School of Physics, the University of Sydney.
- Hill, M., Sharma, M. D., (2014, December) *Scientific Representational Fluency: Defining, Diagnosing, & Developing*. Talk presented at the Australian Institute of Physics Conference, Canberra.
- Hill, M., Sharma, M. D., (2014, December) *Scientific Representational Fluency: Defining, Diagnosing, & Developing*. Talk presented at the Australian Mathematics Society Conference, Melbourne.
- Hill, M. (2015, August) *How Scientists Represent the World: The Standard Model*. Year 12 Physics focus day, Barker College, Hornsby.

## Conference poster presentations

Hill, M., Sharma, M. D., O'Byrne, J. (2011, September), Comparing Student's fluency using multiple representations (graphs, words and equations) with their university physics expertise. Poster presented at the Australian Conference on Science and Mathematics Education.

Hill, M., Sharma, M. D., Airey, J., Priemer, J. (2012, September) *Which representation is best? How students use representational information in problem solving*, Poster presented at the Australian Conference of Science and Mathematics Education.

Hill, M., Sharma, M. D., Johnston, H. (2014, September) *Scientific Representational Fluency: Defining, Diagnosing and Developing*. Poster presented at the Australian Conference of Science and Mathematics Education.

Hill, M., Sharma, M. D., Johnston, H. (2014, October) *Scientific Representational Fluency: Defining, Diagnosing and Developing*. Poster presented at the University of Sydney, Science and Technologies of Learning Research Fest, Sydney.

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# Chapter 1:

## Physics - who can understand it?

*The scene is a typical Australian high school. It is the end of 4<sup>th</sup> period and two hungry students emerge from the science classroom to walk their books to their locker, and retrieve lunch. These students, Timothy and Simon<sup>1</sup>, are both talented students – like many youth at high school – and are similar in many ways. They both like learning, playing sport, watching movies, and were together in the school musical the previous year. En route to their lockers the students debrief from their typical physics lesson; today they were introduced to Kirchhoff's Voltage and Current laws.*

**Timothy:** Do you think the oval will be open at lunch today? There has been a lot of rain.

**Simon:** I hope so, I need to use some energy after that last class.

**Timothy:** Were you bored?

**Simon:** No, not bored. It was interesting – it was just a really hard class this time. I understood the words, but I just don't get what we were trying to learn. Were you able to do all of those problems?

*This surprises Timothy completely – he found nothing difficult about the last hour. It took some thinking, but all he had to do was apply what their teacher was saying and everything seemed like it fell into place. In fact, he had been sitting next to Simon and Simon had given no indication of struggling with understanding.*

**Timothy:** Yeah, I didn't think it was too bad...

*Timothy realises that he doesn't want to suggest that Simon is unintelligent.*

...but you know – physics can be hard to understand. What about it did you find hard?

**Simon:** You could understand that? How! What is the secret? I don't know what in particular was hard about it – but I guess you are right – physics is hard!

---

<sup>1</sup> Coincidentally, the names of the author's siblings.

## 1.1 What is the secret?

How might we explain this scene which has been experienced and witnessed by so many in science education?

What is it about a student that allows them to understand the complex ideas found in physics?

Physics is widely regarded as a discipline containing ideas and problems that are difficult to understand. Many have tried and failed, though some students succeed at navigating the difficult path of attaining physics knowledge and thought. What is it about a person that enables them to understand these ideas when others struggle? What makes someone good at learning physics and participating in the discipline? Crucially, can we identify characteristics of successful physics learners? If so, can we develop these characteristics in others such that they also become successful learners?

This thesis chooses to focus on one potential candidate for such a characteristic, namely representational fluency or the ability of students to use scientific representations of information (e.g. graphs, words, diagrams, or equations) for meaning making and problem solving. It describes a journey of understanding more about representational fluency and its role in physics understanding. The work seeks to answer three questions that surround the issue of representational fluency:

1. What is representational fluency?
2. What role does representational fluency play in physics learning?
3. How can students' development of representational fluency be facilitated?

## 1.2 A brief introduction to *Representational Fluency*

### 1.2.1 *Representations in physics*

Physics, like many of the scientific disciplines, uses various means to present information and ideas. Examples of these means of presentation include graphs, words, diagrams, or equations. In much of the literature, and therefore in this thesis, these means of presentation are referred to as different *representations*. Often, the same information can be depicted through various representations (Figure 1.1). Each representation has particular ways that it is more helpful, or less helpful in different situations, depending on the content and also the purpose of the representation (is it for communication, problem solving, developing one's own understanding, etc). This is referred to as a representation's affordances.



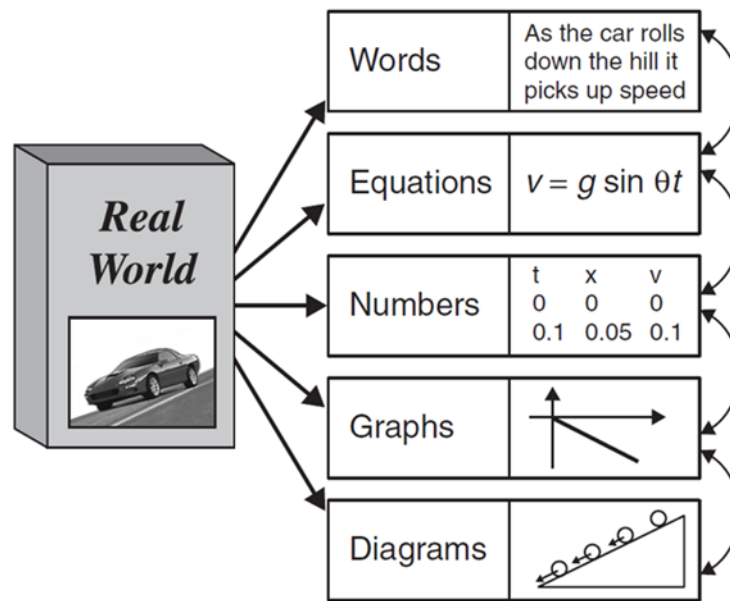


Figure 1.1: An illustration of how physics (similar to other scientific disciplines) uses multiple representations to depict the real world situation (Redish, 2003).

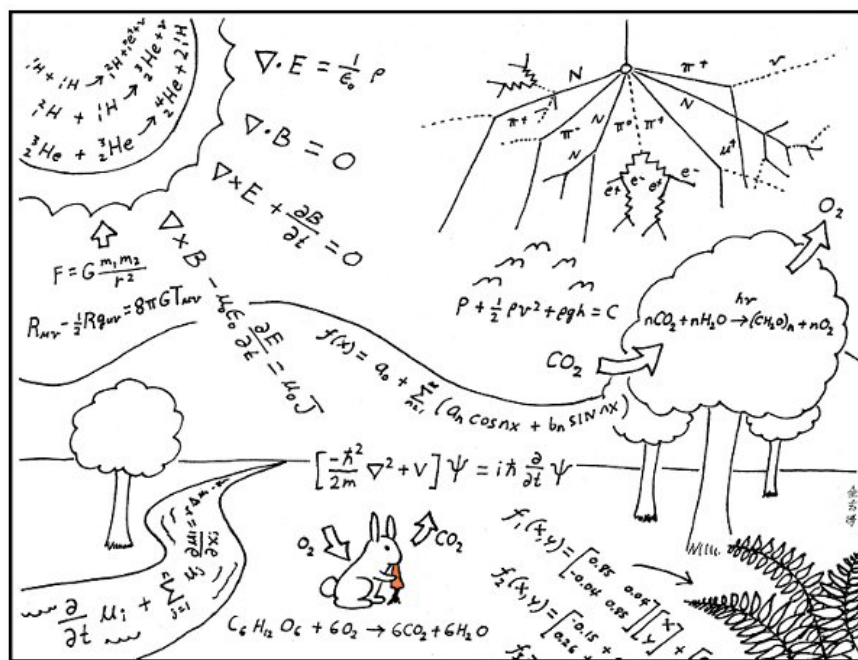
If multiple representations can be used to depict the same situation, the different affordances mean that not all representations are as helpful as each other to do so. As such, it is not surprising that multiple representations are utilised in physics teaching, instructional materials, research articles and popular communication. However, the use of multiple representations assumes that the intended audience can decipher this language of physics. In the case of physics students, they will require familiarity with individual representations and their affordances in order to understand material as it is presented to them. In addition, they must develop the skills or regulative techniques to be selective in choosing the combinations of representations they use in order to achieve the best outcome for their own physics understanding, problem solving, and communication. Students who successfully do this attain what we refer to as representational fluency.

### 1.2.2 Fluency with representations

As alluded to in the above section, learning to use representations in physics can be seen as similar to learning a new language. The person who has successfully mastered a language is commonly referred to as being *fluent* in that language. Language fluency is far more than being merely able to recognise and identify words and their meanings. It is also more than being able to comprehend what messages in that language say (though of course this is a pre-requisite to language fluency). Someone who is fluent in a language can converse fluidly and easily in that language. They can communicate with native speakers. They can understand the overall

meaning of a message even if they are unable to perfectly understand every word. Rather than translating each term or phrase back into a more familiar language, a fluent speaker will begin to comprehend in the new language, they will think in that language and some have even suggested that the mark of fluency is that they will dream in that language.

If representations are the language of physics, one must become representationally fluent before one can participate in the disciplinary discourse, otherwise physics will always seem like it is in a foreign language. Those who are representationally fluent will be able to understand representations and use them with ease. They will be able to process information in a variety of representations (or combinations of representations) and be able choose the best representations for a particular purpose. Even if they are unable to understand every single representation perfectly, they are confident in their ability to make meaning from the context. Importantly, someone who is representationally fluent will begin to think in the language of representations, they will view the world through a representational lens. This is helpfully depicted in the cartoon “how scientists see the world” (Figure 1.2).



**This is how scientists see the world.**

Figure 1.2: Adapted from the "World View" comic by Abstruse Goose (<http://abstrusegoose.com/275>).

Therefore, the simplified definition of representational fluency that is used in this thesis is as follows:

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*Representational Fluency (Physics):*

The ability to work within and translate among representations used in the physics discipline with ease<sup>2</sup>.

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### **1.3 Representational fluency in the literature**

Each of Chapters 2-6 as journal articles include literature reviews. In order to avoid repetition the five separate literature reviews are not compiled here in the introduction. This section focuses exclusively on how research into representational fluency has grown from the literature but until this thesis representational fluency has not been formally identified or defined. Detailed literature reviews on topics ranging from the benefits of using multiple representations, the difficulties of teaching representations, alternative theories regarding multiple representation use, diagnostic testing in science, instructional design, and blended learning, can be found in the following chapters.

Recently, there has been increasing research both into how students use particular representations (e.g. free body diagrams) and into how such representations can best be used for problem solving, communication, and scientific learning. An example of this is Rosengrant, Van Heuvelen, and Etkina's study (2009) finding that students who draw free body diagrams correctly are more likely to solve exam problems correctly and that students draw free body diagrams in order to both help solve problems and as an evaluative tool. Less common, however, is research into the use of not one but *multiple* representations.

For practitioners, teaching methods are being developed and tested to help scaffold the use of particular representations. Research has given helpful insights into how students learn the most effective ways to use graphs (Beichner, 1994; Bowen, Roth, & McGuinn, 1999; Roth & Bowen, 1999; Roth & Bowen, 2003; Woolnough, 2000), free body diagrams (Fisher, 1999; Rosengrant, Van Heuvelen, & Etkina, 2005; Wendel, 2011), equations (Bieda & Nathan, 2009; Leung, Low, & Sweller, 1997; Sherin, 2001) and the like, and especially into how to avoid common pitfalls with using these representations. However, this research invariably focuses on students learning particular types of representations, rather than improving students' ability in using the whole range of representations they need as their education progresses.

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<sup>2</sup> Adapted from Bieda and Nathan (2009).

Finally, those who research multiple representations tend to use three inter-related but distinct terms. These three ideas are known as *metavisualisation* (Gilbert, 2004), *representational competence* (Hand & Choi, 2010; Stieff et al., 2011) and *metarepresentational competence* (diSessa, 2004). See Chapter 3 for a more detailed discussion of different perspectives on multiple representation use. Representational fluency is an amalgamation of these three ideas, drawing on elements of each (Figure 1.3).

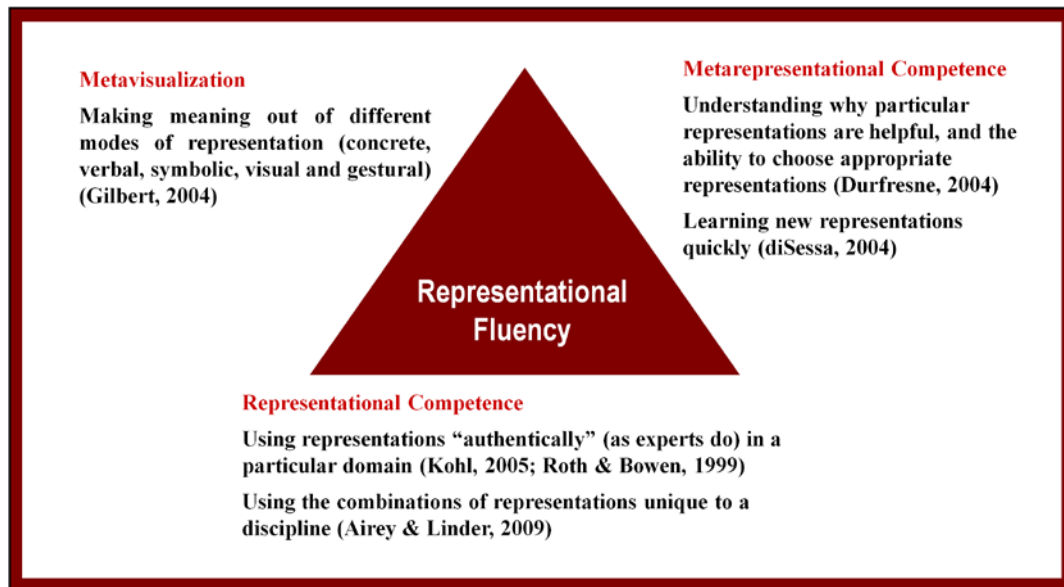


Figure 1.3: Representational fluency - incorporating three views of multiple representations

Airey and Linder (2009, p.27) have suggested that “Fluency in a critical constellation of modes of disciplinary discourse may be a necessary (though not always sufficient) condition for gaining meaningful holistic access to disciplinary ways of knowing”. The term “critical constellation” refers to a threshold level of ability in not only one but some combination of representations for a discipline. This thesis uses this framework in drawing a parallel between representational fluency and this threshold ability to engage with the combination of scientific representations as a person progresses within one disciplinary.

## 1.4 Contribution to the literature

Therefore, this thesis seeks to contribute to the literature in three novel ways. This research:

- Shifts the focus from researching particular, individual representations to integrated research into multiple representations.
- Consolidates different perspectives on multiple representations into a generic idea of “Representational Fluency”, specifically through the creation and use of a survey to measure representational fluency.
- Provides practical, research-driven teaching methods to facilitate students improving their representational fluency in a technologically driven age of education.

## 1.5 Outline of the thesis

### 1.5.1 Phase 1: Defining and diagnosing representational fluency

The first part of this thesis recounts the development of the *Representational Fluency Survey* (RFS), which was used to probe the levels and features of representational fluency in hundreds of students from a broad spectrum of undergraduate students at the University of Sydney. There are three implications arising from the creation and implementation of the RFS at the University:

4. The RFS now exists and has been shown to be a valid and reliable diagnostic test available for use.
5. A deeper understanding of the characteristics of representational fluency has been attained, including evidence for representational fluency being an important contributor to success in university physics.
6. A cross-sectional analysis of the representational fluency of physics students at the University of Sydney was mapped. This also resulted in students who had demonstrated low levels of representational fluency being identified to enable early intervention.

The first of these implications is described in Chapter 2 of the thesis with the paper titled “Developing and Evaluating a Survey for Representational Fluency in Science” (Hill, Sharma, O’Byrne, & Airey, 2014). Points 2 and 3 are elaborated on in Chapter 3 with a follow up paper “Variation in students’ representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the Representational Fluency Survey” (Hill & Sharma, In press).

An important implication of the development and use of the RFS was the identification of a group of first year physics students with significantly lower levels of representational fluency than their fellow first year colleagues who had greater success in physics generally and a higher level of representational fluency. The results of the succeeding research suggested that these students may find progressing through senior years of physics difficult without improving their level of representational fluency. This was not seen as a satisfactory situation, which instigated the second phase of the research into defining, diagnosing and developing representational fluency.

### 1.5.2 Phase 2: Developing representational fluency

In this phase, the research turns to an investigation into how representational fluency can be developed, specifically for first year university physics students who have been identified as having a lower level of representational fluency than may be required for further physics study. A number of factors had to be considered in the construction of an educational resource. Content and delivery method were explored separately before implementing a large scale teaching intervention to support first year students and to conduct first hand research into how we may be able to improve students' representational fluency.

Educational worksheets were developed from a range of previous research studies and these were trialled at two high schools with year 12 physics students (a broadly similar stage of physics education as first year university physics students). The trials were used to iteratively develop the design and this process is presented in Chapter 4 as a paper entitled "Research based worksheets on using multiple representations in science classrooms" (Hill & Sharma, 2015). The result was a framework and initial sets of worksheets that had been shown to develop characteristics of representational fluency as identified by the use of the RFS.

These worksheets needed to be in a form that was sufficiently scalable to allow up to 900 first year university students to complete multiple exercises throughout the semester. The desired format was transforming the worksheets into weekly *online learning modules* intended to cue in students to particular representations that were to be used in the upcoming week's lectures. This was a form of flip-lectures where students are prepared for lecture-based instruction by material delivered to them before face-to-face class time. To ensure that this was a suitable medium of delivery for educational content, a preliminary analysis was completed on how students participated in online learning modules with no consideration of the specific content. Chapter 5, in the form of the paper "Pre-lecture online learning modules in university physics – student participation, perceptions and subsequent performance" (Hill, Sharma, & Xu, 2015), explains how there were high levels of engagement from first year physics students in the modules and

the students themselves indicated changes in the way they were learning in lectures. The conclusion was that this medium was appropriate for an attempt to develop a particular aspect of a students' physics learning.

The preparation for the intervention, described in Chapters 4 and 5 led to a research-based, quasi-experimental study to try and improve the representational fluency of first year physics students. The students were randomly assigned to one of two groups; a treatment group who received representations-based instruction in the form of online learning modules, and a control group who received online learning modules on upcoming physics concepts to be covered in lectures (topics like different types of friction or energy). The conceptual knowledge and representational fluency of the students from each group were measured at the start and end of the semester-long experiment to determine the relative effectiveness of each set of modules. It was found that while both sets of modules resulted in learning gains on both the conceptual and representational fluency tests, students who had completed the online learning modules focussed on physics representations had greater gains in the area of representational fluency. This demonstrates that representational fluency can be improved through physics instruction, and more particularly that instruction targeting physics representations can change how students use these representations in their learning. The successful intervention is described in Chapter 6 in the paper "How online learning modules can improve the representational fluency and conceptual understanding of physics students" (Hill, Sharma, & Johnston, 2015).

In Chapter 7, the thesis concludes with an exploration of the implications of this body of work, particularly the contribution to the body of literature and opportunities for future research. There are also many ways in which the research can inform teaching practices and educational design, demonstrating the immediate practical outcomes of the work.

### *1.5.3 A note on thesis structure*

As chapter 2, 3, 4 and 6 are accepted or published papers, and chapter 5 is a paper to be published, they are included in this thesis with the same words and format as were accepted through the peer-review process. This means that the way that this thesis is arranged is atypical. Rather than having one literature review or reference list, each chapter has its own literature review and references.

In a similar way, the numbering of figures and tables restarts each chapter in order to preserve much of the published form.

In contrast, the appendices are not presented and repeated at the end of each chapter rather they have been grouped together as the Appendices A-D of the thesis.

## 1.6 References

- Airey, J., & Linder, C. (2009). A Disciplinary Discourse Perspective on University Science Learning: Achieving Fluency in a Critical Constellation of Modes. *Journal of Research in Science Teaching*, 46(1), 27-49. doi: 10.1002/tea.20265
- Beichner, R. J. (1994). Testing student interpretation of kinematic graphs. *American Journal of Physics*, 62(8), 750-762.
- Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637-650.
- Bowen, G. M., Roth, W. M., & McGuinn, M. K. (1999). Interpretations of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching*, 36(9), 1020-1043.
- Fisher, K. (1999). Exercises in drawing and utilizing free-body diagrams. *The Physics Teacher*, 37(7), 434-435.
- Gilbert, J. K. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2, 115-130.
- Hand, B., & Choi, A. (2010). Examining the Impact of Student Use of Multiple Modal Representations in Constructing Arguments in Organic Chemistry Laboratory Classes. *Research in Science Education*, 40, 16. doi: 10:1007/s11165-009-9155-8
- Hill, M., Sharma, M. D., O'Byrne, J., & Airey, J. (2014). Developing and Evaluating a Survey for Representational Fluency in Science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 22(6), 22-42.
- Hill, M. & Sharma, M. D. (2015). Research-based worksheets on using multiple representations in science classrooms. *Teaching Science*, 61(3), 37-46.
- Hill, M., Sharma, M. D., Johnston, H. (2015). How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *Eur. J. Phys.* 36 (2015) 045019.
- Hill, M., Sharma, M. D., Xu, Y. (2015). Pre-lecture online learning modules in university physics – Student participation, perceptions, and subsequent performance. Manuscript submitted for publication.
- Hill, M., Sharma, M. D., (In Press). Variation in students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the Representaitonal Fluency Survey. *Eurasia Journal of Mathematics, Science & Technology Education*



- Leung, M., Low, R., & Sweller, J. (1997). Learning from equations or words. *Instructional Science*, 25(1), 37-70.
- Redish, E. F. (2003). *Teaching physics: with the physics suite*: John Wiley & Sons Hoboken, NJ.
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2005). Free-body diagrams: Necessary or sufficient? In J. Marx, P. Heron & S. Frankin (Eds.), *2004 Physics Education Research Conference* (Vol. 790, pp. 177-180).
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2009). Do students use and understand free-body diagrams? *Physical Review Special Topics-Physics Education Research*, 5(1). doi: 10.1103/PhysRevSTPER.5.010108
- Roth, W. M., & Bowen, G. M. (1999). Of Cannibals, Missionaries, and Converts: Graphing Competencies from Grade 8 to Professional Science Inside (Classrooms) and Outside (Field/Laboratory). *Science, Technology and Human Values*, 24(2), 179-212.
- Roth, W. M., & Bowen, G. M. (2003). When are graphs worth ten thousand words? An expert-expert study. *Cognition and Instruction*, 21(4), 429-473.
- Sherin, B. L. (2001). How students understand physics equations. *Cognition and Instruction*, 19(4), 479-541.
- Stieff, M., Hegarty, M., & Deslongchamps, G. (2011). Identifying Representational Competence With Multi-Representational Displays. *Cognition and Instruction*, 29(1), 123-145. doi: 10.1080/07370008.2010.507318
- Wendel, P. (2011). Adding value to force diagrams: Representing relative force magnitudes. *The Physics Teacher*, 49(5), 308-311.
- Woolnough, J. (2000). How do Students Learn to Apply Their Mathematical Knowledge to Interpret Graphs in Physics? *Research in Science Education*, 30(3), 259-267.
- World View. [Graphic illustration]. Retrieved from <http://abstrusegoose.com/275>



## **Chapter 2:**

# **Developing and Evaluating a Survey for Representational Fluency in Science**

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### **2.1 Abstract**

Various representations, used for communication and problem solving in science, are an unspoken prerequisite for learning, understanding, and participating in scientific communities. Work has been done highlighting the importance of competence in particular multiple representations in science learning, the specific representational practices for the different disciplines, and to translating between representations. However, limited attention has been paid to obtaining a threshold level of ability in, not only one, but some combination of representations for a discipline. This notion leads to generic fluency with various representational forms used in science, with discipline specific expertise – representational fluency nuanced for a particular discipline. The aim of this study is to examine representational fluency nuanced for physics. This is achieved through the development of a survey instrument, the Representational Fluency Survey (RFS), consisting of representationally rich multiple choice items obtained predominantly from various validated sources. The survey was implemented with 334 students from first year to postgraduate at an Australian university to capture a cross-sectional snapshot of representational fluency nuanced for the specialization of physics. Reliability and validity were determined through standard statistical analysis and through consultation with experts. The results show that representation fluency develops across the years, and that there is a threshold associated with fluency. However, our study does not comment on causality. We demonstrate that in coalescing existing research on multiple representation while paying attention to disciplinary differences is a potentially fruitful pursuit. The RFS test of representational fluency in science is tailored to be used with university physics students but illustrates that adaption for other specializations may be possible.

## 2.2 Introduction

Societies, and particularly academic communities, rely on individuals and groups being able to communicate effectively. The purpose of using representations e.g. graphs, diagrams, mathematical equations etc. is often in order to communicate more effectively or efficiently, whether it is in collective understandings of financial reports, advertising campaigns or scientific research. These “communities of discourse” use common language and representations (visual, linguistic and symbolic) to communicate (Driver, Asoko, Leach, Mortimer, & Scott, 1994). For science, Airey (2009, p.52) defined the term “disciplinary discourse” to describe the set of representations. He suggested that in order for disciplinary outsiders to become part of an academic discourse community, they must become fluent in disciplinary discourse (Figure 2.1). Airey and Linder (2009, p.27) have suggested that “Fluency in a critical constellation of modes of disciplinary discourse may be a necessary (though not always sufficient) condition for gaining meaningful holistic access to disciplinary ways of knowing”. The term critical constellation refers to a threshold level of ability in, not only one, but some combination of representations for a discipline. Multiple representation fluency is, thus, this threshold ability to engage with the combination of science representations as one progresses within one disciplinary discourse.

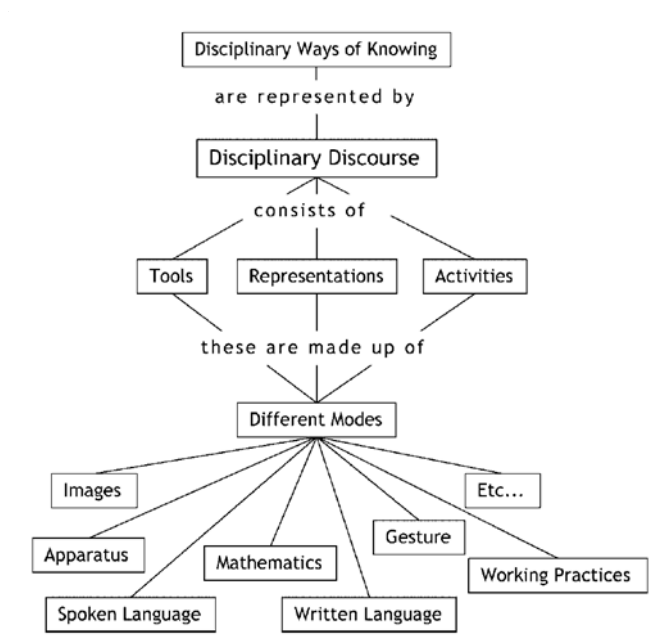


Figure 2.1: The different representational modes required for participation in a disciplinary discourse. These include images, spoken and written language, mathematics, gestures and working practices. Students must develop fluency in a ‘critical constellation’ of these modes to be a part of the community of discourse (Airey & Linder, 2009).

Within sciences, therefore, the multiple representations that make up disciplinary discourse are critical for understanding content, communicating, and for practices including modelling, problem solving and prediction to applications (Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Schwartz, Hug, & Krajcik, 2009).

From the 1970's to the 1990's multiple representations have been embedded (presented but not explicit) in research on problem solving (de Jong & Ferguson-Hessler, 1986; Larkin, McDermott, Simon, & Simon, 1980a) and novice expert studies (Larkin, McDermott, Simon, & Simon, 1980b). The Force Concept Inventory (Hestenes, Wells, & Swackhammer, 1992) paved the way for multiple choice concept surveying of large numbers of students. Such surveys indirectly exploit multiple representations to elicit student understandings. The utility of multiple representations in these areas demonstrate their centrality within science discourse, resonating with the need for developing fluency in a range of modes (Figure 2.1). More recent qualitative studies explore student engagement with the different representations and fluency to translate between them (Fredlund, Airey, & Linder, 2012; Gilbert, 2008; Kozma, 2003; Rosengrant, Van Heuvelen, & Etkina, 2006; Woolnough, 2000). Building on this research, the question of whether students develop generic fluency in a range of science-specific multiple representations which are tuned to a particular discipline, but also somewhat independent of that discipline, has not been broached. In other words, can physics students answer not only physics, but also chemistry and biology questions that require fluency with multiple representations that are common within physics? To investigate this question, we designed a survey, where fluency in a number of representations is tested. In the survey the information necessary for answering the individual survey items is provided within the question. So the physics student has all the information necessary to answer the biology question, using the representation. Of course the survey is for specialization in physics so there are more physics questions and there are subtleties associated with the interplay between the physics and the representation utilized. Our focus in providing all the content information is an attempt to keep content, including conceptual knowledge, somewhat independent of the multiple representational fluency that we are interested in.

This paper describes the development of the survey and its subsequent evaluation when used to investigate a group of undergraduate physics students' fluency with representations.

The specific aims are to

- create a survey to measure scientific representational fluency amongst university physics students; and
- evaluate the survey using relevant statistical analysis.

This study uses a mixed methods approach - quantitative data to statistically analyze the survey and qualitative data considering how students approach the questions.

## **2.3 Background**

### *2.3.1 Multiple representations*

This refers to the many ways that information can be presented. Examples of representations include the spoken or written word, symbols, equations and images (graphs, photographs, diagrams, maps, plans, charts, tables and statistics). Using *appropriate* representations can be helpful because they can be memorable (Aldrich & Sheppard, 2000), overcome cognitive load limitations (Ainsworth, 2006), and portray relationships where they are not obvious (Bowen, Roth, & McGuinn, 1999; Goldman, 2003). In addition, the construction of representations has also been linked with successes in learning science (Prain & Tytler, 2012). The more abstract representations can be seen as short-hand, condensed notation employed by a discipline in its discourse such that fluency with these is central to successfully entering the discipline (Vygotsky, 1978). Hence, due to the co-dependence of representational fluency and disciplinary learning, physics experts are more fluent than novices with physics multiple representations. However, to our knowledge, no attempt has been made to examine generic representational fluency and its interplay with subject specialization.

The study of Chi, Feltovich, & Glaser (1981) highlights the impact of representational format on novice and expert students' perceptions of physics problems. They asked eight PhD students ("experts") in physics and eight undergraduate students with only one semester of physics ("novices") to sort physics problems into categories of their choosing. The experts sorted the problems according to the underlying physics concepts such as conservation laws whilst the novices grouped the problems according to the diagrammatical format relating to the given problem and whether the corresponding diagrams were similar. It was concluded that novices were distracted by the surface or representational features and were less likely to identify the underlying concept of the problem. Experts demonstrate increased ability to translate between representations when asked to reproduce problems (de Jong & Ferguson-Hessler, 1991). Being able to translate between representations, experts are able to use the variety of tools (epistemic

forms) at their disposal to attempt to solve the problem. The suggestion is that there is a threshold level of ability in a combination of representations necessary for solving a given disciplinary problem, representational fluency students need to learn to successfully solve the problem (Airey & Linder, 2009).

Dufresne, Gerace, & Leonard (2004) developed a teaching strategy to illustrate that the representations students choose to use are not always the ideal ones and to help students consider using non-algebraic representations when solving problems. University physics students were given problems and asked to solve them multiple times using strobe diagrams (a time-lapse representational format), algebra and graphs. The students commented that particular representations made solving the problem easier even though they wouldn't have used that representation if they had the choice. This suggests that not only do students require a threshold level of ability in particular representations, but the ability to choose the most appropriate representation to generate a solution, that is to recognise the disciplinary affordances of the different representations (Airey & Linder, 2009; Fredlund et al., 2012), what we term representational fluency.

### *2.3.2 Representational Fluency*

Aspects of representational fluency appear in the literature through three related perspectives. If *visualization* is defined as the process of making meaning out of representations, *metavisualisation* is someone fluent in visualization, or able to “acquire, monitor, integrate, and extend, learning from representations” (Gilbert, 2008, p5-6). This perspective of representational fluency focuses on particular criteria including understanding of *all* representations across three dimensions (1D such as equations, 2D such as most graphs, 3D such as physical objects) and three levels (macro, sub-micro and symbolic). *Metarepresentational competence* (MRC) is another perspective of representational fluency. The primary focus of MRC is a metacognitive approach to representations where individuals are able to understand the rationale and design strategies of creating particular representations. Displays of MRC include the ability to create or invent new representations, to understand, explain and critique representations for adequacy of use and learning new representations quickly (diSessa, 2004). *Representational Competence* (Kohl & Finkelstein, 2005; 2006b) looks more closely at the domain specific constellation of representations, working exclusively in physics, chemistry or biology. The term is also used of ability in particular representations as opposed to cross-representational competence. However, multi-representational instruction and simulations have been identified as methods of developing representational competence (Stieff, 2011).

*Representational fluency*, as described in this paper, is an integration of these perspectives. There are elements of each perspective, such as the importance of translating between representations and making meaning in metavisualization, the metacognitive skills required for metarepresentational competence, and a recognition of domain specific representational competence. What is unique about representational fluency is that it is a cross-disciplinary threshold level of ability that incorporates a level of comfort (hence fluency) with using a variety of representations for a given purpose within a discipline of specialisation.

### *2.3.3 Diagnosing representational fluency*

The most common way to investigate representational use is to leverage either individual problems, or novel combinations of problems to investigate particular facets of representational reasoning (Kohl & Finkelstein, 2006a; 2008; Meltzer, 2005; Woolnough, 2000). Meltzer (2005) used individual problems expressed using various representations to compare how well students would perform on the same physics question (similar to Dufresne et al. (2004)). The results indicated that students in general prefer questions expressed with verbal reasoning, and that female students had more difficulty than male students answering questions presented in a graphical format. The ‘far end of the spectrum’ is observational data, including viewing student work and watching interviews which undoubtedly provides benefit and illumination, but does not allow for large scale quantitative comparisons of representational use and/or understanding across institutions and student groups (Fredlund et al., 2012; Rosengrant et al., 2006; Sia, Treagust, & Chandrasegaran, 2012). To date, there is no investigation into the development of representational use (and/or understandings) with incremental increases in disciplinary expertise, but there are studies that compare experts with novices. This paper attempts to fill this void by providing a cross sectional snapshot of representational fluency.

In contrast to small scale (often qualitative) studies such as those described above, *diagnostic tests* for large classes offer a different way of examining student competencies. Concept inventories have gained in popularity since the 1990s with the formation and extensive use of the Force Concept Inventory (FCI) (Hestenes et al., 1992). There have been extensive conceptual tests developed in a wide variety of disciplines. Concept inventories in physics and engineering may be the most varied and popular (Beichner, 1994; Ding, Chabay, Sherwood, & Beichner, 2006; Muller, Bewes, Sharma, & Reimann, 2008; Streveler, Miller, Santiago-Roman, Nelson, Geist, & Olds, 2011; Tongchai, Sharma, Johnston, Arayathanitkul, & Soankwan, 2009).

One particular type of diagnostic test, using two-tiered multiple choice questions, examines not only student selections from multiple choices but also obtains their reasons for choosing their



answer. These have been used to gain insight into student thinking on topics such as thermodynamics (Rollnick & Mahooana, 1999), biology (Haslam & Treagust, 1987), and logical thinking (Tobin & Capie, 1981). Three-tiered multiple choice surveys can also be found in the literature, typically adding student confidence as a further factor (Caleon & Subramaniam, 2010). Multi-tiered surveys have been shown to be a valid method of diagnosing student conceptual knowledge, specific misconceptions, and variables of student thinking (Tamir, 1989).

There are also a series of surveys focused on a single type of representational use, often in a particular context. Beichner's survey on kinematic graphs investigates graphs but in a highly contextualized situation of interpreting kinematic questions (TUGK) (Beichner, 1994). Another recognised representation-based survey is the Purdue Spatial Visualization of Rotation (PSVT:R) test (Bodner, 1997) investigating spatial ability for introductory chemistry. These, along with the qualitative papers on representational reasoning with regards to individual questions (Fredlund et al., 2012), are all related to specific representations and not directly about the threshold level of ability in one or more representations necessary to access disciplinary discourse.

Therefore, the Representational Fluency Survey (RFS) presented in this paper is designed to be the first diagnostic test of the threshold level of ability in a range of representations necessary to access disciplinary discourse for the domain of university physics.

## **2.4 Iterative Development of the Survey**

### *2.4.1 Philosophy of the Survey*

Practitioners often suggest that students who have learning experience in one scientific domain find learning in another scientific domain somewhat easier than students with no science experience. This aligns with the notion of the disciplinary discourse one gets accustomed to in science, suggesting there is a generic element to students' fluency in a repertoire of multiple representations. In addition, as students specialize in their science subjects, the discourse within that discipline specializes too, such that a biology student is accustomed to a nuanced discourse within the sciences. In this study we focus on science multiple representations nuanced for a physics specialization. The problem questions on the survey are from across the sciences but have been selected for the physics specialization (see Appendix A). Each problem contains all the explicit content including conceptual knowledge information necessary to answer the problem. This, combined with the choice of problems from different sciences, facilitates a level

of decoupling of the multiple representations from explicit content including conceptual knowledge. The primary goal of the survey was therefore to examine physics students' fluency with different representations somewhat decoupled from testing how well they know physics concepts.

This posed two key challenges. Firstly, which representations should be included and secondly, how will *representational fluency* be examined. "Representational fluency" is the threshold level of ability in, not only one, but a combination of representations, such as graphs, words, equations and diagrams, to effectively solve problems. This could involve solving problems (i) presented in a particular representational format, (ii) requiring a particular representational response, or (iii) allowing for alternative representations to help elucidate the information presented in a problem.

The representational reasoning selected from within the science discourse as providing affordances for the physics specialization are:

- Graph-based – A symbolic/visual representation
- Word-based – A linguistic representation
- Equation-based – A symbolic representation focused on arithmetical and algebraic equations
- Diagram-based – A visual representation

Problems were presented with different combinations of either graph-based and/or word-based representations but were designed so that all four sets of representations (and potentially others not listed) may be helpful for students to use during the process of solving the problem.

The second challenge in measuring representational fluency was addressed by working with a team of experts, strategically sourcing questions, utilizing a two-tier structure to the problems (Haslam & Treagust, 1987) and a three-tier scoring scheme (a variation of (Caleon & Subramaniam, 2010), checking with interviews and utilizing an iterative development process. The development process involved the four phases shown in Figure 2.2 and described in the sections below.

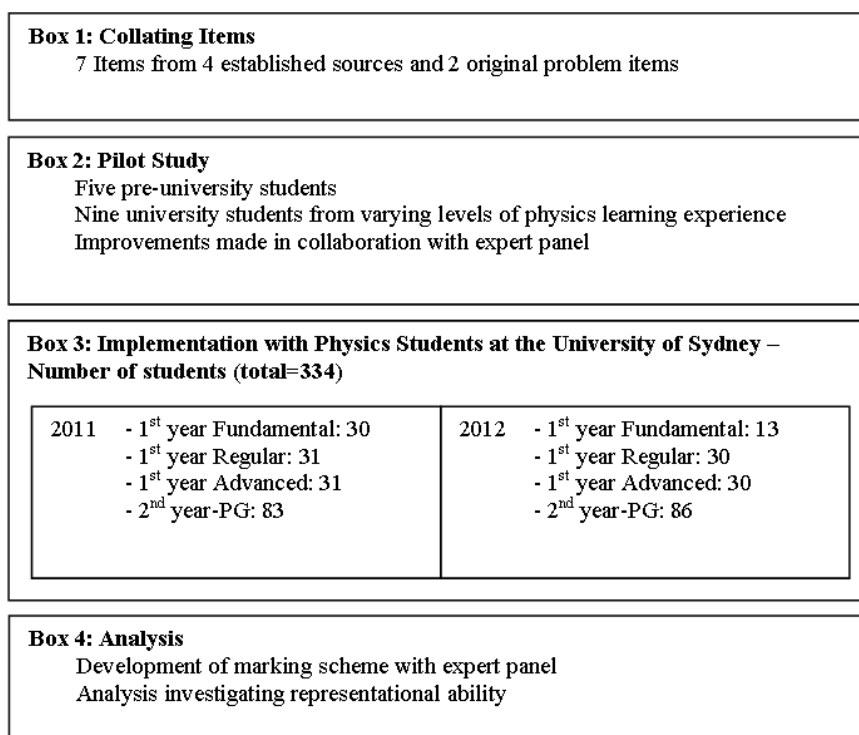


Figure 2.2: Flow chart summarizing the development and use of the survey.

#### 2.4.2 Collating items

The criteria for problem items (hereafter referred to as “items”) was for them to utilize representations from the science discourse with affordances for physics specialization. Furthermore, the items had to contain all the information necessary and require minimal extra content, including conceptual knowledge, such that every student doing the survey (covering all levels of physics student at university) would be able to answer correctly, provided that they could use the representations fluently. The items were to be typically multiple choice and allow for various pathways for students to get to the answer utilizing multiple representations.

It was initially decided not to generate items but to choose from those available and to scrutinize the existing data for those questions. The existing data included an item’s difficulty and discrimination from published and unpublished results, including local data (the known difficulty for some questions is presented in table 2.1). After an extensive search through a range of question sets and surveys, four sources were used to generate a short list of nine possible items that met the required criteria. With permission, items were selected from the Rio Tinto Big Science Competition<sup>3</sup> senior paper 2007, and The Australasian Schools Science

<sup>3</sup> The Big Science Competition is run in many Australian, New Zealand and Singaporean high schools by Australian Science Innovations, a not for profit organization committed to providing high quality science extension programs for students and teachers. Further information on Australian Science Innovations can be found on their website: [www.asi.edu.au](http://www.asi.edu.au).

Competition<sup>4</sup> 2003 and 2004 papers. These papers are produced by established academic organizations which undertake thorough testing with high school students validating the questions' difficulty and discrimination. Three items were drawn from well established surveys in published literature. Two were selected from the Force and Motion Concept Survey (FMCS) (Thornton & Sokoloff, 1997), along with one item used by Beichner (1994) on testing student understanding of kinematic graphs (another established survey). Finally, two items were specially created, designed to allow for varied representational choices for how students gave an explanation in their answer.

The representations in the survey were in the format of three graph-based items (problems based around interpretations of graphs with some supporting words), three word-based items, two items involving both word and graph-based representations, and one item requiring the construction of a graph. Each had the capacity for students to include at least three different types of representations in their explanations of how they attained their answer (See table 2.1). The items were compiled into an initial survey which was put through an iterative process of two pilot studies, and cross-checked by a panel of experts.

#### *2.4.3 Pilot Study*

To investigate whether the items were sufficiently decoupled from physics content including conceptual knowledge, the initial survey was administered to a group of students undertaking a preparatory program prior to studying science at University (Box 2 in Figure 2.2). They had limited background experience in physics or other science subjects. Based on the student responses, the suitability of each item was assessed by a panel of ten experts in the field of physics education research, five of whom have over thirty years of physics education experience. The assessment was based on the criteria that when students answered a question incorrectly, their explanations revealed that their misunderstandings were due to misreading the graphs or verbal information, or mistakes while working with various representations rather than their limited background in physics or science. This analysis of the pilot study supported the premise that the survey was successful in appropriately decoupling physics content, including conceptual knowledge from fluency with representations.

To further confirm that the questions had a sufficient difficulty and level of discrimination for undergraduate physics students, the survey was then deployed to 9 randomly selected university

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<sup>4</sup> The Australasian Schools Science Competition (ASSC) was produced annually by the Educational Testing Centre, University of New South Wales (UNSW). ASSC is now published as the International Competitions and Assessments for Schools (ICAS) by Educational Assessment Australia, an education group of UNSW Global Pty Limited, a not-for-profit provider of education, training and advisory services and a wholly owned enterprise of UNSW.

students covering various levels of undergraduate physics learning experience. Again, the expert panel was engaged in this process. On average, students answered 7.8 of the 9 questions correctly, which was higher than expected. There was a trend where students from higher levels of physics learning experience scored better than novice students. As a result, two items which had both a very high success rate, and where most students used the same representations in their explanation, were removed. This increased the sensitivity of the instrument and resulted in the seven items of the final survey. Once students' explanations were taken into account, the difficulty and discrimination of the survey was deemed appropriate to be run with all levels of undergraduate physics students at the university.

#### 2.4.4 Final survey

The link to the full survey can be found in Appendix A but it is summarized in table 2.1, which describes the main representations which constitute the item, the most common representations utilized in student explanations, the original source, and difficulty from previous studies (table 2.1). Each item is two-tiered (Haslam & Treagust, 1987) and a three-tiered scoring scheme, as described below, has been utilised (a variation of (Caleon & Subramaniam, 2010)).

Table 2.1: Summary of each item in the RFS

<b>Item number</b>	<b>Main representation format in information</b>	<b>Representation format in student explanations</b>	<b>Source</b>	<b>Difficulty<sup>5</sup></b>
1	Graphs	Words Graphs Equations	Beichner (1994)	16% Of USA high school and university students tested
2	Words	Words Equations Diagrams	FMCE (Sharma, Johnston, Johnston, Varvell, Robertson, Hopkins, Stewart, Cooper, & Thornton, 2010; Thornton & Sokoloff, 1997)	17% Of 1 <sup>st</sup> year fundamental physics students at the University of Sydney (Sharma et al., 2010)
3	Graphs	Words Equations	Australasian Schools Science Competition 2003, Year 12, Q37	42.7% Of Australian, year 12, high school students tested
4	Graphs	Words Graphs Equations	Australasian Schools Science Competition 2004, Year 12, Q32	44% Of Australian, year 12, high school students tested

<sup>5</sup> The difficulty is the percentage of students giving the correct answer in previous research.

5	Words	Words Graphs Diagrams	Written for this survey	n/a
6	Graphs	Words Graphs Equations	Written for this survey	n/a
7	Graphs, Words	Words Graphs Equations Diagrams	Big Science competition	35% Of Australian, year 12, high school students tested

## **2.5 Analysing student responses: marking and coding**

For each item, up to three marks were awarded corresponding to the three tiers. The criteria for success of each tier is:

- 1.1 Selecting the correct answer to the representationally rich multiple choice question-(referred to as the student's "*answer*")
- 1.2 A scientifically congruent explanation (using any representation), relevant to the question and leading to the answer. It may not always end up producing the answer chosen by the student. (referred to as the student's "*explanation*")
- 1.3 Consistency between the chosen "*answer*" and the "*explanation*" in that the explanation leads to the selected multiple choice answer, further demonstrating representational fluency. (referred to as a "*consistent/inconsistent explanation*")

The items were presented one per page and, for each item, the page involved space where students were invited to "Provide information supporting your answer or why you chose your answer" (Figure 2.3). The exceptions were questions 4 and 6 (see Appendix A), although each had space where extra explanation was required.

This multifaceted marking scheme allowed for examining the threshold level of ability in, not only one, but some combination of representations, that is a broad scale of representational fluency. A selection of five student responses for question 1 is presented and coded in Figure 2.3.

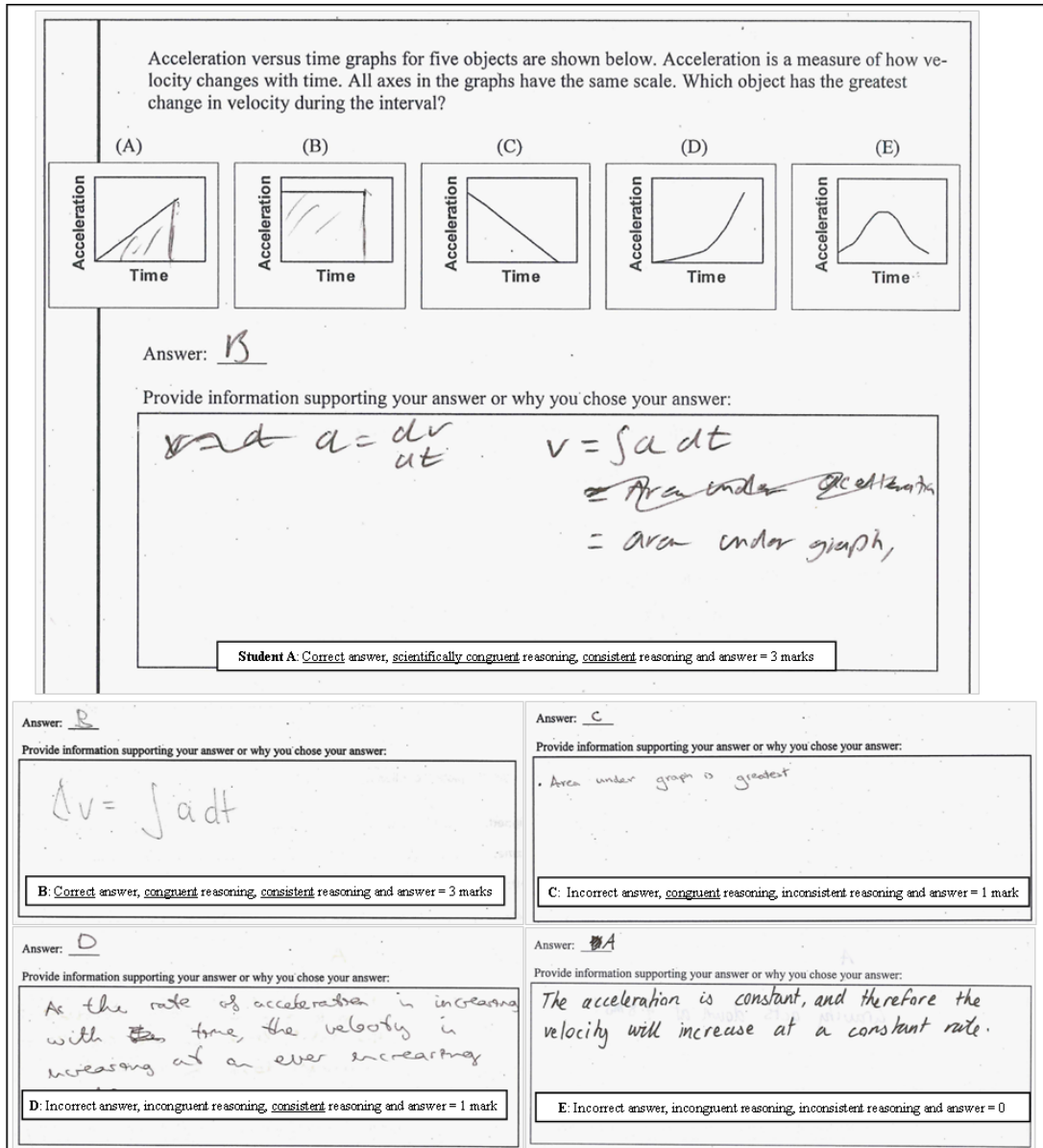


Figure 2.3. Five student (A-E) responses to item one showcasing various representational responses and demonstrating the use of the three-tier marking system in Table 2.2 below.

Table 2.2. Demonstration of the three-tier marking system. To be read with Figure 2.3.

Question Number →	1.1	1.2	1.3	Total
	Correct Answer	Scientifically Congruent Explanation	Consistent answer & explanation	
Student A	✓	✓	✓	3
Student B	✓	✓	✓	3
Student C	✗	✓	✗	1
Student D	✗	✗	✓	1
Student E	✗	✗	✗	0

For this question, students who chose the correct multiple choice answer “B” demonstrated an ability to interpret the words of the question and the graphs presented for the possible answers (Student A and Student B). Those students who were also able to give a scientifically congruent explanation in any representations, consistent with their answer, would attain a full three marks for that item. In Figure 2.3, Student A uses correct equations and graphical representations (describing that they are looking at the “area under the graph”) and by filling in the area under graphs and Student B also uses a correct equation.

Student C did not choose the correct answer (chose “C”) but did offer a scientifically congruent explanation, “Area under graph is greatest”. Therefore Student C will attain one mark for the explanation, but neither marks for the answer or the consistency.

Similarly, Student D will receive only one mark. This student’s answer “D” was consistent with the explanation: “As the rate of acceleration is increasing with time, the velocity is increasing at an ever increasing rate”. But the answer was incorrect, and the explanation, while a true statement in the same context area as the question, was not in any way leading to the answer and therefore the second-tier mark could not be awarded.

Finally, Student E did not achieve a mark on any tier. The answer was incorrect, the explanation was not scientifically congruent, and there was no consistency between the explanation and the chosen answer.

From here on, it will be considered that the seven item survey had a total of 21 “questions” referred to as questions 1.1, 1.2, 1.3, 2.4, 2.5... 7.20, 7.21 etc, where the number before the point indicates the item and the second number indicates the question. This resulted in the survey being worth a maximum of 21 marks.

## **2.6 Implementation**

The instrument was used with physics students from different levels of physics learning experience within undergraduate physics at the University of Sydney. The phrase “levels of physics learning experience” refers to the six different groups of students grouped according to the level of physics course being undertaken at university. The groups include 1st year fundamental, regular and advanced, 2nd year, 3rd year, and a postgraduate level masters equivalent cohort (PG).



Students were given a maximum of 30 minutes to complete the survey, but on each occasion participation was voluntary and students were not required to use the maximum time. From anecdotal evidence, many students did not stay for the whole time for various reasons unrelated to the activity. Students in 1st and 2nd year completed the survey during a supervised laboratory session at the end of semester 1. The 3rd year students completed it in a supervised laboratory session at the start of the following semester. The postgraduate students were offered the survey in a controlled environment during the four week break between semesters. This process was repeated in 2011 and 2012 at the university.

On average, the response rate was 50%. Surveys which had more than one answer missing (that is, did not choose a final answer for more than one item) or surveys with more than two (2) explanations left uncompleted, did not meet the minimum criteria. These strict criteria ensured the validity of the implementation by focusing on only the students who were engaged at the same level. This allowed for the diversity of responses across the various levels of learning experience to be adequately compared. As a result, approximately 25% of the manuscripts conformed to the criteria and were used for analysis.

Z-tests to compare the final physics examination marks of students who completed the RFS manuscripts, according to the criteria above, with the full cohort showed that there was a low probability ( $P < 0.15$ ) that there was a self-selection bias amongst the students resulting in an uncharacteristic sample from the student groups.

## **2.7 Evaluation of the Survey**

In this section, the validity and reliability of the RFS will be examined.

### *2.7.1 Validity*

Validity is a process which will need to be continually assessed (Streveler et al., 2011) through the various future uses of the RFS to determine its suitability for various groups of students. Here the focus will be on content validity and face validity, as indicated by the development process, results of the survey, and interview data.

#### Content validity – The breadth of the questions covers the breadth of representational ability

As discussed earlier, there is considerable difficulty measuring a broad range of representational ability, with many researchers choosing to focus on individual representations, such as a particular form of graphs (e.g. Beichner (1994)). With the constraint of a 30 minute test, the

maximum of 7 items limited the breadth of the items. Items were chosen such that various visual and verbal representations could be used to reach the answer. In particular, the graphs in items 1, 3, 4 and 7 are very different – using a kinematic graph, a column graph, a nomogram, and multiple two variable line graphs needing to be combined. This diversity, combined with the varied integration of words, from sparse (items 1 and 3), even (item 7), to only words (items 2 and 5), allows the measurement of a broad range of representational fluency.

In addition to this, the form of the questions contributes to the content validity. By assigning three separate marks for each item (e.g. 1.1, 1.2 and 1.3) the RFS not only measures the ability of individuals to interpret the given representation to attain the correct answer, but also their own form of representational reasoning and their ability to relate self-constructed representations to both the information and answer. This means that the questions cover a wide breadth of representational fluency.

Face validity –The questions appear to differentiate between students on the basis of some measure of their representational ability

Face validity was determined using three mechanisms: the criteria for item selection, comparisons to results from conceptual surveys, and interviews.

Firstly, the items were chosen to have low conceptual knowledge requirements to minimise the effect on the survey's validity for assessing representational fluency. Some items had been selected from other tests already verified as examining a particular facet of representational ability. Finally, the explicit process of selecting representation-rich items was carried out in regular collaboration with the expert panel (including multiple individuals with over 30 years physics education experience).

Secondly, RFS results were compared with results of surveys testing conceptual knowledge. The University of Sydney has been implementing the structure of separating the 1<sup>st</sup> year cohort into fundamental, regular and advanced students for 20 years. Research has shown that the groups' performance on valid conceptual surveys (Tongchai, Sharma, Johnston, Arayathanitkul, & Soankwan, 2011) shows a linear trend, see figure 2.4a.

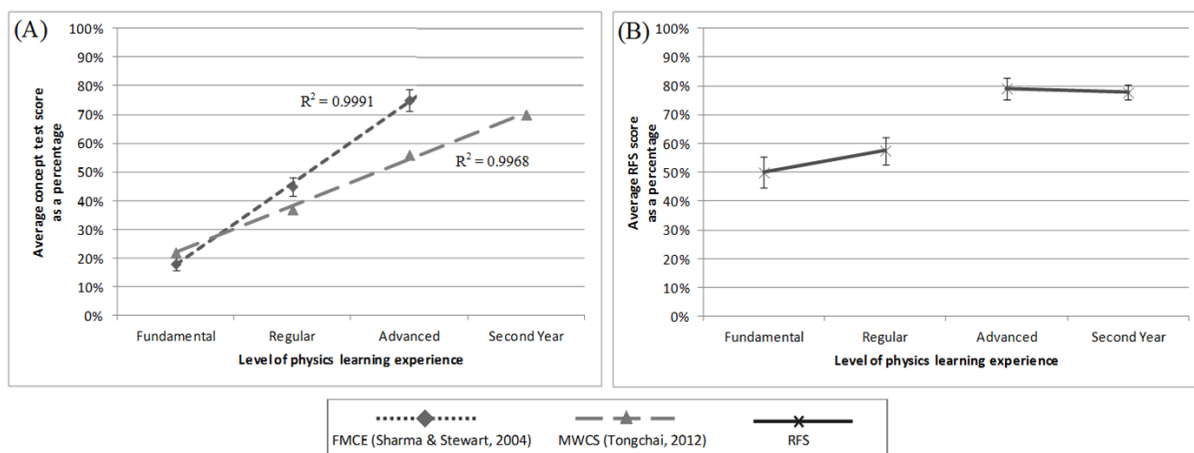


Figure 2.4: (A) The average student mark from conceptual surveys. (B) The average student mark for the representational survey (RFS). Error bars, where available, depict 95% Confidence Intervals. The  $R^2$  values indicate the linear increase of conceptual understanding across the four levels of physics learning experience rather than indicating a correlation between continuous data as normally used. The linearity of the concept test results across the four levels is not reflected in the RFS scores. Rather, we see two groups represented by the joining lines in figure (B).

The figure shows results from two internationally recognised conceptual surveys - The Force Motion Concept Evaluation used with Regular and Advanced Students in 2004 (Sharma & Stewart, 2004) and Fundamental students in 2007-2009 (Sharma et al., 2010), and the Mechanical Waves Conceptual Survey (Tongchai et al., 2011). In comparison, figure 2.4b shows the results from the RFS, administered to the same level of students, at the University of Sydney. The RFS indicates almost no discernible increase from the 1<sup>st</sup> year fundamental to regular students then a jump to advanced. The different trend clearly shows that the survey used in this investigation is assessing a different ability, and we argue that this ability is representational fluency.

Lastly, interviews were conducted with eleven 1<sup>st</sup> year regular students in 2013 at the University of Sydney. Students who had already completed the RFS under test conditions were given blank copies and asked to explain why particular questions were difficult. None of the students indicated that they did not have the appropriate content, including conceptual knowledge to solve any problem. The quotes below indicate that students' difficulties were associated with interpretation and use of representations.

Student F referring to item 4: “(I) have never done this before, and never seen this graph before”

Student F referring to why item 7 was difficult: “The stimulus, with the written part describing the different types of dwellers and the graphs... I probably couldn't put them together and synthesise that information”

Student G referring to item 5: “I tend to have struggle (sic) with problems where there is a whole bunch of stuff you have to integrate [interpret] that are presented in words... translating this text (to vectors) takes a lot more time”.

The interview results, together with the design and comparative analysis of results, support the thesis that the RFS has high face validity.

### *2.7.2 Reliability*

The consistency, potential for repeatability and discrimination power of the survey were evaluated using four statistical tests (Tongchai et al., 2009): the difficulty index, discrimination index, point biserial coefficient, and Chronbach’s alpha reliability index. The formulas and statistical methods for each index can be found in other publications of Ding et al. (2006; 2009) and Wuttirom, Sharma, Johnston, Chitaree, & Soankwan (2009).

#### Difficulty index (P)

To function as a reliable diagnostic survey each question of the test, and the test as a whole, should not be too easy or too hard. The difficulty index is the fraction of the number of students in each group who answered the question correctly divided by the number of students who attempted the question. The lower the difficulty index (P) the more difficult the question. Typically, an acceptable difficulty index will be between 0.2 and 0.8 (Kubiszyn & Borich, 2003), though some argue that even questions with a difficulty of up to 0.9 are acceptable (Ding et al., 2006). See table 2.3 for the difficulty index of each question of the RFS.

Values lightly shaded are of a difficulty index greater than 0.8, but less than 0.9. Values greater than 0.9, where questions are too difficult for a group, have been coloured with a darker shade. Observation indicates that there are no questions that are too difficult, rather some questions are easy across all groups of students (questions 6.17 and 6.18 have difficulty indices above 0.8 for almost all groups). Question 1.3 has a high index. This indicates that participants have written consistent answers and responses for item 1. We consider it appropriate to have such an item where students give consistent working to give students confidence for the rest of the survey. The difficulty for question 2.1 is very different when comparing the Fundamental (0.28) and Regular (0.80) students. Overall, different groups of students are finding different questions and representations difficult to varying degrees.

Table 2.3: Difficulty indices of each question separated for student groups

Item	Question	Overall n=334	1 <sup>st</sup> year n=165	1 <sup>st</sup> Fund n=43	1 <sup>st</sup> Reg n=61	1 <sup>st</sup> Adv n=61	2 <sup>nd</sup> Year-PG n=169
1	1	0.79	0.65	0.47	0.57	0.87	0.93
	2	0.79	0.66	0.47	0.61	0.85	0.92
	3	0.90	0.83	0.74	0.75	0.97	0.96
2	4	0.68	0.65	0.28	0.80	0.77	0.70
	5	0.72	0.62	0.40	0.56	0.85	0.82
	6	0.76	0.68	0.47	0.66	0.85	0.85
3	7	0.63	0.53	0.35	0.44	0.74	0.74
	8	0.53	0.45	0.28	0.33	0.69	0.62
	9	0.84	0.83	0.84	0.75	0.90	0.85
4	10	0.69	0.62	0.56	0.59	0.69	0.76
	11	0.63	0.55	0.42	0.49	0.70	0.70
	12	0.70	0.65	0.53	0.62	0.75	0.76
5	13	0.87	0.87	0.74	0.85	0.98	0.86
	14	0.82	0.78	0.70	0.69	0.93	0.86
	15	0.85	0.85	0.74	0.82	0.95	0.86
6	16	0.77	0.76	0.74	0.75	0.77	0.78
	17	0.97	0.96	0.98	0.90	1.00	0.99
	18	0.85	0.84	0.91	0.77	0.87	0.85
7	19	0.41	0.33	0.16	0.28	0.51	0.49
	20	0.40	0.33	0.19	0.23	0.52	0.48
	21	0.63	0.55	0.47	0.51	0.66	0.72
	Mean	0.73	0.67	0.54	0.62	0.80	0.78

No Shading,  $P \leq 0.8$ ; light shading,  $0.8 < P \leq 0.9$ , dark shading  $P > 0.9$

#### Discrimination index (D)

Discrimination is important for diagnostic surveys as it allows the students who have a representational fluency to be clearly distinguished from the students who do not. It is measured by subtracting the difficulty index individual questions for the students within each group who scored in the top 25% and bottom 25% on the overall RFS. Questions with little or no discrimination ( $D < 0.3$ ) are deemed unhelpful in contributing to a meaningful total score. Table 2.4 presents the discrimination indices for each question.

In table 2.4, the shaded cells indicate that the discrimination index is less than 0.3, that is, the question does not discriminate for that group. There is more discrimination for the 1<sup>st</sup> year fundamental and regular groups than the other two groups. Items 1, 2 and 3 have one question which has a low discrimination but the other two questions for those items have high discrimination indices.

Table 2.4: Discrimination indices of each question separated for student groups

Item	Question	Overall n=334	1 <sup>st</sup> year n=165	1 <sup>st</sup> Fund n=43	1 <sup>st</sup> Reg n=61	1 <sup>st</sup> Adv n=61	2 <sup>nd</sup> Year-PG n=169
1	1	0.57	0.51	0.72	0.74	0.27	0.18
	2	0.51	0.44	0.72	0.67	0.27	0.16
	3	0.27	0.29	0.22	0.34	0.07	0.09
2	4	0.25	0.17	0.08	0.20	-0.07	0.11
	5	0.58	0.54	0.34	0.61	0.27	0.30
	6	0.53	0.39	0.43	0.54	0.20	0.34
3	7	0.59	0.51	0.63	0.49	0.40	0.43
	8	0.66	0.56	0.54	0.43	0.33	0.64
	9	0.23	0.24	0.30	0.28	0.07	0.27
4	10	0.52	0.49	0.43	0.80	0.67	0.48
	11	0.59	0.61	0.45	0.74	0.73	0.48
	12	0.49	0.44	0.54	0.34	0.67	0.55
5	13	0.37	0.27	0.60	0.20	0.07	0.34
	14	0.41	0.39	0.70	0.34	0.13	0.30
	15	0.40	0.22	0.60	0.27	0.07	0.39
6	16	0.24	0.17	0.11	0.01	0.27	0.36
	17	0.07	0.12	0.00	0.20	0.00	0.02
	18	0.11	0.12	0.01	0.01	-0.07	0.16
7	19	0.69	0.54	0.17	0.43	0.67	0.73
	20	0.66	0.51	0.26	0.37	0.53	0.77
	21	0.58	0.44	0.32	0.35	0.73	0.66
	Mean	0.44	0.38	0.39	0.40	0.30	0.37

No Shading,  $D \geq 0.3$ ; Shading,  $D < 0.3$

Point biserial coefficient ( $r_{pbs}$ )

The point biserial coefficient indicates the consistency of results between individual questions and the survey as a whole. A high value of  $r_{pbs}$  for a particular question indicates that a student who gets a high score on the survey is likely to get that question correct. Criteria of  $r_{pbs} \geq 0.2$  is generally considered adequate. Figure 2.5 shows the point biserial coefficients for each question.

The three questions which have  $r_{pbs} < 0.2$  are all from the same item, questions 6.16, 6.17 and 6.18. Item 6 has also returned non-ideal results for each of the previous statistical tests. All other questions are above the threshold of 0.2. Excluding question 6, the average is  $r_{pbs} = 0.47$  which supports the hypothesis that the survey is internally consistent.

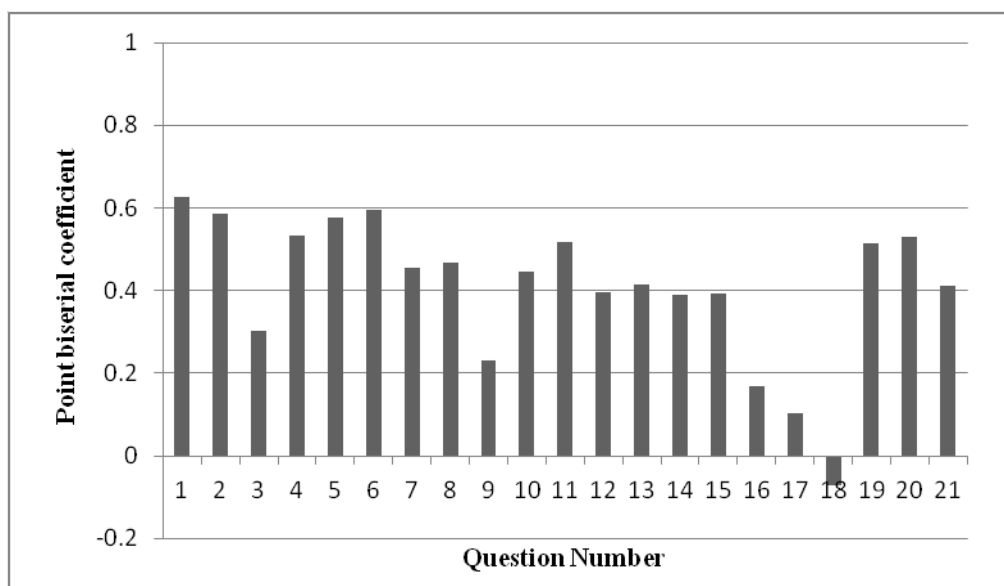


Figure 2.5. Point biserial coefficients for each question

Chronbach’s alpha reliability index

Another measure of internal consistency, Chronbach’s alpha takes into account multiple questions when correlating with the total score. An alpha  $\geq 0.7$  is generally considered adequate. The values of alpha for the survey are presented in table 2.5. Item 6 was excluded from this analysis due to low discrimination and point biserial coefficient. For each student group, the value of Chronbach’s alpha is high and the overall value of 0.78 indicates a high level of internal consistency on the survey.

Table 2.5: Chronbach's alpha reliability indices separated for student groups

<b>Overall n=334</b>	<b>1<sup>st</sup> Fund n=43</b>	<b>1<sup>st</sup> Reg n=61</b>	<b>1<sup>st</sup> Adv n=61</b>	<b>2<sup>nd</sup> Year-PG n=169</b>
0.78	0.67	0.69	0.64	0.71

**2.8 Discussion**

We have described the formation and evaluation of the RFS designed to test the fluency of physics students in science representations. The survey was verified through consultation with experts and also through the observations by students when reflecting on what made the survey difficult. Student observations were that items 4 and 7 were the most difficult, consistent with the numerical results, and that the reason for the difficulty was often due to not understanding representations along the lines of not having a threshold level of ability to engage with the necessary combination of representations. The questions associated with these items also had high discrimination indices along with all other questions, except those associated with item 6.

The analysis of 334 student manuscripts allowed for a determination of the reliability of the RFS. The results present appropriate difficulty, high discrimination indices and point biserial coefficients for most questions giving a quantitative measure of the consistency and appropriateness of the survey. The stand out exception was item 6 and the associated questions. It is therefore recommended that item 6 be removed from analysis as it does not meet the required criteria for a reliable item in the RFS.

While item 6 is not reliable for the RFS, its use may still provide benefit in other areas. Many research projects have involved cataloguing and recording student representational use and drawing and interpreting graphs is just one example of where this is possible. Observation of student manuscripts for item 6 highlighted various interesting trends, including differing reactions among students to dealing with outliers in data. Dealing with real data is often unusual for new students who are used to the conforming data often presented in high school (particularly mathematics) (Bowen & Roth, 2005). Therefore, depending on the objectives, a researcher may decide to retain item 6 for alternative analysis.

Another consideration for a researcher or educator is whether the difficulty and discrimination suits the intended cohort, as a particular threshold level of ability is necessary to access disciplinary discourse for different cohorts. This paper has shown the RFS is optimized for first year university students. There is still clear and helpful information for more senior years of university physics but care will need to be taken.

The results presented in figure 2.4 reveal that the level of representational fluency across different levels of physics learning experience at the University of Sydney does not correlate with scores on conceptual surveys. Most notably is the distinct difference in RFS scores between the lower and upper two groups. The 1<sup>st</sup> year Regular students have a similar representational ability to the 1<sup>st</sup> year Fundamental students who have studied two years less of high school physics. Furthermore, the 1<sup>st</sup> year advanced students and 2<sup>nd</sup> year students have no difference in scores. This supports the existence of a critical constellation of representational modes required for participation in the discipline (Airey & Linder, 2009) and affirms the premise of the RFS.



## **2.9 Further Research**

There are multiple other ways to analyze student answers to the RFS. These include coding for which a particular representation is used, and creating novel ways to present trends in representational use across various questions and groups of students. Preliminary analysis indicates that these further support the notion that the RFS is truly a test of representational fluency. In addition to this, the results of the RFS, particularly the way that expert students chose to use representations in completing the items, have been used to inform research and practice at the University of Sydney, including the creation of online teaching supplements designed to target and improve student representational use. In 2013, the authors have used the RFS as a set of tests (pre and post) to measure first year student gains in representational fluency across a semester of university physics. This highlights the diversity of use of the survey in influencing practice and measuring the effectiveness of teaching activities.

The RFS is a survey that measures representational ability in science. It is targeted at a specific domain (physics) and a particular demographic (university students). As described earlier, it is therefore a measure of a physics student's representational ability (science representational fluency nuanced for physics students). In its current form it would also be of use to researchers investigating the representational fluency of students in their final years of secondary education before entering university. Modifications to the RFS may allow research to be conducted with students even earlier in their education investigating the extent of the development of representational fluency of students throughout secondary education. We also suggest that there are elements in the survey that may be generalizable to other scientific domains and that the survey has the potential to be adapted to suit the needs of research and teaching further afield as the requirement of representational fluency is not unique to physics. We do, however, recommend that care is taken, and the motivation and processes presented in this paper are considered.

## **2.10 Conclusion**

In this study, we developed a robust survey to measure representational fluency in science for university physics students. The design was optimised to combine elements of representational fluency in order to compare representational use amongst individuals or groups. The survey has been tested with students of various levels of physics learning experience, undergraduates to postgraduates. Through pilot studies, and standard statistical analysis of the main implementation, the final survey is a valid and reliable measure of scientific representational

fluency and can therefore be used by instructors to measure the development of representational skills of students at different stages of their time at university, or to evaluate the effectiveness of teaching strategies to improve representational fluency.

## 2.11 References

- Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, 16(3), 183-198. doi: 10.1016/j.learninstruc.2006.03.001
- Airey, J. (2009). Science, Language and Literacy. Case Studies of Learning in Swedish University Physics. Acta Universitatis Upsaliensis. Uppsala Dissertations from the Faculty of Science and Technology 81. Uppsala Retrieved 2009-04-27, from <http://publications.uu.se/theses/abstract.xsql?dbid=9547>
- Airey, J., & Linder, C. (2009). A Disciplinary Discourse Perspective on University Science Learning: Achieving Fluency in a Critical Constellation of Modes. *Journal of Research in Science Teaching*, 46(1), 27-49. doi: 10.1002/tea.20265
- Aldrich, F., & Sheppard, L. (2000). 'Graphicacy': the fourth 'R'? *Primary Science Review*, 64, 8-11.
- Beichner, R. J. (1994). Testing student interpretation of kinematic graphs. *American Journal of Physics*, 62(8), 750-762. doi: 10.1119/1.17449
- Bodner, G. M., & Guay, R. B. (1997). The Perdue Visualization of Rotations Test. *Chemical Educator*, 2(4), 1-17. doi: 10.1007/s00897970138a
- Bowen, G. M., Roth, W. M., & McGuinn, M. K. (1999). Interpretations of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching*, 36(9), 1020-1043. doi: 10.1002/(SICI)1098-2736(199911)36:9<1020::AID-TEA4>3.0.CO;2-#
- Bowen, G. M., & Roth, W. M. (2005). Data and graph interpretation practices among preservice science teachers. *Journal of Research in Science Teaching*, 42(10), 1063-1088. doi: 10.1002/tea.20086
- Caleon, I., & Subramaniam, R. (2010). Development and Application of a Three-Tier Diagnostic Test to Assess Secondary Students' Understanding of Waves. *International Journal of Science Education*, 32(7), 939-961. doi: 10.1080/09500690902890130
- Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 32.
- de Jong, R., & Ferguson-Hessler, M. (1986). Cognitive structures of good and poor novice problem-solvers in physics. *Journal of Educational Psychology*, 78(4), 10. doi: 10.1037//0022-0663.78.4.279

- de Jong, R., & Ferguson-Hessler, M. (1991). Knowledge of problem situations in physics: a comparison of good and poor novice problem-solvers. *Learning and Instruction*, 1(4), 14.
- Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical Review Special Topics-Physics Education Research*, 2(1). doi: 10.1103/PhysRevSTPER.2.010105
- diSessa, A., (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, 22(3). 293-331. doi: 10.1207/s1532690xci2203\_2
- Driver, R., Asoko, H., Leach, J., Mortimer, E., Scott, P. (1994). Constructing Scientific Knowledge in the Classroom. *Educational Researcher*, 23(7), 5-12. doi. 10.3102/0013189X023007005
- Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). *Solving Physics Problems with Multiple Representations*. Department of Physics & Astronomy and Scientific Reasoning Research Institute. University of Massachusetts.
- Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction. *European Journal of Physics*, 33(3), 657-666. doi: 10.1088/0143-0807/33/3/657
- Gilbert, J. K. (2008). Visualization: An Emergent Field of Practice and Enquiry in Science Education. In J. K. Gilbert, R. Miriam & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (pp. 3-24): Springer.
- Goldman, S. R. (2003). Learning in complex domains: when and why do multiple representations help? *Learning and Instruction*, 13(2), 239-244. doi: 10.1016/s0959-4752(02)00023-3
- Haslam, F., & Treagust, D. F. (1987). Diagnosing Secondary Students Misconceptions of Photosynthesis and Respiration in Plants using a 2-Tier Multiple-Choice Instrument. *Journal of Biological Education*, 21(3), 203-211. doi: 10.1080/00219266.1987.9654897
- Hestenes, D., Wells, M., Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, 30, 141-158. doi: 10.1119/1.2343497
- Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(1), doi: 10.1103/PhysRevSTPER.1.010104
- Kohl, P. B., & Finkelstein, N. D. (2006a). Effect of instructional environment on physics students' representational skills. *Physical Review Special Topics-Physics Education Research*, 2(1). doi: 010102
- Kohl, P. B., & Finkelstein, N. D. (2006b). Student representational competence and the role of instructional environment in introductory physics. In P. Heron, L. McCullough & J.

Marx (Eds.), *2005 Physics Education Research Conference* (Vol. 818, pp. 93-96). doi. 10.1063/1.2177031

- Kohl, P. B., & Finkelstein, N. D. (2008). Patterns of multiple representation use by experts and novices during physics problem solving. *Physical Review Special Topics-Physics Education Research*, 4(1). doi: 10.1103/PhysRevSTPER.4.010111
- Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, 13(2), 205-226. doi: 10.1016/s0959-4752(02)00021-x
- Kubiszyn, T., & Borich, G. D. (2003). *Educational testing and measurement: Classroom application and practice* (7<sup>th</sup> ed.). Wiley
- Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980a). Expert and Novice Performance In Solving Physics Problems. *Science*, 208(4450), 1335-1342. doi: 10.1126/science.208.4450.1335
- Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980b). Models of Competence in Solving Physics Problems. *Cognitive Science*, 4(4), 317-345. doi: 10.1016/s0364-0213(80)80008-5
- Meltzer, D. E. (2005). Relation between students' problem-solving performance and representational format. *American Journal of Physics*, 73(5), 463-478. doi: 10.1119/1.1862636
- Muller, A., Bewes, J., Sharma, M. D., & Reimann, P. (2008). Saying the wrong thing: improving learning with multimedia by including misconceptions. *Journal of Computer Assisted Learning*, 24(2), 144-155. doi: 10.1111/j.1365-2729.2007.00248.x
- Prain, V., & Tytler, R. (2012). Learning Through Constructing Representations in Science: A framework of representational construction affordances. *International Journal of Science Education*, 34(17), 2751-2773. doi: 10.1080/09500693.2011.626462
- Rollnick, M., & Mahooana, P. P. (1999). A quick and effective way of diagnosing student difficulties: two tier from simple multiple choice questions. *South African Journal of Chemistry-Suid-Afrikaanse Tydskrif Vir Chemie*, 52(4), 161-164. [http://journals.sabinet.co.za/ej/ejour\\_chem.html](http://journals.sabinet.co.za/ej/ejour_chem.html)
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2006). Case study: Students' use of multiple representations in problem solving. *2005 Physics Education Research Conference*, 818, 49-52. doi. 10.1063/1.2177020
- Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Acher, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners. *Journal of Research in Science Teaching*, 46(6), 632-654. doi: 10.1002/tea.20311
- Sharma, M. D., & Stewart, C. (2004). *Exploring the differences between students trained under the old and new HSC syllabuses*. Paper presented at the 11th Biennial Science Teachers' Workshop, Sydney. Unpublished Manuscript

- Sharma, M. D., Johnston, I. D., Johnston, H., Varvell, K., Robertson, G., Hopkins, A., Stewart, C., Cooper, I., & Thornton, R. (2010). Use of interactive lecture demonstrations: A ten year study. *Physical Review Special Topics-Physics Education Research*, 6(2). doi: 10.1103/PhysRevSTPER.6.020119
- Sia, D. T., Treagust, D. F., & Chandrasegaran, A. L. (2012). High School Students' Proficiency and Confidence Levels in Displaying Their Understanding of Basic Electrolysis Concepts. *International Journal of Science and Mathematics Education*, 10(6), 1325-1345. doi: 10.1007/s10763-012-9338-z
- Stieff, M., Hegarty, M., Deslongchamps, G. (2011). Identifying Representational Competence With Multi-Representational Displays, *Cognition and Instruction*, 29(1), 123-145. doi: 10.1080/07370008.2010.507318
- Streveler, R. A., Miller, R. L., Santiago-Roman, A. I., Nelson, M. A., Geist, M. R., & Olds, B. M. (2011). Rigorous Methodology for Concept Inventory Development: Using the 'Assessment Triangle' to Develop and Test the Thermal and Transport Science Concept Inventory (TTCI). *International Journal of Engineering Education*, 27(5), 968-984.
- Tamir, P. (1989). Some Issues Related to the Use of Justifications to Multiple-Choice Answers. *Journal of Biological Education*, 23(4), 285-292. doi: 10.1080/00219266.1989.9655083
- Thornton, R. K., & Sokoloff, D. R. (1997). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352. doi: 10.1119/1.18863
- Tobin, K. G., & Capie, W. (1981). The Development and Validation of a Group Test of Logical Thinking. *Educational and Psychological Measurement*, 41(2), 413-423. doi: 10.1177/001316448104100220
- Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2009). Developing, Evaluating and Demonstrating the Use of a Conceptual Survey in Mechanical Waves. *International Journal of Science Education*, 31(18), 2437-2457. doi: 10.1080/09500690802389605
- Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2011). Consistency of students' conceptions of wave propagation: Findings from a conceptual survey in mechanical waves. *Physical Review Special Topics-Physics Education Research*, 7(2). doi: 10.1103/PhysRevSTPER.7.020101
- Vygotsky, L. (1978). Interaction between Learning and Development (pp. 79-91). In *Mind in Society*. (Trans. M. Cole). Cambridge, MA: Harvard University Press.
- Woolnough, J. (2000). How do Students Learn to Apply Their Mathematical Knowledge to Interpret Graphs in Physics? *Research in Science Education*, 30(3), 259-267. doi: 10.1007/BF02461633

Wuttirom, S., Sharma, M. D., Johnston, I. D., Chitaree, R., & Soankwan, C. (2009).  
Development and Use of a Conceptual Survey in Introductory Quantum Physics.  
*International Journal of Science Education, 31(5)*, 631-654. doi:  
10.1080/09500690701747226

# **Chapter 3:**

## **Students' representational fluency at university:**

### **A cross-sectional measure of how multiple representations are used by physics students using the Representational Fluency Survey.**

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#### **3.1 Abstract**

To succeed within scientific disciplines, using representations, including those based on words, graphs, equations and diagrams, is important. Research indicates that the use of discipline specific representations (sometimes referred to as expert generated representations), as well as multi-representational use, is critical for problem solving and developing understanding. This paper consolidates these ideas using the Representational Fluency Survey (RFS) over two years with 334 students at the University of Sydney. Analysis shows that there was a significant difference between the representational fluency of the 1st year Fundamental and Regular students (low level 1st year physics courses) compared to the 1st year Advanced, 2nd year, 3rd year and Postgraduate level students. The existence of this distinct gap is further supported by evidence from qualitative coding that students with a high level of representational fluency use a greater number of representations and more visual and symbolic representations to explain their answers. There is no mention of such an overall trend of variation of representational use in extant literature, largely because there have been no studies that compare representational fluency across closely spaced levels of physics, or science, learning.

#### **3.2 Introduction**

It has regularly been identified that participation in scientific disciplines is based on the interplay between conceptual understanding, the use of representations and experiential learning (Duschl & Osborne, 2002; McCormick, 1997). To succeed within the discipline, using multiple

representations becomes central to problem solving, understanding, and communicating. Research on multiple representations range from in-depth investigations of students' use of specific representations to how students can attain a greater competency with a range of representations. This paper focuses on the later. We examine representation use, through an analysis of the results of the Representational Fluency Survey (Hill, Sharma, O'Byrne, & Airey, 2014), consolidating ideas of *metavisualisation* (Gilbert, 2004), *representational competence* (Hand & Choi, 2010; Stieff, Hegarty, & Deslongchamps, 2011) and *metarepresentational competence* (diSessa, 2004) which have emerged in the last decade.

### **3.3 Theoretical Framework: Multiple Representations**

There is extensive literature on the role and use of multiple representations. Multiple representations refer to the combination of formats used to generate, process or present information (Gilbert, 2004). In the context of the natural sciences, generic examples include graph, word, equation and diagram based representations along with specific discipline representations, for example Lewis structures in chemistry and free body diagrams in physics. Collectively, these form part of the disciplinary community of discourse, defined by a common language expressed through shared understandings of representations (Driver, Asoko, Leach, Mortimer, & Scott, 1994). As students progress in their studies, instructors and students use multiple representations to communicate, develop understandings and demonstrate understandings. Appropriate use of multiple representations in instruction can make information more memorable (Aldrich & Sheppard, 2000), more easily processed in working memory and integrated with prior knowledge in long term memory through overcoming cognitive load limitations (Ainsworth, 2006), and portray relationships that are not easily identifiable (Goldman, 2003; Roth, Bowen, & McGinn, 1999).

When focussing on student use of multiple representations, especially in the sciences, student difficulties are associated with both understanding the representations themselves as well as how to reason using representations while learning and during problem solving. This is demonstrated through the considerable research in the area of "graphicacy", or student use of graph-based representations, essential for science students (Roth et al., 1999). Focusing on physics, the difficulties with graphing become more pronounced as the need to use them appropriately becomes more critical (Beichner, 1994; Woolnough, 2000; Wu & Krajcik, 2006). Student difficulties are associated with interpretation of the axes, understanding the gradient and failing to understand why two different graphs that look the same, but have different variables, don't necessarily represent similar situations (Beichner, 1994). Interestingly, students



understandings are sensitive to context, for example, many are unable to answer graphical questions which include the same level of mathematics which they have already demonstrated proficiency in, in another context (Leinhardt, Zaslavsky, & Stein, 1990). Such inconsistency is part of how students negotiate tenuous understandings as they co-construct conceptual knowledge in physics (Britton, New, Sharma, & Yardley, 2005). Experience also suggests that some students simply lose confidence when a question includes a graph, or requires them to use a graph, leading to a higher level of stress and incorrect answers (Engelbrecht, Harding, & Potgieter, 2005). There has been a range of investigations into student difficulty with other representations key to physics including equation-based (Bieda & Nathan, 2009), diagram-based (Pollock, Thompson, & Mountcastle, 2007) and word-based representations (Dufresne, Gerace, & Leonard, 2004; Jacobs, 1989).

To succeed within a discipline, students do not simply need to be competent with one representational format, rather to shift their tenuous and often inconsistent understandings, towards those that are more scientifically congruent; which inherently means, choosing and using appropriate individual representations and integrating between them when needed. Consequently, while continued research into individual representations is immensely valuable, the field of multiple representation research has continued into broader descriptions of representational use, grouping representations as “modes” and even investigating inter-modal and multi-modal use. Three perspectives on integrating representational use are described briefly here, followed by a discussion on representational fluency.

Gilbert (2004) suggested that different representations could be grouped into five “modes” including concrete, verbal, symbolic, visual and gestural and that *visualization* describes making meaning out of representations. *Metavisualization* is the metacognitive side of this, where students can “acquire, monitor, integrate, and extend, learning from representation” (Gilbert, 2008, p5-6).

The second perspective, *representational competence* utilises Gilbert’s (2004) framework. Representational competence focuses on the domain specific constellation of representations. Studies in representational competence isolate representation use specific to a domain and then investigate scaffolding student attainment of such representational use (Kohl & Finkelstein, 2005; Kohl & Finkelstein, 2006b). Representational competence begins with using representations authentically (Roth & Bowen, 1999) and being able to extract information from given representations (Shafir, 1999) but has been extended to cross-representational use where multiple modes of representation in Gilbert’s model (2004) are used in student answers and instructional material (Hand & Choi, 2010; Stieff et al., 2011).

*Metarepresentational competence* (MRC), as the name implies, is the metacognitive aspect of representational competence where individuals understand the rationale behind representations and includes creating new representations and learning or utilizing new representations quickly (diSessa, 2004). Important is the *why* of a particular representation, more technically referred to as the representation's affordance (Fredlund, Airey, & Linder, 2012; Gibson, 1977). The ability to choose the most appropriate representation for a given situation is a skill of those with metarepresentational competence (Dufresne et al., 2004)

This paper consolidates the above literature by relating to all three different perspectives on integrating representational use. What is being measured by the Representational Fluency Survey will relate to each of Metavisualisation, representational competence, and metarepresentational competence. This means that none of these terms alone is able to fully encompass what is being measured and investigated in this paper.

*Representational fluency* used by Nathan, Stephens, Masarik, Alibali, & Koedinger. (2010) is suggested as an integration of these perspectives. Lesh (1999) explained that representational fluency facilitates students to be analysing problems and planning multi-step solutions, justifying and explaining representational use, assessing progress, and "integrating and communicating results in forms that are useful to others" (p 331). Individuals who are representationally fluent have a competence in domain specific representations and the metacognitive skills to apply their knowledge of representations effectively (Uesaka & Manalo, 2006). Proficiency at translating between representations, a characteristic of metavisualization, is also a defining characteristic of representational fluency (Bieda & Nathan, 2009; Nistal, VanDooren, Clarebout, Elen, & Verschaffel, 2009). Representational fluency is a genre of thinking important for all science students and despite the dependence on discipline-specific representations, the representational thinking component allows for it to be transferable across scientific disciplines. Mathematics educators capture representational fluency as *representational flexibility* (Thomas, Wilson, Corballis, Lim, & Yoon, 2010). Hill et al. developed the Representational Fluency Survey (2014) to measure representational fluency. The focus is on science multiple representations nuanced for a physics specialization, that is, representations for physics and wider science incorporating as a relevant skill for physics students, encapsulating the transfer of representational use.

### **3.4 Significance of the study**

Previous research involving representations in science typically uses individual problems, or sets of problems focussing on particular facets of reasoning (Kohl & Finkelstein, 2006a; Kohl & Finkelstein, 2008; Meltzer, 2005; Woolnough, 2000). For example, an important contribution was when Meltzer (2005) varied the representation used to portray a physics question to compare how students would respond (similar to Kohl & Finkelstein (2005)). Many studies are predominantly observational data allowing for qualitative description of student behaviour often presented through case studies (Fredlund et al., 2012; Rosengrant, Van Heuvelen, & Etkina, 2006; Sia, Treagust, & Chandrasegaran, 2012; Tytler, Prain, Hubber, & Waldrup, 2013). In particular, studies in metarepresentational competence (diSessa, 2004) and metavisualisation (Gilbert, 2008), to our knowledge, are largely qualitative in nature.

There have been some large-scale, quantitative measures related to representational use, however these focus on a specific subset of representations in a particular context. Two examples are the Test of Understanding Graphs in Kinematics (Beichner, 1994), which focuses on the one representation, graphs, and difficulties associated with use in the context of kinematics, and the Perdue Spatial Visualization of Rotation (Bodner & Guay, 1997) which measures spatial ability in introductory chemistry.

The RFS allows for a large-scale, quantitative measure of the broad area of representational fluency, rather than one category of representations. Therefore, this is the first study to allow for direct comparisons to be made across closely spaced levels of physics learning experience at university. The importance of this is two-fold, firstly, that this study has been able to determine that there is a significant gap in representational fluency between cohorts of 1<sup>st</sup> year students which may result in many students being unable to continue with physics in later years, and secondly, the results have allowed for a more quantitative understanding of what constitutes representational fluency to be developed which is significant for instructional design in this area.

Both of these areas of significance are investigated through the two research questions of this paper.

*Research Question 1* – How does representational use as measured by the Representational Fluency Survey vary across different cohorts of university physics students?

*Research Question 2* –What are the characteristics associated with proficient use of representations?

### **3.5 Purpose of the Study**

To answer these research questions, this paper presents an analysis of the results of the RFS administered cross-sectionally over two years to different student cohorts from first year students with minimum background in physics to Postgraduate physics students. The first section (Part 1: Research Question 1) compares results across the different cohorts to examine trends in students' representational use. The aim is to find whether there are distinguishable differences or a gradual development of representational use.

The second section on (Part 2: Research Question 2) uses the framework of representational modes (Gilbert, 2004; 2005) to characterise representational use. The way that students combine representations and whether particular modes, especially more sophisticated modes, are used by particular groups of students will also be investigated.

This paper is presented in two parts. Each part focuses on one of the research questions. The methodology that applies across both parts is outlined in the methods section, then within each part there are separate sections for analysis methodology, results, and analysis with implications. After the two parts there is a general discussion drawing together the two research questions.

### **3.6 Methods**

#### *3.6.1 The instrument*

The Representational Fluency Survey (RFS) (Hill et al., 2014) is a published diagnostic test designed to measure the representational fluency of university-level physics students. The reliability and validity of the test have been demonstrated in a previous publication (Hill et al., 2014). Face and content validity were confirmed using student feedback and interviews, and regular collaboration with a physics education expert panel. The RFS has seven multiple choice items, six of which are recommended for general use have satisfied the criteria for standard statistical tests (difficulty index, point biserial coefficient and Cronbach's alpha).

Of the survey's seven items, the context of three items is deliberately not physics, and the remaining have physics contexts. The disciplinary information needed to answer both the

physics and non-physics items is contained within the item. The items have specifically been designed and tested such that students who have studied senior high school science subjects and mathematics are able to interpret the context. The difficulty that the student has with each item is associated primarily with the representations used. Hence the RFS probes students use of representations, and is a representational survey specialising for physics. Respondents are asked to choose an answer for each item and “provide brief information which supports the answer you have chosen”. Table 3.1 lists the characteristics of each item and the representations used in each. Student responses to most items are presented in the figures listed in the final column of the table. The full survey is found in Appendix A.

Table 3.1: Characteristics of each item of the RFS emphasising the representations used in each. The last column lists where student responses are presented in this paper.

<b>Item Number</b>	<b>Question description</b>	<b>Completed item presented in this paper</b>
I	Words explain that “acceleration is a measure of how velocity changes with time” and asks participants which of five graphs shows the greatest change in velocity. Five simple line graphs are given.	Figure 3.1
II	Words describe the motion of a coin tossed into the air. Eight options are given (in words) that are to be chosen to describe the force on the coin at various points in the motion.	Figure 3.6
III	Two bar graphs are given displaying the proportions of boron and oxygen in the compound boronic oxide by mass and by number of atoms in the compound. In words, the question asks for the mass of an oxygen atom compared to boron and there are four numerical (decimal) answers to chose from.	Not pictured. See Appendix A
IV	Words introduce students to a “nomogram” and give an example of a set of information that is discernible from the graph. A nomogram (graph) is presented with two parallel scales with a third at an angle between them. Participants are asked to find a particular numerical reading using the graph.	Not pictured. See Appendix A
V	Words explain the motion of two competitors in an orienteering tournament. There is substantial extraneous information not necessary to answer the question. The question asks which competitor will reach the checkpoint first.	Figure 3.4
VI	Words explain different types of plant in a rainforest and particular needs. Two graphs give information about rate of fern growth and height compared to light intensity for an unknown plant. Five descriptions of plants are given for participants to choose from.	Figure 3.5
The original survey included seven items however the authors recommended against using the original item six.		

It is important to note that four items of the RFS do come from the physics discipline. This does not invalidate the claim that the RFS measured representational fluency independent of content

knowledge. The development and testing of the RFS affirmed that the difficulty that students have with each item is associated with the representations used, the theory behind each item is learnt at a pre-university level in Australia (Hill et al., 2014).

The first research question probing variation in representational use amongst different cohorts of students was approached using an analysis based on a three-tier marking criteria, quantitatively comparing student groups. The second research question needed in-depth analysis involving qualitative coding of the rich data. The two analysis techniques are explained separately within the findings and analysis sections for each research question.

### *3.6.2 Procedure and the sample*

The RFS was deployed with students from first, second and third year of undergraduate physics as well as Postgraduate students in Semester 1 of 2011 and 2012 at the University of Sydney according to university Human Ethics Committee protocols. Within first year we have 3 separate cohorts, Fundamental, Regular and Advanced. These cohorts have very different experiences prior to university. The 1<sup>st</sup> year Advanced students scored exceptionally well in their senior high school studies, have high physics marks and generally have engaged in a range of extracurricular and enrichment programs which are not part of the mandatory school curriculum. The 1<sup>st</sup> year Regular students also did physics in senior high school but did not do so well and the 1<sup>st</sup> year Fundamentals students have done limited or no physics in the final years of high school. Each of these groups have a different level of 'physics learning experience' which includes a combination of class time, personal study and engagement from educational professionals. The 'physics learning experience' of all the cohorts then progresses from 1<sup>st</sup> year Fundamentals, 1<sup>st</sup> year Regular, 1<sup>st</sup> year Advanced, 2<sup>nd</sup> year, 3<sup>rd</sup> year to postgraduates. This progression is reflected in an increasing trend on performance on conceptual tests, increasing linearly with the levels of physics learning experience (Sharma et al., 2010; Tongchai, Sharma, Johnston, Arayathanikul, & Soankwan, 2011). Consequently we use the phrase, 'levels of physics learning experience' to refer to these six different cohorts of students. A total of 335 student responses are used in this study. Table 3.2 shows the numbers from each level of physics learning experience for 2011 and 2012. There was no overlap in students participating in the study across the two years.

Table 3.2: The number of student responses from each level of physics learning experience across 2011 and 2012.

Level of physics learning experience		2011	2012	Total
1 <sup>st</sup> Year	Fundamental	30	15	45
	Regular	31	30	61
	Advanced	31	30	61
2 <sup>nd</sup> Year		32	40	72
3 <sup>rd</sup> Year		36	33	69
Postgraduate		15	12	27
Total		175	160	335

### 3.7 Part 1: Research Question 1

#### 3.7.1 Analysis methodology

To answer the first research question, we developed the specific three-tiered marking scheme shown below. The marking scheme captured whether students were obtaining the ‘correct answer’, tier I.1, but more importantly whether students use of representations were appropriate, tier I.2, and consistent, tier I.3. The three-tiered scheme (from Hill et al., 2014) is as follows:

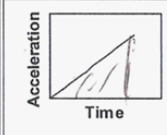
- I.1 Selecting the correct answer to the representationally rich multiple choice question irrespective of what was provided in support of the answer. (referred to as the student’s “*answer*”).
- I.2 A scientifically congruent explanation (using any representation), relevant to the question and leading to the answer. It may not always end up producing the answer chosen by the student (referred to as the student’s “*explanation*”).
- I.3 Consistency between the chosen “*answer*” and the “*explanation*” in that the explanation leads to the selected multiple choice answer, and can use any representation (referred to as a “*consistent/inconsistent explanation*”).

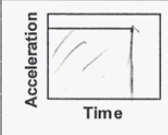
In this way, it is possible for students to get a score of zero, one, two, or three for each item.


The following example illustrates the marking scheme using three student responses for item I. Figure 3.1 shows responses from Student A who selected the correct multiple choice answer “B”, provided a scientifically congruent explanation using equations and was consistent, scoring the full 3 marks. Student B did not choose the correct answer (chose “C”) but did offer a scientifically congruent explanation, “Area under graph is greatest” that was relevant and leading to the correct answer. Student B’s explanation did not align with the answer they selected making it inconsistent. Therefore Student B scored one mark for the explanation under criteria I.2. Similarly, Student C received only one mark. This student’s answer “D” was consistent with the explanation: “As the rate of acceleration is increasing with time, the velocity is increasing at an ever increasing rate”. But the answer was incorrect, and the explanation,

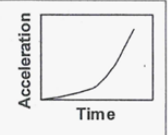
while a true statement in the context of the question, was not in any way leading to the answer and therefore the second-tier mark, I.2, could not be awarded.


Acceleration versus time graphs for five objects are shown below. Acceleration is a measure of how velocity changes with time. All axes in the graphs have the same scale. Which object has the greatest change in velocity during the interval?

(A)  


(B)  


(C)  


(D)  


(E)  


Answer: B

Provide information supporting your answer or why you chose your answer:

$$a = \frac{dv}{dt} \quad v = \int a dt$$

*= Area under acceleration  
= area under graph,*

**Student A:** Correct answer, scientifically congruent reasoning, consistent reasoning and answer = 3 marks

---

Answer: C

*Area under graph is greatest*

**B:** Incorrect answer, congruent reasoning, inconsistent reasoning and answer = 1 mark

---

Answer: D

*As the rate of acceleration is increasing with ~~the~~ time, the velocity is increasing at an ever increasing rate.*

**C:** Incorrect answer, incongruent reasoning, consistent reasoning and answer = 1 mark

Figure 3.1: Three student (A-C) responses to item one illustrating representational use and demonstrating the use of the three-tier marking system.

The three tiers allow for different elements of representational use to be incorporated. One element is attaining the correct answer (tier 1) requiring students to utilise the presented information and to commitment to an appropriate answer which can be done by implicit or explicit use of representations. Another element, is in providing an explanation (tier 2), students need to choose and use representations authentically, meaning making in the process. This is often demonstrated through student shading and markings on visual representations presented in



the question or through student sketching. The last element is when students offer a consistent explanation (tier 3) with their chosen answer, they are displaying transfer between their chosen representation in the explanation to the representation used in the question.

The next stage of the analysis was determining if the distributions for each levels of physics learning experience are normal and selecting the appropriate tests for comparing means. Kolmogorov-Smirnov tests of normality revealed that the distribution of the survey score was not normal for all groups of students. Consequently, the Kruskal-Wallis tests (non-parametric) was used to determine whether there is significant differences between any of the means (Field, 2003). Post-hoc analysis to identify where the difference exists between particular means was done using an Games-Howell tests (Toothaker, 1993). Man-Whitney Tests with Bonferroni Corrections were completed to ensure the reliability of the Games-Howell tests but the results are not presented in the paper as there was no deviation from the Games-Howell results.

The mean RFS score for each level of physics learning experience were compared to investigate representational fluency as a whole The results were compared to conceptual surveys completed at the same institution with the same levels of physics students from previous years. This was to validate that the RFS was measuring representational fluency distinct from content knowledge. The mean scores on each tier of the RFS for each level of physics learning experience were also compared to investigate whether the trends present with the overall RFS score are mirrored in any of the tiers.

### *3.7.2 Results: Comparing Means*

First we plotted the means for the different levels of physics learning experience. The results are presented in figure 3.2b. The striking point to note is that the trend is not linear. This is in contrast to the linear trend these groups exhibit when results from conceptual surveys are compared in a similar manner, demonstrated in figure 3.2a. These two concept tests, the Force Motion Concept Evaluation (Thornton & Sokoloff, 1997), and the Mechanical Waves Conceptual Survey (Tongchai et al., 2011) are established tests which have been used at the institution in the last decade to measure conceptual knowledge across different groups of physics students. Results from these tests being used on these groups have been published (Sharma et al., 2010, Tongchai et al., 2011) and can therefore be used to compare with the representational fluency of the current cohort of students. While the conceptual ability of the levels of physics learning experience at the University of Sydney increases linearly (as depicted by the  $R^2$  values in figure 3.2: a.), this linearity is not reflected in RFS scores which show the student groups forming two bands, with a gap in between. The four highest levels of physics learning experience (from 1<sup>st</sup> year Advanced to Postgraduate students) form the upper band and

the lowest two levels of physics learning experience (1<sup>st</sup> year Fundamentals and Regular) form the lower band.

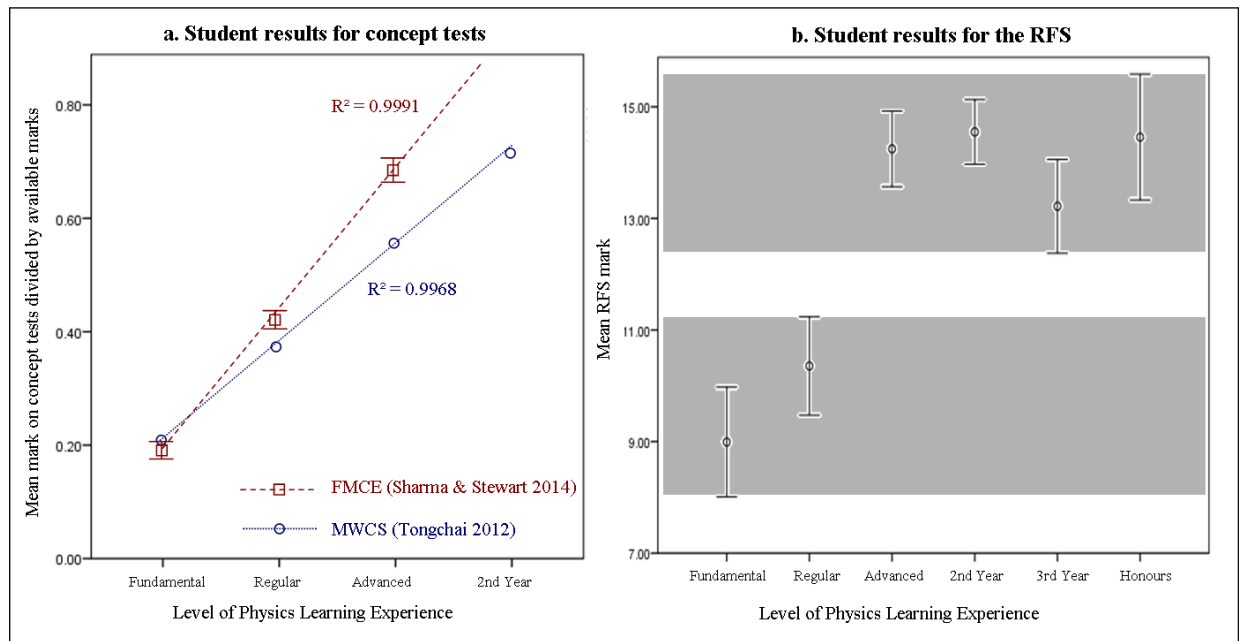


Figure 3.2: a. The average student mark from conceptual surveys (linear relationship). b. The average student mark for the RFS (non-linear relationship). Error bars, where available, depict 95% Confidence Intervals.

The Kruskal-Wallis test reveals a significant difference in the average marks ( $P < 0.001$ ) which is consistent with two clusters as revealed by the post-hoc analysis. The 1st year Fundamental and Regular students typically scored less than 11 out of 18. There was no statistically significant difference between the average mark of these two groups ( $P = .311$ ). The higher band, consisting of 1st year Advanced, 2nd yr, 3rd yr and Postgraduate students, have averages ranging from 13.2 to 14.4. Similar to the lower band, the differences in the means of these four groups is not statistically significant. This relationship is illustrated in figure 3.2 through the emphasis of the two bands which take into account the 95% confidence intervals but show the clear difference between the two sets of groups. Games-Howell tests reveal that when comparing any group in the lower band with any group in the upper band there is a significant difference in the mean scores.

### 3.7.3 Results: Comparing means across each tier of the RFS

The two bands are not only evident when looking at the marks on the whole RFS but also when more detailed data exploration is undertaken. One example is that the bands are evident when student scores for each marking tier are investigated. Figure 3.3 presents the mean marks for each marking tier for the different levels of physics learning experience revealing again the

distinctive lower band (1<sup>st</sup> year Fundamental and Regular) and higher band (1<sup>st</sup> year Advanced, 2<sup>nd</sup> year, 3<sup>rd</sup> year and Postgraduate) with the gap in between.

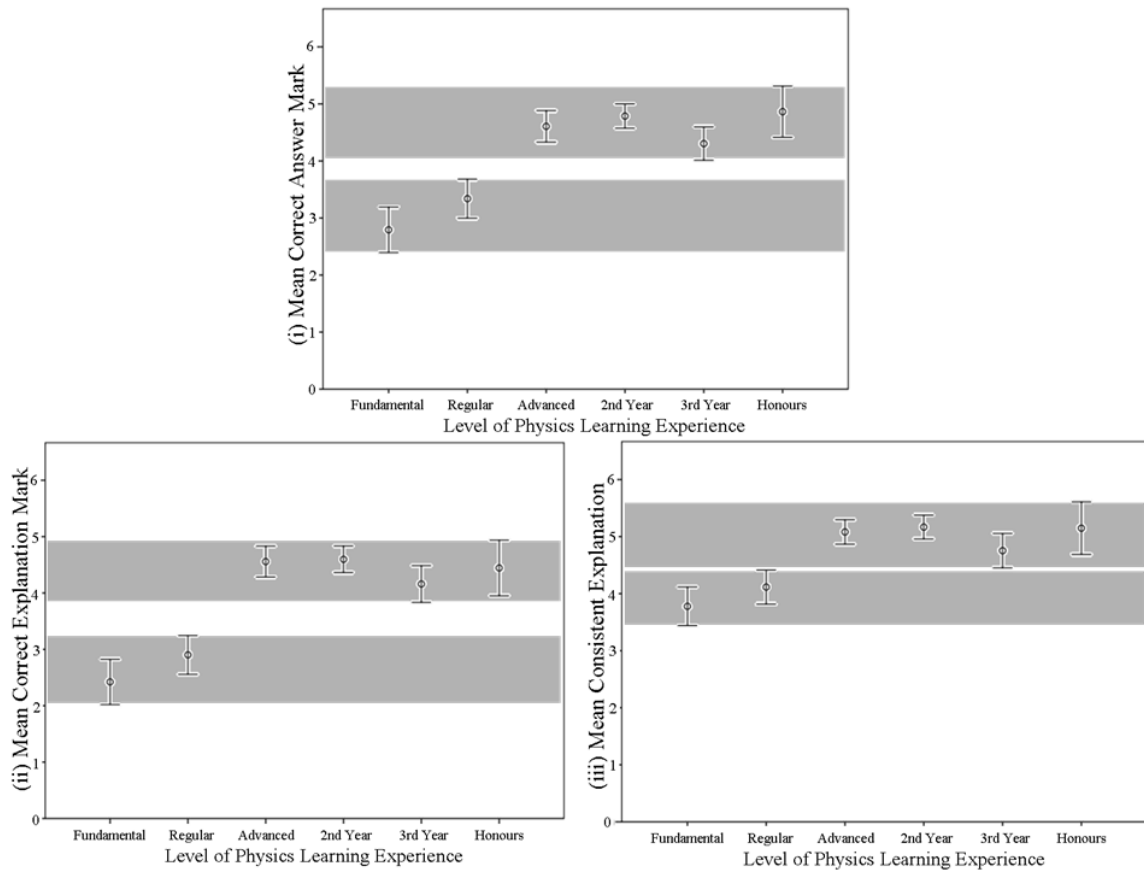


Figure 3.3: Average RFS marks divided into the three tiers of representational fluency. Each graph shows the same band structure as the average overall marks. Error bars represent 95% confidence intervals.

Each tier represents a different element of representational fluency. Tier 1 is whether the chosen multiple choice answer, to the representationally rich question, is correct. Tier 2 represents whether any correct and related information using any representation is used. Finally tier 3 is whether an answer is consistent with the information presented in the students chosen representation/representations. Each tier clearly depicts two separate bands. Statistical analysis is consistent with the visual assumptions as every time, the average scores of those in the lower band are not significantly different from each other, but are from each of those in the higher band. Again, none of those in the higher band are significantly different from each other. The tier with the smallest separation is tier 3, the element based on the consistency between student representations and their answer chosen. This is also the tier with the highest average scores so the ceiling effect results in most of the average scores being closer to each other. Therefore the bands and gap in representational use applies not only to the elements combined but also to the different elements of representational use.

#### *3.7.4 Implications*

Our findings indicate that there is a gap in representational use between the 1<sup>st</sup> year Regular and Advanced learning experience levels. This is somewhat surprising given that these two groups of students are in 1<sup>st</sup> year of university studies, and they would have experienced the same formal educational high school physics curriculum. Rather than having the same representational fluency as the 1<sup>st</sup> year Advanced students, the results show that on average the level of representational fluency of the 1<sup>st</sup> year Regular students is no different from that of the 1<sup>st</sup> year Fundamental students, who had not studied physics in their final years of high school. It also appears that, the 1<sup>st</sup> year Advanced students, the 2<sup>nd</sup> year students, and 3<sup>rd</sup> year students may have the representational fluency which are present in the highest level (Postgraduate) students as measured by the RFS. These are novel findings which are, to our knowledge, to date not present in the literature.

The results provide evidence against the claim that correctly answering some items was due to learning about the content in previous instruction. Prior instruction results in the linear trend with conceptual tests (see figure 3.2a) with Fundamental students scoring lower than the Regular students who in turn score lower than the Advanced cohort. With the RFS, the Regular students are on par with the Fundamental students indicating something beyond conceptual understandings and content knowledge is being measured.

#### *3.7.5 Using the RFS to identify a threshold of representational fluency*

The results presented so far reveal a gap in representational fluency, possibly a threshold above which students could be described as “representationally competent”. The average student from any of the four higher levels of physics learning experience are above the threshold, indicating high representational fluency (HRF), while those in the lower band are below the threshold indicating low representational fluency (LRF). Very few are in the gap not bound by the 95% confidence intervals presented in figure 3.2.

The threshold will need to be in the gap, and for the purposes of answering the second research question we need to choose a value for the threshold. This way of choosing is by no means definitive, but provides a value to work with.

The lower bound of the 95% CI for the lowest scoring HRF group was for the third year students with a lower bound of 12.4, and therefore we have set a boundary minimum for representation fluency as 13. Students who score 13 out of 18 or higher in the RFS can be regarded as displaying high representational fluency. The upper bound of the 95% CI for the

highest scoring group in the LRF group is 11.2, so the boundary maximum mark to be regarded as having low representational fluency is therefore 11.

It is important to note that not all students from particular levels of physics learning experience matched the average trend for that cohort of students. For example, while the average mark for the 1<sup>st</sup> year Regular students was clearly in the category of LRF and the 95% confidence interval was below the gap, there were 17 students who displayed HRF with their RFS mark. Similarly, 8 of the 1<sup>st</sup> year Advanced students attained a mark of less than 12 demonstrating LRF despite the cohort average of over 14. This is unsurprising as the entry criteria for these cohorts are not strictly enforced, there is student choice. There are students studying Regular physics for example who have the academic achievement to undertake Advanced physics and some students in the Advanced cohort who were awarded a place in the course due to their overall high school results which may include many non-science subjects.

Thus having investigated the first research question by comparing levels of physics learning experience, we have also obtained a threshold mark of 12 out of 18 (66%) on the RFS to help us investigate the second research question.

### **3.8 Part 2: Research Question 2**

The second research question involves examining the characteristics associated with proficient use of representations. The characteristics can be probed by counting the representations to analysing based on representational modes (Gilbert, 2004; 2005). Three findings arise from investigating these characteristics of students with high representational fluency:

7. They use significantly more representations;
8. They use a greater variety of representations, which are more scientifically congruent;  
and
9. They use more representations that are visual and symbolic in nature.

#### *3.8.1 Analysis Methodology*

Student explanations provided an avenue for a richer, qualitative analysis. Initial close scrutiny of the types and variations of representations used revealed that most were based on graphs, words, equations and diagrams (similar to Meltzer (2005) and Kohl & Finkelstein, (2005)). Consequently, a coding scheme based on these representations was developed. The coding scheme was validated by three researchers with experience in science education varying from four to 25 years. The intercoder reliability was calculated using Fleiss' Kappa. The value of

Fleiss' Kappa varied had an average of 0.83 and varied from 0.76 to 0.89 or “substantial” to “almost perfect”. Any disagreement between the markers has been investigated and exemplars prepared to maintain consistency of coding. Table 3.3 shows the final coding scheme. The full sample of student responses was then coded. Figure 3.4 then provides an example using item V.

Table 3.3: Final coding scheme for representational use on the RFS.

<b>Representation Code</b>	<b>Description</b>	<b>Responses using this representation include:</b>	<b>Responses which do not satisfy this code:</b>
<b>Graph-based (Symbolic &amp; Visual)</b>	Graphs require content that relates multiple axis. Graphs are both visual and symbolic in nature.	Drawing a graph Drawing lines on a graph to illuminate meaning Marking, circling or shading particular areas on a given graph	Referring to the graph using words: “This can be seen in the right graph”
<b>Word-based (Verbal)</b>	Words provide meaning either through explanation or to present statements of information.	Phrases that contribute to student reasoning including: Working out the answer: e.g. “It seems that the right graph is double the left graph and therefore the higher answer will be correct” Phrases explaining working: e.g. “I did this because...” Phrases explaining the steps: e.g. “Next I solved this by...”	Single word answers: e.g. “Gravity” Comments to the marker: e.g. “I don’t know how to solve this problem”
<b>Equation-based (Symbolic)</b>	Equations are most commonly used as working however may also be to present statements of information.	Responses with an equals sign (=) and numerals or pro-numerals on each side. When mathematical operators are used in calculation steps Covers both algebraic and arithmetic equations	Writing numbers on the page distinct from mathematical working Using a mathematical operator as an index of measurement: e.g. “Intensity = 6x10Lux”
<b>Diagram-based (Visual)</b>	Diagrams provide situational context and allow students to visualize the scenario.	Drawing a picture of the scenario Drawing a free-body or flow diagram Drawing a 1D line diagram (similar to a graph with only one axis).	Unrelated pictures or marks on the page Circling or underlining information presented in the question.

A boy was competing in an orienteering tournament. He was initially stationary but accelerated at  $1.5 \text{ m/s}^2$  east for 2 seconds. He then maintained a constant speed in the same direction for another 30 seconds, before stopping suddenly upon reaching his first checkpoint.

A competitor started at the same point attempting to reach the same marker. She began stationary, accelerated at  $1 \text{ m/s}^2$  for 3 seconds, maintained a constant speed for 28 seconds before decelerating at  $1 \text{ m/s}^2$  for 3 seconds.

Given that they started at the same time, will the boy or the girl reach the checkpoint first?

<p>After they stopped accelerating, they were both travelling at the same speed, but the girl had taken longer to get to that speed, and she decelerated at the end so she was behind there second.</p> <p>Student A: Word-based representation</p>	<p>Student B: Graph-based representation</p>
<p>Student C: Diagram-based and Equation-based representations</p>	<p>Boy: <math>v = u + at</math>  <math>= 0 + 1.5 \times 2</math>  <math>v = 3.0</math>  <math>d = 3.0 \times 30</math>  <math>= 90 \text{ m}</math></p> <p>Girl: <math>v = u + at</math>  <math>= 0 + 1 \times 3</math>  <math>v = 3</math>  <math>d = 3 \times 28</math>  <math>= 84 \text{ m}</math></p> <p>Student D: Equation-based representation</p>

Figure 3.4: Four responses to item V demonstrating coding of explanations as word, graph, diagram and equation based representations (To be read with table 3.3).

Once the student responses were coded according to the representations present, a number of tests were run comparing averages for HRF and LRF students. These include comparing the number of representations used, the variety of representations used, and most favoured modes of representations from each group.

### 3.8.2 Results: They use significantly more representations

For each item, the number of representations used by each student was counted. There were no instances where a student used all four representations for an individual item. Table 3.4 lists the number of representations used by LRF and HRF students for each item.

Table 3.4: The distribution of responses using various numbers of representations for each item.

<b>Item</b>	<b># of Reps</b>	<b>Number of LRF students (n=86)</b>	<b>Number of HRF students (n=74)</b>	<b>Averages</b>
I	0	12	1	LRF = 1.10
	1	57	35	HRF = 1.43
	2	13	17	
	3	4	4	
II	0	6	3	LRF = 1.40
	1	50	37	HRF = 1.30
	2	20	16	
	3	10	2	
III	0	12	4	LRF = 1.05
	1	58	37	HRF = 1.24
	2	16	17	
	3	0	0	
IV	0	27	2	LRF = 1.06
	1	27	10	HRF = 1.79
	2	32	45	
	3	0	1	
V	0	7	1	LRF = 1.37
	1	45	28	HRF = 1.59
	2	29	21	
	3	5	7	
VI	0	33	13	LRF = 0.80
	1	38	18	HRF = 1.47
	2	14	20	
	3	1	9	

For example, in answering item I, 12 LRF students gave no explanation or gave an explanation which was not able to be coded as one of the four chosen representations. 57 students used one representation, 13 used two and four students used three representations. This means that on average LRF students used 1.10 representations in explaining their answer to item I. In a similar manner we obtain an average for HRF students of 1.43 representations. Figure 3.5 shows one of the nine HRF respondents who used three different categories of representations (word, graph and equation based) to construct meaning for item VI.



Different species of rainforest ferns require different levels of sunlight to survive. They obtain the required level of light as a result of their growth habit. The main types of ferns according to their growth habits are:

- Ground dwellers.
- Climbers, using the lower tree trunks to support their upward growth.
- Epiphytes that fasten onto the upper trunks and branches of trees.

The leaves (canopy) of the rainforest trees reduce the amount of light reaching the forest floor. The average height of the canopy trees is 25 metres above the ground, and the average depth of the canopy is 8 metres.

$25 - 8 = 17$

Graph 1 below shows the effect of the intensity of sunlight on the growth (measured as mass increase) of a particular species of fern.

Graph 2 below shows the variation in the intensity of sunlight in a rainforest against height above the forest floor.

Graph 1

Graph 2

From the information provided above, which of the following is the best description of the fern represented in Graph 1?

- A ground dweller close to the base of trees
- An epiphyte fastened onto the branches inside the canopy
- An epiphyte fastened onto branches emerging above the canopy
- A climber that grows to 10m up the trunk of the canopy trees
- An epiphyte fastened onto tree trunks just below the main canopy

Answer: e

Provide information supporting your answer or why you chose your answer:

~~isa~~ from graph 1, the lux can be found.  
 using graph 2 this correspond to = 15m.  
 this is above climber level but below canopy,  
 so must be an epiphyte below the canopy.

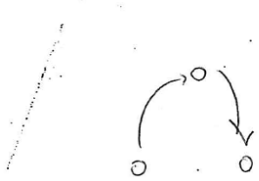
Figure 3.5: A HRF item VI response demonstrating three different categories of representation (word, graph and equation based).

From table 3.4, in five out of six cases the HRF students are using more representations (as a percentage) than LRF students. The exception is Item 2 where on average LRF students used 1.4 representations compared to the average of 1.30 representations used by HRF students. Distinct from each of the other items, for this particular item, using more than one representation was not necessarily correlated with students choosing the correct answer (“A”). Figure 3.6 shows a response from “Student A” who constructs an inaccurate free body diagram where the upward velocity is drawn as a force. This is incongruous with the verbal

representation (that the coin is slowing down) which would imply that the force would be down rather than up.


A coin is tossed straight up into the air. After it is released it moves upwards, reaches its highest point and falls back down again. For each three points described below, choose one of the options A-G. If you think that none apply, write the letter J.

A. The force is **down** and constant.  
 B. The force is **down** and increasing.  
 C. The force is **down** and decreasing.  
 D. The force is **zero**.  
 E. The force is **up** and constant.  
 F. The force is **up** and increasing.  
 G. The force is **up** and decreasing.



**Point 1:** The coin is moving upward after it is released:

Answer: A  
 Provide information supporting your answer or why you chose your answer:



Moving up but slowing down

**Student A:** Word-based and diagram-based representations

---

**Point 1:** The coin is moving upward after it is released:

Answer: A  
 Provide information supporting your answer or why you chose your answer:

The force is due to gravity so it acts downwards and there are no other forces acting

**Student B:** Word-based representation

Figure 3.6: Two responses to Point 1 of item II.

If we total the number of times representations are used across the whole survey, we find that HRF students typically used more representations than LRF students, see figure 3.7.

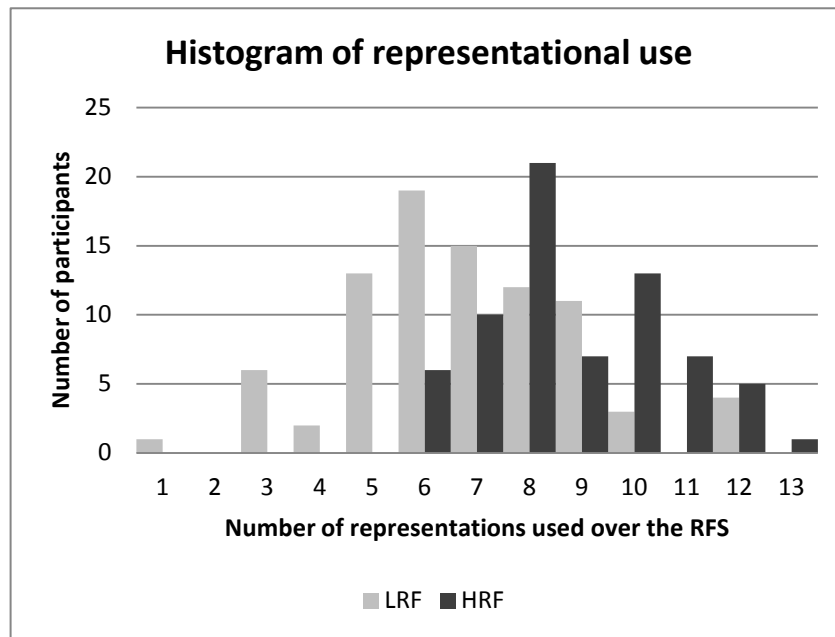


Figure 3.7: Histogram of the number of students using 1-13 representations across the RFS

*3.8.3 Results: They use greater variety of representations, which are more scientifically congruent*

To answer the next two sub-questions, a novel way of interpreting and presenting data is explored - a representation quadrant. It combines the four common representations used in problem solving in science aligning with modes described by Gilbert (2005). The written modes are visual, symbolic and verbal (or word-based). The coding in this paper aligns with the three written modes through graph and equation-based representations being of the symbolic mode, graph and diagram-based representations being of the visual mode and clearly word-based representations are categorised as verbal.

The utility of the representation quadrant is that it allows a mechanism for comparing individual student or groups of students with regards to their explanations of individual questions or groups of questions. It is a form of a radar plot where an outer quadrilateral is drawn to represent the frequency of representations used. For example, figure 3.8 shows a representation quadrant for one HRF student who used word-based representations for five of the six possible times (83%), equation-based representations two of the four possible times, graphs for all four possible times and diagrams one of the three possible times. The representation quadrant illustrates the representations used regardless of whether the responses are correct or not.

A second inner quadrilateral (the lighter shade in figure 3.8) only includes the representations that were used in a scientifically congruent manner (tier 2 of the three-tier marking scheme) For this particular student, every time they used equation and diagram based representations they

used them congruently and this was not the case for graph and word based representations where they were not congruent.

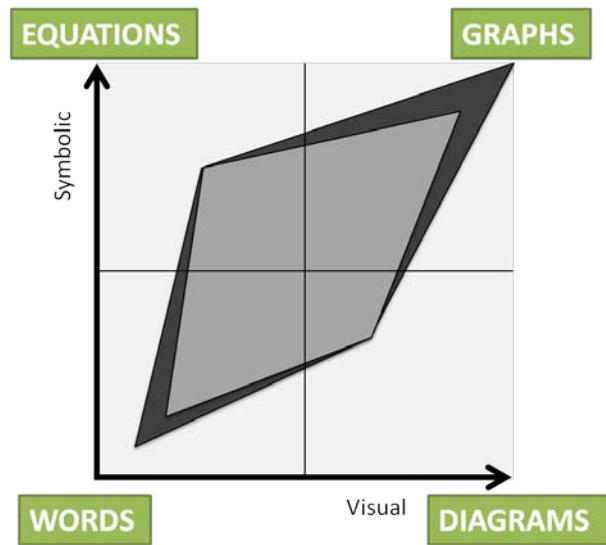


Figure 3.8: Representation Quadrant for one particular HRF student revealing that word and graph based representations were used most prolifically.

The representational quadrant can also be used for groups of students. Figure 3.9 compares representational use for LRF and HRF students. It reveals that HRF students use a greater number (shown by the larger area encompassed by the outer quadrilateral) and greater variety (as the corners of the outer quadrilateral are further from the centre marked by the cross hair). Another very clear difference between LRF and HRF students is the degree to which they use representations coherently (as the corners of the inner and outer quadrilaterals are closer together).

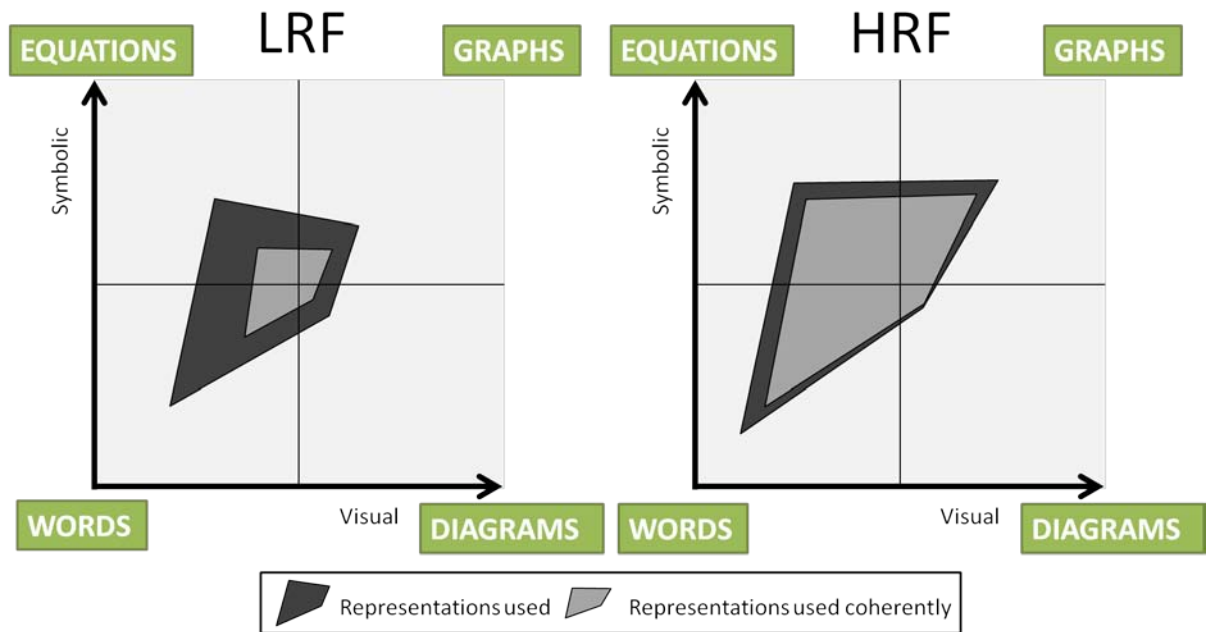


Figure 3.9: Representation quadrants for LRF and HRF students on average.

3.8.4 Results: They use more representations that are visual and symbolic

So far we have shown that HRF students use more representations and they do so in a manner that is more scientifically congruent. But do they choose or prefer to use particular representations more often. Figure 3.10 compares the average percentage of the word, graph, equation or diagram-based representations used by LRF and HRF students. In the case of words, graph and equation-based representations, there is a significant difference between the average use of LRF and HRF students ( $P < 0.001$ ,  $P < 0.001$ , and  $P = 0.006$  respectively). There was no significant difference in diagram use ( $P = 0.355$ ), and the trend is reversed. The effect size is largest for the use of graph-based representations. On average HRF students use almost twice as many graph-based representations than LRF students (Effect Size, Cohen's  $d = 0.91$ ). This is compared to the smaller effect sizes of word-based (Cohen's  $d = 0.63$ ) and equation-based ( $0.45$ ) representations.

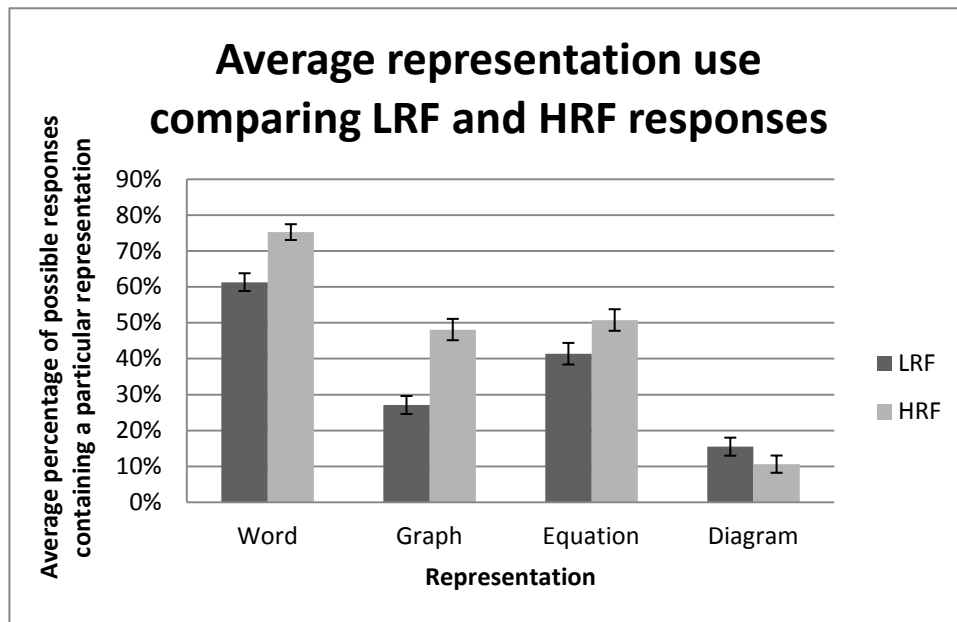


Figure 3.10: The average representation use of LRF and HRF responses (Error bars are 95% Confidence Intervals)

Considering the use of diagram-based representations, the item that most often elicited a diagram-based response from students was item 2, example shown in figure 3.6. For this particular question, diagrams allowed students to visualise the situation, rather than prompt the utilisation of a particularly sophisticated diagram-based representation such as a free-body diagram which assisted in solving the question. It is likely that HRF students generally did not use more diagram-based representations in this manner while LRF students did. Whether this applies more generally needs further research with questions that may require diagrams to reach a solution.

The greatest difference is seen in the use of graph-based representations, which is a representational mode that is both visual and symbolic. This is consistent with Gilbert's (2005) conclusions that novices use more verbal representations and find it harder to branch out into visual and symbolic representations.

To capture our findings, we use the representational quadrant, figure 3.11 which is an adaption of figure 3.9. The area of the representation quadrilateral which is in the symbolic/visual sectors of the quadrant is highlighted. This itself is a graph-based/visual representation depicting how HRF students may be using symbolic and visual representations more often, and more scientifically congruently than LRF students.

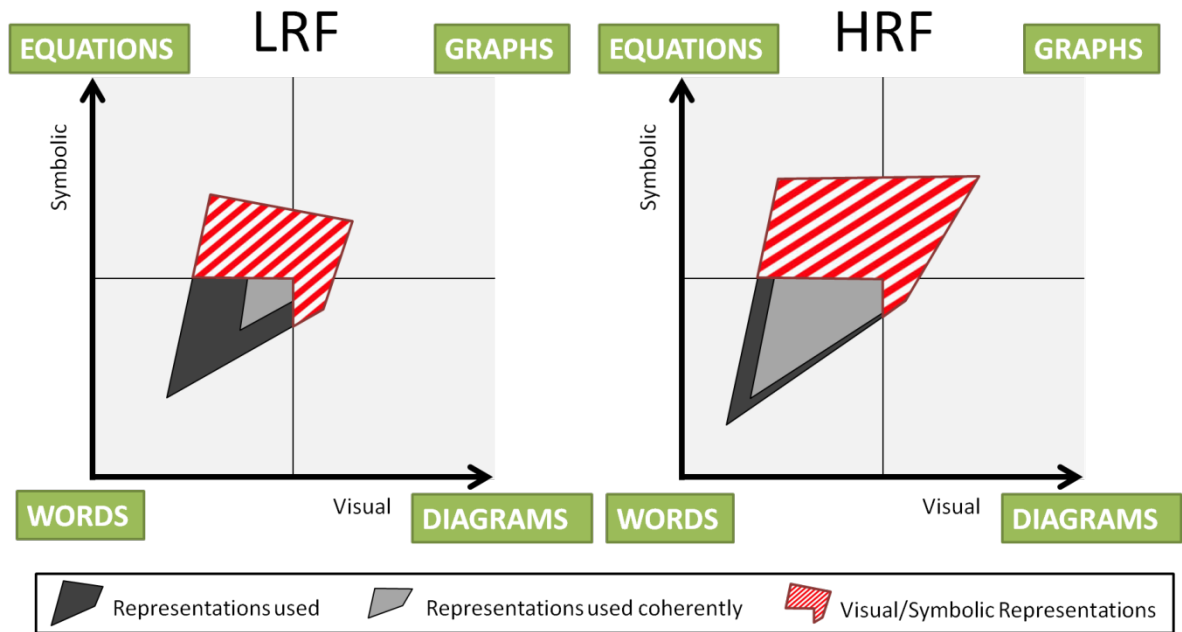


Figure 3.11: Representational quadrants for the average representational use of LRF and HRF students highlighting the greater use of visual and symbolic representations by HRF students.

### 3.8.5 Implications

Our analysis of the RFS shows that HRF students when compared to LRF students:

- Use more representations per question and for the whole survey,
- Use a greater variety of representations and more congruently, and
- Use more symbolic and more visual representations.

While there is research on the importance of representations both individual and multiple for learning science and physics, (Aldrich & Sheppard, 2000; Fredlund et al. 2012; Roth & Bowen, 2003) and conceptual advancements (frameworks) in understanding multiple representational use (diSessa, 2004; Gilbert, 2008), studies on how these manifest themselves with large sample sizes are rare. This paper demonstrates that the frameworks can be utilised to obtain systematic evidence on how multiple representations manifest themselves. An implication of our study is to continue such large-scale studies.

The finding that integrated use of multiple modes indicates stronger physics knowledge is not new. This point was implied by Lemke (1998), and taken up by various researchers (diSessa, 2004; May, Hammer, & Roy, 2006; Tytler et al., 2013). However each of these have qualitatively investigated smaller groups of primary and high school level students whereas this paper describes a study with a large sample size of tertiary students to illustrate that the issue of representational fluency manifests in particular ways at the university level. As a result, our study confirms the criticality of considering and incorporating multiple representations into the

development of instructional methods, in particular to focus on improving representational fluency at a university level. Instruction should both implicitly and explicitly promote students representational use in an integrated way and scaffold towards the often avoided symbolic and visual modes. The lesser use of variety and particularly visual and symbolic representations by LRF students is telling. It may appear, as has been suggested in literature (Dufresne, 2004; Gilbert, 2004), that LRF students feel uncomfortable using representations that are highly symbolic or visual and therefore prefer to use the verbal mode even if the problem is not best solved in this way. Therefore, engaging students with more visual and symbolic representations more often during instruction, complementing words presented both verbally and in written form, may increase their willingness to use such representations scaffolding a greater representational fluency.

Using multiple representations in particular requires students to be able to combine representations meaningfully. To do this, students need to translate between representations therefore teaching strategies designed to facilitate this are consistent with our findings.

### **3.9 General Discussion**

#### *3.9.1 Variation of Representational Fluency*

The results of this paper provide key insights into the use of representations by physics students at university. By analysing the results of the RFS we show a gap in proficiency of representational use. This gap, and clear separation between those who have high representational fluency and those who have low representational fluency is consistent with the notion of there existing a set modes (including representations) that students must be sufficiently fluent with to participate in a disciplinary discourse (Airey & Linder, 2009). The data revealed an unusual point of difference between the cohorts at the University of Sydney. First year Advanced students used representations authentically (Bowen, Roth, & McGuinn, 1999) as second year, third year and Postgraduate (expert) students do, however the first year Regular students did not score significantly different to the first year Fundamental students (novices) who had not studied physics in their final years before university.

This suggests that what the RFS is measuring is distinct from conceptual knowledge (Hill et al., 2014) and rather a measure of inter-representational use, or *representational fluency*. Importantly, as representational fluency is not continuously increasing with levels of physics learning experience it emphasises the significance of developing representational fluency among students with no physics background or limited prior success in physics. For first-year



physics students who did not excel at high school physics, they will need to develop representational fluency in order to continue to learn at university and participate in the disciplinary discourse (Driver et al., 1994).

A more particular implication for instruction is that should students continue to avoid, or have trouble with symbolic or visual representations on paper, discerning information in these forms will remain difficult. This has the potential of being a limitation on learning in any class format and a barrier to continued study in the discipline. Promoting representational fluency amongst students who have not excelled in physics prior to university may result in increased retention rates across science-based degree programs as more students have the both the tool-box and way of thinking to participate in this disciplinary context.

### *3.9.2 Characteristics of Representational Fluency*

Gilbert defined three written modes of representation; verbal, symbolic and visual (2004). By analysing first year student responses by coding them into representational categories, we have been able to link representational fluency to various facets of multi-representational use.

#### *The importance of combining multiple modes*

Representationally fluent students used significantly more representations per question than those with low representational fluency. Such students are not reliant on only one mode to make meaning, rather they demonstrate the metacognitive skill of recognising the particular suitability of a range of representations to convey different information for varied purposes. This means that they can not only choose the most appropriate representation for a given situation (Dufresne, 2004), but will combine representations in order to best present their response. This practice of combining multiple modes relies on the ability to translate between representations, an essential element of representational fluency (Bieda & Nathan, 2009; Nistal et al., 2009).

Therefore, representationally fluent students utilise multiple modes of representations in order to make meaning, solve problems and communicate within a scientific discipline.

#### Gaining proficiency in symbolic and visual modes

Over the whole survey, the students who had low representational fluency had a high dependency on word-based representations. This verbal mode of representations is the written mode most in common with other communities of discourse such as historical or literary studies. In contrast, the visual and symbolic modes are more prevalent in mathematical and scientific disciplines than other contexts. The “authentic” level of representational use (that used by experts) on the RFS involved a high level of symbolic and visual modes, graph-based

representations being an example of both modes. In addition to students over-dependence on the verbal mode, qualitative analysis of the RFS supports prior research that physics students do have a preference for the symbolic mode over the visual mode (Meltzer, 2005). This was evident for item III as well as other items on the survey.

Scientific representational fluency therefore involves a proficiency in symbolic and visual modes, in addition to the more universal verbal mode.

#### The requirement of representational fluency for learning physics

Finally, analysing the responses that students gave through the perspective of representational fluency reveals not only their approach to problem solving but the method by which they integrate new information with prior knowledge (that is, the method by which they learn). Their responses give an indication to the way they use representations to make sense of the world around them. As each representation has different affordances (Gibson, 1977), individuals who can use a wide variety of representations will be more likely to be adept at making meaning from any scientific perspective, not just the particular lens that physicists use to view the world.

The development of scientific representational fluency is essential for successful physics students.

### **3.10 Conclusion**

Representational fluency has been defined through analysing university physics student responses to the RFS. Representational fluency includes authentically making meaning using combinations of modes of representations including verbal (word-based), visual (diagram and graph based) and symbolic (equation and graph based) representations. The cross-sectional analysis of representational fluency at the University of Sydney revealed that students who were exceptional at high school physics are more likely to exhibit a high representational fluency than other students who had studied the same levels of physics pre-university. This presents a particular challenge to first year physics instruction at tertiary institutions to ensure that students can develop representational fluency in order to participate in the disciplinary discourse.

### **3.11 References**

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*(3), 183-198.

- Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching*, 46(1), 27-49.
- Aldrich, F., & Sheppard, L. (2000). 'Graphicacy': the fourth 'R'? *Primary Science Review*, 64, 8-11.
- Beichner, R. J. (1994). Testing student interpretation of kinematics graphs. *American Journal of Physics*, 62(8), 750-762.
- Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637-650.
- Bodner, G. M., & Guay, R. B. (1997). The Purdue visualization of rotations test. *The Chemical Educator*, 2(4), 1-17.
- Bowen, G. M., Roth, W. M., & McGuinn, M. K. (1999). Interpretations of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching*, 36(9), 1020-1043.
- Britton, S., New, P., Sharma, M. D., & Yardley, D. (2005). A case study of the transfer of mathematics skills by university students. *International Journal of Mathematical Education in Science and Technology*, 38, 13.
- diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, 22(3), 293-331.
- Driver, R., Asoko, H., Leach, J., Mortimer, E., Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.
- Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). Solving physics problems with multiple representations. University of Massachusetts.
- Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education.
- Engelbrecht, J., Harding, A., & Potgieter, M. (2005). Undergraduate students' performance and confidence in procedural and conceptual mathematics. *International Journal of Mathematical Education in Science and Technology*, 36(7), 701-712.
- Field, A. (2003). *Discovering Statistics using SPSS for Windows*. London: SAGE Publications Ltd.
- Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction. *European Journal of Physics*, 33(3), 657-666.
- Gibson, J. J. (1977). *The theory of affordances*. Hilldale, USA.
- Gilbert, J. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2, 16.

- Gilbert, J. (2005). Visualization: A metacognitive skill in science and science education. In J. Gilbert (Ed.), *Visualization in science education*. Dordrecht: Springer.
- Gilbert, J. K. (2008). Visualization: an emergent field of practice and enquiry in science education. In J. K. Gilbert, R. Miriam, & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (pp. 3-24): Springer.
- Goldman, S. R. (2003). Learning in complex domains: when and why do multiple representations help? *Learning and Instruction*, 13(2), 239-244.
- Hand, B., & Choi, A. (2010). Examining the impact of student use of multiple modal representations in constructing arguments in organic chemistry laboratory classes. *Research in Science Education*, 40, 16.
- Hill, M., Sharma, M. D., O'Byrne, J., & Airey, J. (2014). Developing and evaluating a survey for representational fluency in science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 22(6), 22-42
- Jacobs, G. (1989). Word usage misconceptions among 1<sup>st</sup>-year university physics students. *International Journal of Science Education*, 11(4), 395-399.
- Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(1).
- Kohl, P. B., & Finkelstein, N. D. (2006a). Effect of instructional environment on physics students' representational skills. *Physical Review Special Topics-Physics Education Research*, 2(1).
- Kohl, P. B., & Finkelstein, N. D. (2006b). Student representational competence and the role of instructional environment in introductory physics. In P. Heron, L. McCullough, & J. Marx (Eds.), *2005 Physics Education Research Conference* (Vol. 818, pp. 93-96, Aip Conference Proceedings).
- Kohl, P. B., & Finkelstein, N. D. (2008). Patterns of multiple representation use by experts and novices during physics problem solving. *Physical Review Special Topics-Physics Education Research*, 4(1).
- Leinhardt, G., Zaslavsky, O., & Stein, M. K. (1990). Functions, graphs, and graphing - tasks, learning, and teaching. *Review of Educational Research*, 60(1), 1-64.
- Lemke, J. L. (1998). *Teaching all the languages of science: Words, symbols, images, and actions*. Paper presented at the Conference on Science Education in Barcelona.
- Lesh, R. (1999). The development of representational abilities in middle school mathematics. *Development of mental representation: Theories and application*, 323-350.
- May, D. B., Hammer, D., & Roy, P. (2006). Children's analogical reasoning in a third-grade science discussion. *Science Education*, 90(2), 316-330.
- McCormick, R. (1997). Conceptual and procedural knowledge. *International journal of technology and design education*, 7(1-2), 141-159.

- Meltzer, D. E. (2005). Relation between students' problem-solving performance and representational format. *American Journal of Physics*, 73(5), 463-478.
- Nathan, M. J., Alibali, M. W., Masarik, K., Stephens, A. C., & Koedinger, K. R. (2010). Enhancing middle school students' representational fluency: A classroom-based study (WCER Working Paper No. 2010-9). Retrieved from University of Wisconsin–Madison, Wisconsin Center for Education Research website: <http://www.wcer.wisc.edu/publications/workingpapers/papers.php>
- Nistal, A. A., Van Dooren, W., Clarebout, G., Elen, J., & Verschaffel, L. (2009). Conceptualising, investigating and stimulating representational flexibility in mathematical problem solving and learning: a critical review. *ZDM*, 41(5), 627-636.
- Pollock, E. B., Thompson, J. R., & Mountcastle, D. B. Student Understanding Of The Physics And Mathematics Of Process Variables In P-V Diagrams. In *2007 Physics Education Research Conference, 2007* (Vol. 951, pp. 168-171, Vol. 1): AIP Publishing
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2006). Case study: Students' use of multiple representations in problem solving. *2005 Physics Education Research Conference*, 818, 49-52.
- Roth, W. M., & Bowen, G. M. (1999). Of cannibals, missionaries, and converts: graphing competencies from grade 8 to professional science inside (classrooms) and outside (field/laboratory). *Science, Technology and Human Values*, 24(2), 179-212.
- Roth, W. M., & Bowen, G. M. (2003). When are graphs worth ten thousand words? An expert-expert study. *Cognition and Instruction*, 21(4), 429-473.
- Roth, W. M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching*, 36(9), 977-1019.
- Shafir, U. (1999). Representational competence. In I. E. Sigel (Ed.), *Development of mental representation: Theories and applications* (Vol. xiii, pp. 371-389). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.
- Sharma, M. D., Johnston, I. D., Johnston, H., Varvell, K., Robertson, G., Hopkins, A., ... Thornton, R. (2010). Use of interactive lecture demonstrations: A ten year study. *Physical Review Special Topics-Physics Education Research*, 6(2).
- Sharma, M., & Stewart, C. (2004). exploring the differences between students trained under the old and new HSC syllabuses. Paper presented at the 11th Biennial Science Teachers' Workshop, Sydney.
- Sia, D. T., Treagust, D. F., & Chandrasegaran, A. L. (2012). High school students' proficiency and confidence levels in displaying their understanding of basic electrolysis concepts. *International Journal of Science and Mathematics Education*, 10(6), 1325-1345.
- Stieff, M., Hegarty, M., & Deslongchamps, G. (2011). Identifying representational competence with multi-representational displays. *Cognition and Instruction*, 29(1), 123-145.

- Thomas, M. O., Wilson, A. J., Corballis, M. C., Lim, V. K., & Yoon, C. (2010). Evidence from cognitive neuroscience for the role of graphical and algebraic representations in understanding function. *ZDM*, 42(6), 607-619.
- Thornton, R. K., & Sokoloff, D. R. (1997). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352. doi. 10.1119/1.18863
- Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2011). Consistency of students' conceptions of wave propagation: Findings from a conceptual survey in mechanical waves. *Physical Review Special Topics-Physics Education Research*, 7(2).
- Toothaker, L. (1993). *Multiple Comparison Procedures* (Sage university paper series on quantitative applications in the social sciences). Newbury Park, CA: Sage.
- Tytler, R., Prain, V., Hubber, P., & Waldrup, B. (2013). *Constructing Representations to Learn in Science*: Springer.
- Uesaka, Y., & Manalo, E. (2006). Active comparison as a means of promoting the development of abstract conditional knowledge and appropriate choice of diagrams in math word problem solving. In *Diagrammatic Representation and Inference* (pp. 181-195): Springer.
- Woolnough, J. (2000). How do students learn to apply their mathematical knowledge to interpret graphs in physics? *Research in Science Education*, 30(3), 259-267.
- Wu, H. K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, 43(1), 63-95.

## **Chapter 4:**

# **Research-based worksheets on using multiple representations in science classrooms**

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### **4.1 Abstract**

The ability to represent the world like a scientist is difficult to teach; it is more than simply knowing the representations (e.g., graphs, words, equations and diagrams). For meaningful science learning to take place, consideration needs to be given to explicitly integrating representations into instructional methods, linked to the content, and supported by explanations as to why the representations play an important role. Unfortunately, developing instructional materials for representations is not trivial. While there is substantive research on student understanding and use of representations, this effort is not reflected in the design of representations-based instructional methods. The purpose of this research is to create research-based worksheets which aid student learning of representations, demonstrate their impact on student practices and extract a framework for developing further worksheets. The method draws on work on teaching science concepts to iteratively develop simple, interactive worksheets that can be used in a school setting with immediate results. We present worksheets that support Year 12 physics students engaging with (1) free-body diagrams and (2) equations of energy. Pre- and post- responses are compared, and reflection questions and focus group data are analysed. A framework that can be used to teach a wide variety of representations from various science disciplines is proposed. Throughout this process we endeavoured to research how instructional design can be done effectively.

## 4.2 Introduction

Duit (2007) describes three significant issues related to science instructional design.

*First, development needs to be fundamentally research-based and needs serious evaluation employing empirical research methods.*

*Second, development should be viewed also as an opportunity for research studies to be included.*

*Third, improving practice is likely only if development and research are closely linked. (Duit, 2007, p. 9)*

Our research endeavours to demonstrate consideration of each of these issues in the design of a framework and worksheets to teach science representations to high school students. While the immediate context is Year 12 physics, the study has broader implications in that the framework can be used to generate worksheets for representation-rich topics in the different science subjects in high school.

## 4.3 Literature: Development needs to be fundamentally research based

A literature search was conducted on various aspects of multiple representation and instructional methods for improving student learning of multiple representations. These are presented below.

### 4.3.1 Using Multiple Representations in Science

Scientists represent the world through a combination of verbal, visual and symbolic representations among others (Gilbert, 2004). Etkina et al. (2006) describe this as the first of seven abilities that science students must possess. From an early age children are taught how words, pictures and numbers can represent things around them. As their science learning experience increases the sophistication of the representations also increases. Words become explanations, pictures are now graphs and diagrams, and numbers are superseded by algebra and equations. The ability to use various types of scientific representations coherently, efficiently, and effectively is referred to as representational fluency (Bieda & Nathan, 2009; Hill, Sharma, O'Byrne & Airey, 2014; Nathan, Stephens, Masarik, Alibali, & Koedinger, 2002).



Helping students experience multiple representations is important in science as not only does knowing multiple representations improve learning, but representational fluency is essential for problem-solving and communication as a scientist. However, “before students can benefit from using a representation, they need to learn the conventions that regulate the way the representation is used, how it relates to reality and how it relates to other representations” (Nistal, Van Dooren, Clarebout, Elen, & Verschaffel, 2009, p. 628). Various instructional methods could be used for realising the above. We decided to focus on worksheets as they are commonplace and provide the opportunity for distilling an overall framework.

#### *4.3.2 Instructional Methods: Experiencing Multiple Representations through Worksheets*

From our review of the literature, we discovered four helpful studies that captured research findings, provided strategies for instructional methods, and had real data supporting their work. Furthermore, the strategies could be purposefully integrated into worksheets, bridging the gap between research and classroom practice in a meaningful way. Key ideas from the four studies for representations-based worksheet design are as follows.

1. Experiencing conceptually based scientific material in a module (similar to a worksheet) before a class improves learning during the lecture or class. Seery and Donnelly (2012) demonstrated this with university chemistry students.
2. Representations-based teaching worksheets are effective at university when there is a set structure which includes explaining the purpose of the modules to students (Jackson & Johnson, 2013).
3. A strongly directed approach to teaching representations has a greater effect on student learning. A strongly directed approach involves explicitly directing students how and when to use a particular representation. (Kohl, Rosengrant, & Finkelstein, 2007).
4. One way of learning the affordances (or helpfulness) of representations for a particular situation is to give students the same problem to be solved multiple times with different representations (Dufresne, Gerace, & Leonard, 2004).

These key ideas were used to create 15-minute worksheets designed to allow students to experience material prior to class discussion (cf. Seery & Donnelly, 2012). The worksheets used a set structure adapted from Jackson and Johnson (2013) and utilised validated approaches to teaching representations (Dufresne et al., 2004; Kohl, et al., 2007).

## 4.4 Research Design: Development needs serious evaluation employing empirical research methods

This section describes the development process, data gathered through two trials and how evidence was used to refine the worksheets.

### 4.4.1 Purpose of the Study

1. To create research-based worksheets in two topics to aid teaching of multiple representations.
2. To empirically demonstrate that the representations-based worksheets can impact student practices.
3. To provide a framework for developing representations-based instruction in other topics and disciplines.

### 4.4.2 The Worksheets

Since Seery and Donnelly (2012) had based their work on conceptual material (chemistry content knowledge rather than representations), we decided to create two sets of worksheets. One was on physics concepts which we call the ‘concepts worksheets’ and the other on multiple representations which are the ‘representations worksheets’. For the concepts worksheets, we drew on the vast array of literature on alternative conceptions, conceptual understandings and, in line with recent efforts, using multimedia (Chen, Stelzer and Gladding, 2010). Both sets of worksheets were created on the topics of forces and energy. Therefore, a total of four worksheets were created (see table 4.1). Appendix B has links to all four final worksheets.

Table 4.1: The four worksheets. Two on the topic of forces, two on the topic of energy.

Topic	Representations Worksheets	Concepts Worksheets
Forces	Free-body diagrams	Tension and friction
Energy	Equations of energy	Kinetic and potential energy

Each pair of worksheets was on the same topic for two reasons. Firstly, the content was to be parallel as both were to be helpful in preparation for a lesson on the topic (forces or energy). The content was equivalent, but very different in that representations worksheets would address student learning difficulties with regards to representations while concepts worksheets would focus on supporting students to further understand physics concepts (such as understanding different forms of energy). Secondly, this allowed for a common question to be embedded across both worksheets to compare student learning from each worksheet.

Each worksheet had three parts; *information* where the representations or concepts were explicitly introduced, *questions* where ideas were to be internalised through application in two questions specific to the information in each worksheet and one common question that was appropriate to the information from both worksheets, and *reflection* which included two questions designed to promote students' metacognition and self-evaluation. The template in figure 4.1 shows the structure, the commonalities, and differences between the representations and concepts worksheets.

<b>Representations Worksheet</b>	<b>Part 1: Information</b>		
	<b>What to master:</b> A list of up to 3 skills	<b>Why you need to know this:</b> Explaining how the skills can be helpful in physics	<b>How to master the skills:</b> Strongly directed/explicit instruction on how to use the representation
	<b>Part 2: Questions</b>		
	<b>Question 1R:</b> Question requiring representational use/thinking	<b>Question 2R:</b> Question requiring representational use/thinking	<b>Question 3: (Common Question)</b> Question appropriate to information from both worksheets
<b>Concepts Worksheet</b>	<b>Part 3: Reflection</b>		
	<b>How well do you think you know when and how to use <i>Representation</i>? (Likert)</b> Allows students and teachers to identify whether further work needs to be done in this area		<b>How helpful was this information for your study of physics this year? (Likert)</b> Helps students connect the instruction to the wider course as a whole
	<b>Part 1: Information</b>		
	<b>Key terms to know by the end of the session:</b> A list of up to 5 linked physics concepts	<b>Why you need to know these concepts:</b> Explaining how the concepts are important to physics	<b>What you need to know:</b> Clear concise definitions, explanations and applications of the concepts
<b>Concepts Worksheet</b>	<b>Part 2: Questions</b>		
	<b>Question 1C:</b> Question requiring conceptual knowledge/thinking	<b>Question 2C:</b> Question requiring conceptual knowledge/thinking	<b>Question 3: (Common Question)</b> Question appropriate to information from both worksheets
	<b>Part 3: Reflection</b>		
	<b>How well do you think you know the concept of <i>Concept</i>? (Likert)</b> Allows students and teachers to identify whether further work needs to be done in this area		<b>How helpful was this information for your study of physics this year? (Likert)</b> Helps students connect the instruction to the wider course as a whole

Figure 4.1: Template for a 15-minute worksheet introducing students to scientific representations or concepts prior to further instruction. Can be used for various scientific disciplines.

#### 4.4.3 Determining effectiveness of the worksheets

A critical question in instructional design is how to determine its effectiveness. Here we capitalised on another opportunity for research (the second of Duit's (2007) significant issues in educational design). We had the students complete the common questions twice, once before doing the worksheets and then as part of the worksheets. This meant that we could ascertain whether completing the worksheet produced change in the student responses. Hence the common questions were a 'measurement' tool, as were the reflection questions. We also held a focus group discussion after the worksheets. Consequently, we had three sets of data to be analysed.

1. Common questions (including comparing answers pre- and post- worksheet instruction, and comparing answers of representations students with concepts students)
2. Reflection questions
3. Focus group discussion

## 4.5 Implementation

In the spirit of Duit's third issue (Duit, 2007), we closely linked development and research. Hence two trials were undertaken to develop and assess the worksheets. Each trial followed the structure of table 4.2.

Table 4.2: The structure of the research experiment.

<b>Duration</b>	<b>Representations Students</b>	<b>Concepts Students</b>
10 Minutes	Common questions 1 and 2	
15 Minutes (Forces)	Worksheet 1: Free body diagrams (contains common question 1)	Worksheet 1: Understanding tension and friction (contains common question 1)
15 Minutes (Energy)	Worksheet 2: Equations of energy (contains common question 2)	Worksheet 2: Kinetic and potential energy (contains common question 2)
10 Minutes	Focus group discussion	

Data were analysed after the first trial with a group of students. Changes were made to the worksheets or questions and the second trial was conducted with a new group of students. Therefore the worksheets were iteratively developed and critically analysed in order to produce a set of research-based instructional materials with demonstrated effectiveness.

#### 4.5.1 The Sample

Each trial was conducted at different schools, with different groups of Year 12 physics students (in their final year of high school instruction). Both schools are classified as independent, non-

selective, K–12 schools in the Sydney region. A total of 32 students from School A completed either the representations or the concepts worksheets. This formed the first trial in the development. School B involved fewer students as some students associated with the class were completing the course by distance. Responses from 13 students from School B were collected.

## 4.6 Results: Common questions

In this section we present the results and discuss how evidence from Trial 1 was used to improve the worksheets for Trial 2. Results of Trial 1 indicated limited benefit of the worksheets, but Trial 2 revealed that the modified worksheets were beneficial for student learning. This clearly affirms Duit’s reminder that experimentation and evaluation is crucial to the development process.

### 4.6.1 Worksheet 1: Forces

Figure 4.2 shows the common question from the forces worksheets. The question was seeking four main forces: weight, friction, a pulling force from the rope (tension) and a normal/restorative force from the ground on the box. Both sheets were designed, in different ways, to help the students to identify these forces. We expected students who had completed the concepts worksheet to more readily identify tension and friction by name, and the students who had completed the representations worksheet to be more likely to identify the often forgotten normal force.

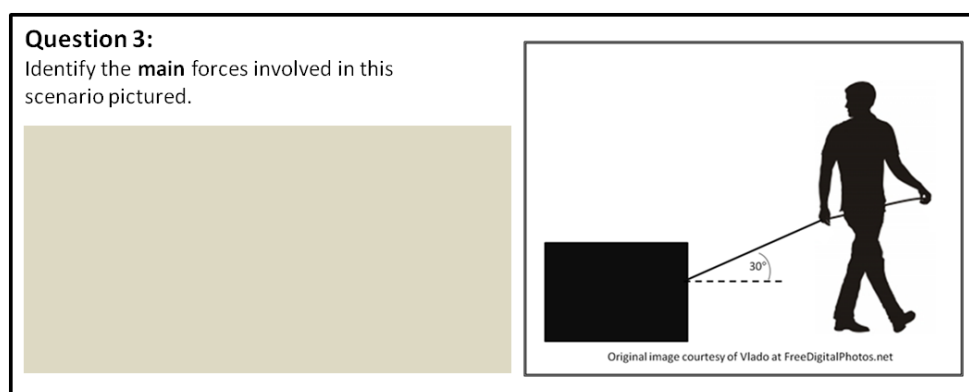


Figure 4.2: The common question from the worksheets on forces.

To illustrate changes in student responses before and after completing the worksheet we calculated gains. The gain is the increase in the percentage of students identifying a particular force after completing the worksheet, divided by the percentage of students who did not identify the force before instruction. For example, 21% of the concepts students had identified tension by name pre-instruction and 79% had not. After instruction, those 79% of students had all also

identified tension, giving a gain of 100%. In figure 4.3 the size of the arrow shows the gain with arrows pointing to the right indicating positive gain, or more students identifying the force. Arrows pointing to the left indicate negative gain, or fewer students identifying the force.

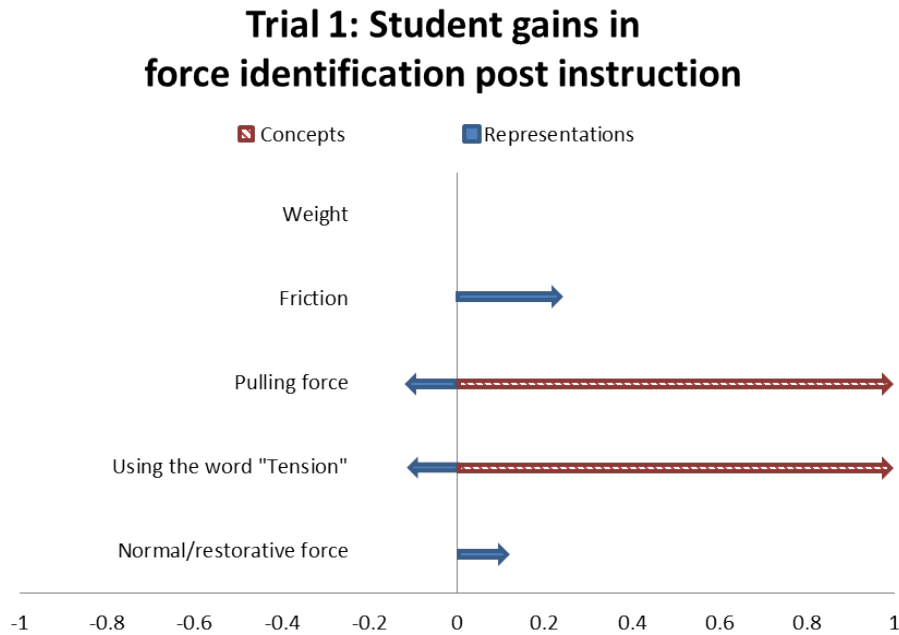


Figure 4.3: The gain in students identifying forces for common question 1. When there is a 100% gain, all students who did not identify the force pre-instruction identified it post-instruction. No arrow indicates no change.

From figure 4.3, we note that with all concepts students identified the pulling force as “tension” post-instruction; the gain is 100%. This occurred in two categories for the concepts worksheets, but there was no gain in the other categories. For the representations students, two categories registered small positive gains (including the elusive normal force). However, there were two which had negative gains as fewer students identified the force post-instruction.

In summary, these results indicate that the concepts worksheet is effective at scaffolding student learning. However, there is limited indication of the benefit of the representations worksheet. This was therefore the worksheet that needed to be developed prior to the second trial.

Specific changes to the representations worksheet on free-body diagrams were made. The *Information* and *Questions* sections were made more strongly directed (Kohl, et al., 2007). Explicitly, instead of pointing to features of a free-body diagram and giving examples, a four step process of how to draw a free-body diagram was provided, followed by one example with a 90 word explanation of the image.

The new worksheets were used in Trial 2 with the same common question and analysis. See figure 4.4 for gains.

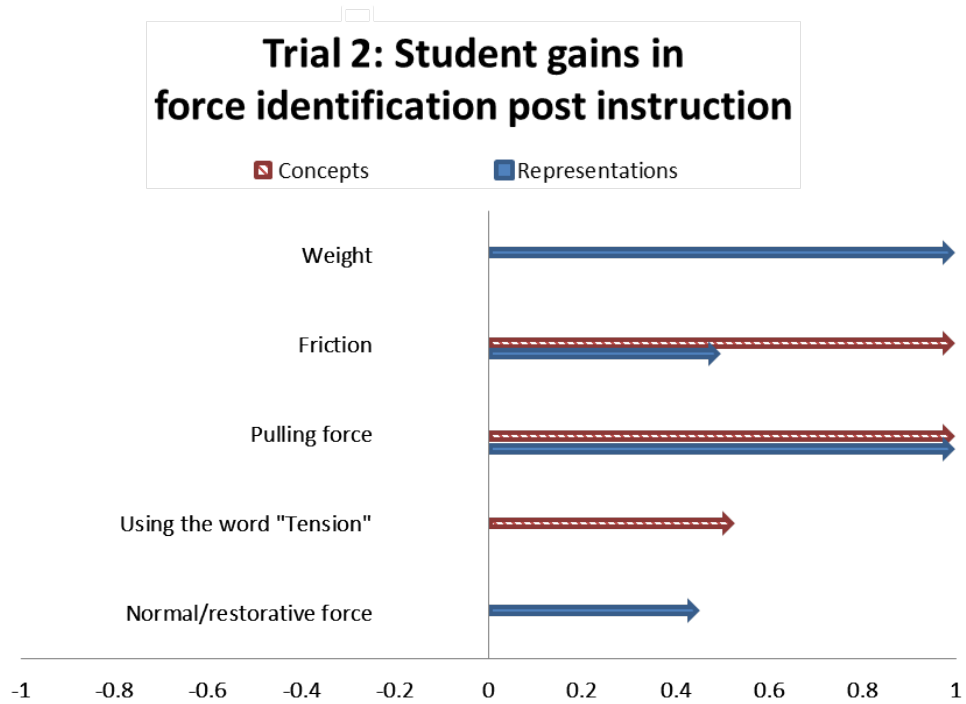


Figure 4.4: The gain in students identifying forces for common question 1 during Trial 2 showing much larger gains for the representations worksheet than during the first trial.

The concepts worksheet remained relatively unchanged from Trial 1 to Trial 2 and so unsurprisingly, there was 100% gain for pulling force and a large gain of 60% for tension. The students who did not use the word tension communicated the forces using a diagram rather than words which accounts for less than 100% of students naming the force “tension”. Rather pleasingly, this group of students also had a 100% gain in identifying friction.

In the case of the representations students there is an increase in almost every category but most distinct from the concepts students is the increase in students identifying weight and identifying the normal force. The difference in student responses suggests that the students with representations instruction were more likely to visualise the situation through the lens of a free-body diagram resulting in greater increases in forces identified by students with representations instruction than those with concepts instruction. This is especially true for identifying the normal force which often is remembered after drawing a free-body diagram requiring the balancing of forces.

#### 4.6.2 Worksheet 2: Energy

Figure 4.5 shows common question 2 on energy used in Trial 1. The goal was to see which representations students would use in their answer, especially whether the representations students would use more sophisticated representations of equations or diagrams.

**Question 3:**

Write out a plan (i.e. What steps you would take) in the box below for how you would solve the following problem: A car is travelling along a level icy road with no traction (that is, no friction) and comes to a rise 20m long at an inclination of 25 degrees. What minimum speed does the car need to be going at the bottom of the slope to reach the top?

Figure 4.5: The common question for the Energy worksheets. This is the question used in Trial 1 which was then modified for Trial 2.

Many students found this question confusing and were unable to provide coherent answers. The typical response was to draw a picture and write a long list of equations, many not suitable to solve the problem. For this question, student responses were coded as utilising one or more of three representations - words, equations or diagrams. It was found that students completing both worksheets used similar representations in their answers (figure 4.6).

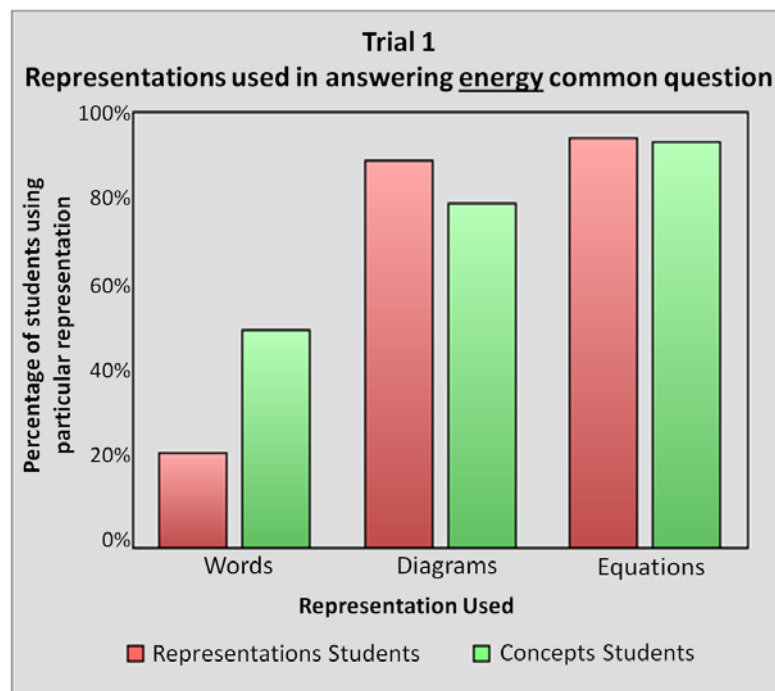


Figure 4.6: Percentage of students using particular representations (words, diagrams and equations) to answer the common question of the energy worksheets (Trial 1).

In the case of the worksheets on forces described earlier, we had modified and improved the Information section of the worksheet. For the worksheets on energy there is a different issue as the common question is not distinguishing between representations students and concepts students. Therefore, in consultation with experts in education research, the common question



was made more sensitive. Therefore, for Trial 2, a rollercoaster travelling in a loop rather than a car sliding without friction was used for the common question. The premise behind the question was fundamentally the same, but the content was changed and an image was included. The new common question for Trial 2 is included as figure 4.7.

**Question 3:**  
 Solve the following problem: For a roller coaster to make it around a vertical loop (see diagram) it must be going at a minimum speed based on the loop. If the loop is a circle with radius 15m, how fast must the roller coaster car be going at the bottom of the loop to make it around the whole loop?

Please explain your method in solving the problem as you go, even if you are not sure how to solve it:




Image used with permission from freemages.com

Figure 4.7: The common question for the energy worksheets (Trial 2).

Figure 4.8 shows the results of Trial 2. Concepts students predominantly used words in their answer while representations students were more likely to draw or refer to a diagram and to use equations in their response. These representations are regarded as more sophisticated than a simply words-based response in the research literature (Dufresne, et al., 2004; Gilbert, 2004). These data reveal that the modified question was sensitive to insights gained by students from the different worksheets. In particular, that the representations students were able to use more diagrams and equations in their problem solving methods.

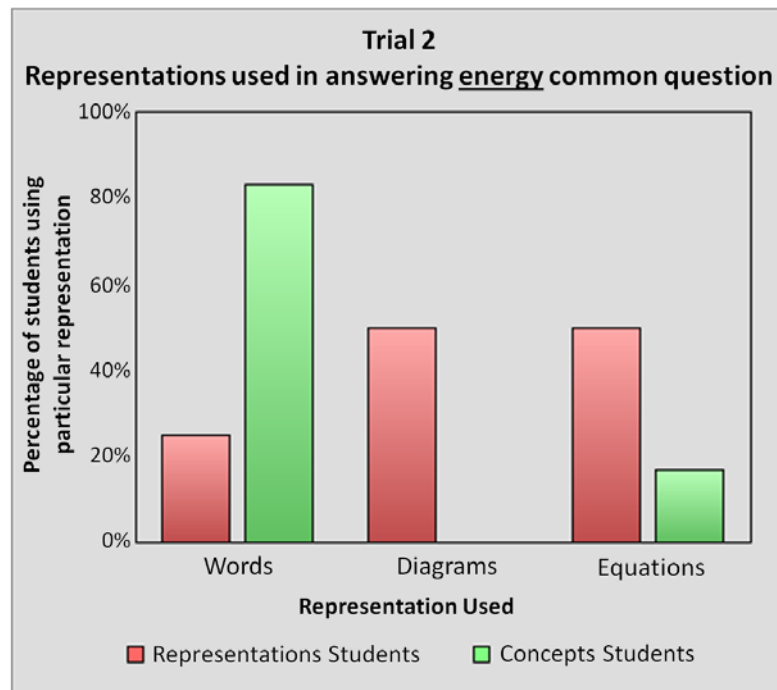


Figure 4.8: Results of energy worksheets common question (Trial 2). Percentage of students using the representations of words, diagrams or equations in their responses.

## 4.7 Results: Reflection Question and Focus group discussion

While student perception of their own learning does not always correlate with actual learning (Spinello & Fischbach, 2008) the students' opinions on the worksheets and their feedback for improvements was a valuable resource. We will make brief mention of the results that impacted worksheet development.

### 4.7.1 Reflection questions

Typically students found the worksheets helpful for their study of Year 12 physics. On average, 86% of students indicated that the worksheets were at least partly helpful. Few students indicated that the worksheets were "very helpful" but we predict that this is because there may be limited perceived helpfulness of an exercise that only lasts 15 minutes. In addition, the worksheets were not designed to be a complete lesson, rather to put students into the right frame of mind for a regular class on the topics of forces or energy.

### 4.7.2 Focus group discussions

During class discussions after completing worksheets on both topics (forces and energy) the students as a group were asked questions including: "Did they have enough time for the worksheets?", "What did they learn?", and "What did they find confusing?" These were conducted after each trial.

Results across the board indicated that the worksheets were of the right length, with some students responding that there was too much time for the forces worksheet. There is potential for greater content but one should be careful not to put too much into any worksheet.

Students were able to articulate a variety of new things that they had learned, despite the limited content. Students who completed the concepts worksheets felt that they had been reminded of the definitions of certain concepts and were interested in the particular fact that "*kinetic friction is less than the force of the static friction*" (Concepts Student). Students who completed the representations worksheet recognised the process and problem-solving strategies that they had learned; "*the conservation of energy, I wouldn't generally think in that way of using an equation ... for question A (common question 2 given before instruction) I actually wrote an equation without realising it but then on part B (common question 2 given after instruction) I realized, "oh", and changed it so that it used the law of conservation of energy*" (Representations Student).

When asked what they found confusing, multiple students remarked after the first trial that they were still confused about free-body diagrams. No students made this comment after the second trial when completing the updated and simplified worksheet. There were other terms that needed clearer definitions including “static friction” and “work”.

## **4.8 Discussion**

Instruction must incorporate both teaching and research. This is the fundamental idea behind the three important principles identified by Duit (2007). While there will always be those who specialise in one of these two areas, it is important that teachers understand and participate in research and that researchers do not see themselves independent from teachers.

### *4.8.1 Demonstrating how research-based representations worksheets can impact student practice*

Classroom teachers recognise this as a nontrivial task. After two trials, we were able to show that by completing a 15-minute worksheet on representations students were more likely to use diagrams and equations in problem solving than students learning about related physics concepts. We cannot hope to completely change the students representational practices with such a short worksheet, however these students are now prepared to view further class instruction (or homework) through the lens of the particular representation introduced, resulting in improved learning in class (Nistal, et al., 2009).

Further study is needed to investigate the long-term impact of regular, brief representation experiences used in this study. Already, research at a university level by the authors has indicated long-term gains in both representational fluency, and conceptual understanding as a result of similar activities.

### *4.8.2 Providing a template and process of how teachers can develop representations-based instruction suitable to their discipline*

This was achieved in two ways. Firstly, the explicit structure of representations-focused (and concepts-focused) worksheets set out in Figure 1, which has shown to have the potential to be effective through this study. The second way is through demonstrating the development process, which includes reflective assessment of the worksheets and student answers. In the case of the worksheets on the topic of forces, the content of the worksheet on free-body diagrams needed to be modified after Trial 1. The same common question was able to be used. However, we demonstrated how it is not always the content that needs modification. In the case

of the worksheets on the topic of energy, the common question wasn't sensitive enough to measure differences in student learning. In this case, the question had to be changed. Each of these issues in instructional design, both improving content and assessment, are common problems to address which are encountered in research.

Through taking the template of the worksheet structure, and following the model set out in this paper, teachers from different scientific disciplines are further enabled to produce research-based, tested, instructional material for their students. Using the template, worksheets could be developed as needed for particularly 'representation-rich' topics and 'conceptually rich' topics for local contexts.

## 4.9 Conclusion

We have highlighted and demonstrated key elements of instructional design. A set of worksheets that can be used to teach students representations in physics, a novel template for worksheet design, and an example of integrating research and teaching applicable to any lesson planning or design are included.

## 4.10 References

- Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637–650.
- Chen, Z., Stelzer, T., & Gladding, G. (2010). Using multimedia modules to better prepare students for introductory physics lecture. *Physical Review Special Topics—Physics Education Research*, 6, 010108,
- Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). Solving Physics Problems with Multiple Representations. Department of Physics & Astronomy and Scientific Reasoning Research Institute. University of Massachusetts.
- Duit, R. (2007). Science education research internationally: Conceptions, research methods, domains of research. *Eurasia Journal of Mathematics, Science & Technology Education*, 3(1), 3–15.
- Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy, S., Rosengrant, D., & Warren, A. (2006). Scientific abilities and their assessment. *Physical Review Special Topics—Physics Education Research*, 2(2), 020103.
- Gilbert, J. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2, 115–130.

- Hill, M., Sharma, M. D., O'Byrne, J., & Airey, J. (2014). Developing and Evaluating a Survey for Representational Fluency in Science. *International Journal of Innovation in Science and Mathematics Education, 22(6)*.
- Jackson, D. C., & Johnson, E. D. (2013). A hybrid model of mathematics support for science students emphasizing basic skills and discipline relevance. *International Journal of Mathematical Education in Science and Technology, 44(6)*, 846–864.
- Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics-Physics Education Research, 3(1)*. doi: 10.1103/PhysRevSTPER.3.010108
- Nathan, M., Stephens, A., Masarik, D., Alibali, M., & Koedinger, K. (2002). Representational fluency in middle school: A classroom based study. Paper presented at the Proceedings of the twenty-fourth annual meeting of the North American chapter of the International Group for the Psychology of Mathematics Education. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.
- Nistal, A. A., Van Dooren, W., Clarebout, G., Elen, J., & Verschaffel, L. (2009). Conceptualising, investigating and stimulating representational flexibility in mathematical problem solving and learning: a critical review. *ZDM, 41(5)*, 627–636.
- Seery, M. K., & Donnelly, R. (2012). The implementation of pre-lecture resources to reduce in-class cognitive load: A case study for higher education chemistry. *British Journal of Educational Technology, 43(4)*, 667–677.
- Spinello, E. F., & Fischbach, R. (2008). Using a web-based simulation as a problem-based learning experience: perceived and actual performance of undergraduate public health students. *Public Health Reports, 123(Suppl 2)*, 78–84.



# **Chapter 5:**

## **Pre-lecture online learning modules in university physics: Student participation, perceptions, and performance**

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### **5.1 Abstract**

In our earlier paper published in this journal, we described short-weekly online learning modules (OLMs) that were carefully created to supplement a first-year university physics course (Hill, Sharma, & Johnston, 2015). Where the previous paper was focussed on the merits of the content of the OLMs, this paper is focussing on the student uptake to allow for fellow practitioners to benefit from our experience. Online learning is often tried, but less often tested. For practitioners, it is useful to understand when and how students participate, why do or don't students participate, and what are students' opinions of online learning. Here we present the frequency and duration of student engagement with OLMs based on data collected automatically by the learning management system, and results of a survey. Over 75% of students who completed the final exam were deemed to have actively participated in the OLMs for an average of approximately 15 minutes each week. Despite the flexibility of having almost four days to complete the modules, the majority of students completed them 24 hours before the deadline. Students reported that they completed the modules as they found them helpful for learning and for the 1% contribution to the final course mark regardless of correctness of answer. Students reported that the modules improved their understanding, prepared them for lectures, and provided other benefits such as motivating regular participation. When considering performance, students who achieved high distinctions completed the most OLMs at an average of  $10.7 \pm 1.4$  modules, while students who failed the course only completed  $4.1 \pm 3.8$  modules on average. As each grade level increases, so does the average number of OLMs completed. From another perspective when comparing students who completed more than eight OLMs with those who completed less than 4 using an established physics concepts test (the Force & Motion Concept Evaluation), students who completed more modules had higher learning gains across the semester. Results from this study assist educators

in understanding the dynamics of introducing online learning in face-to-face courses and contribute to the growing body of literature into the efficacy of blended learning. For the practitioner often baffled by the significant amount of data that can be queried through learning management systems, this paper offers an analysis using these data to consider what blended learning looks like for the students.

## **5.2 Introduction**

### *5.2.1 The move towards online learning*

Online environments have been used for learning for over 40 years (Harasim, 2000). More recently, particular forms of online education have emerged such as flip-lectures and MOOCs (Massive Open Online Courses). Despite an apparent consensus, as stated in Oncu & Cakir (2011), that learning through an online learning environment may be superior to classroom instruction, researchers have pointed out the lack of rigorous efforts to demonstrate how learning in an online environment can achieve its potential (Chen, Wang, & Chen, 2014; Lack, 2013; Oncu & Cakir, 2011). Integrating online instruction with face-to-face teaching is popular in university courses. This is known as blended learning (Black, 2002; Swan, 2009).

### *5.2.2 Types of blended learning*

As is the case for online learning in general, there is mixed evidence and a lack of rigorous research studies into the effectiveness of blended learning (Means, Toyama, Murphy, Bakia, & Jones, 2009; Zhao & Breslow, 2013). Despite this, there are many instances where blended learning has been shown to be effective, often more so than traditional classroom instruction (Black, 2002; Chen, Stelzer, & Gladding, 2010; Day & Foley, 2006; Day, Foley, Groeneweg, & Van der Mast, 2004; Lumsden, 1976; McFarlin, 2008; Moore, 2014; Neumann & Hood, 2009; Pargas, 2006; Seery & Donnelly, 2012; Stelzer, Brookes, Gladding, & Mestre, 2010; Stelzer, Gladding, Mestre, & Brookes, 2009; Utts, Sommer, Acredolo, Maher, & Matthews, 2003).

Several ways of considering the extent to which the different learning opportunities integrate, and the anticipated student time on particular activities are available. Two of which are presented here. Twigg describes four models of blended learning (2003)

1. Supplemental: adding extra online instructional activities to an existing course,
2. Replacement: replacing activities in an existing course with online instruction,
3. Emporium: mainly online with some classroom instruction
4. Buffet: students can choose from a variety of online and in the classroom activities, further elaborated in (Hood, 2013).



This can be compared to Alammary, Sheard, and Carbone's (2014) three approaches; "low-impact blend" (similar to supplemental), "medium-impact blend" (similar to replacement), and "high-impact blend" which includes both emporium" and "buffet". The 'impact' refers to the extent of change that introducing an online component makes to the course. For the practitioner considering blended learning, these descriptions provide ways of articulating the incorporation online learning into the design of the course.

### 5.2.3 *Measuring student participation in online activities*

In their review article, Means et al. (2009) suggest that the positive effects of blended learning (and purely online learning) may often be due to more time on task rather than online learning environments being a better medium (see also (Beer, Jones, & Clark, 2009; Chen et al., 2010; McFarlin, 2008; Stelzer et al., 2010)). Spending extra time on task using online learning environments, through increased student motivation or greater accessibility to resources, is a recognised benefit (Ruiz, Mintzer, & Leipzig, 2006) and therefore it is vital that studies explicitly measure participation related to time students spend on online activities.

Online environments allow for tracking of student usage, however few studies go into details of when, how often, and for how long students use online resources in their learning experience. Often studies in online learning fail to report on retention rates and instead, like many course providers, choose to focus on how many students have enrolled (Means et al., 2009). In contrast to this, one instance of detailed reporting is a large-data study in medical education using log files to track how students accessed online lectures (Craig, Wozniak, Hyde, & Burn, 2009). The researchers found that the frequency of student participation certainly justified the financial cost and instructor effort required to publish the content. Student participation in the many facets of the blended learning course were mapped allowing the administrator to separate self-directed students with regular participation in many learning activities from those who accessed online lectures in the lead up to an assessment. Studies into blended learning can neglect reporting the level of engagement with online activities, possibly implying all students completed them (Chen et al., 2010; Stelzer et al., 2010). Some studies do report on these patterns and have found relatively high levels of participation despite small credit incentives and also that students are likely to complete exercises very close to the due date despite the inherent flexibility of online access (Seery & Donnelly, 2012). This paper will continue to investigate these questions of student engagement in particular how often, for how long, and when during the week and over the semester do students utilize online learning in the case of a blended learning course in university physics. This paper adds to the current research as it is a large scale study within a calculus based first year university physics case using the supplemental model of blended learning.

#### 5.2.4 *Student perception of online activities and blended learning*

Student motivation and self-efficacy are key contributors to time on task and effective learning engagement (via likert-scale surveys in Lindstrøm and Sharma, 2011), especially when it comes to activities in the less regulated online learning environment (measured using a motivation strategies learning questionnaire in Wang, Shannon, & Ross (2013)). Measuring student satisfaction and student perceptions of online learning activities allows for a deeper understanding of the positive elements of a blended learning course and identification of barriers to effective engagement. Alammary et al. (2014) give warnings and recommendations for blended learning courses (specifically courses of the supplemental model). Specifically, they warn that adding extra online activities can be a burden to students and recommend that online activities should be integrated well with the existing course in order to address a pedagogical need (this was further argued by Wu, Tennyson, & Hsia (2010)). Successful studies report students perceive a benefit to learning from a blended course structure (Black, 2002) and especially that face-to-face time was used more effectively (Day et al., 2004; Moore, 2014). Why students complete online activities differs depending on the type of activity and the distribution of learning activities. To maximize student engagement, it is recommended that students recognise the intended benefit of particular online learning activities as they complete them. Why students chose to, or chose not to, complete online learning activities is another matter for investigation in this paper. It must be briefly noted that engagement is due to a range of factors and has been particularly associated with active learning (for review articles see Prince (2004) and Freeman et al. (2014)). In this paper the focus is on online learning and engagement but for explicit examples of active learning in physics see Georgiou and Sharma (2015) and Sharma et al. (2010).

#### 5.2.5 *Purpose of the study*

In light of the current state of research focusing more on design and final outcomes of blended learning courses this paper will focus on student engagement in an online learning environment to supplement learning in a large first year university physics course (supplemental model). The general research question probes the patterns and perceptions of student engagement with weekly pre-lecture OLMs throughout a semester of undergraduate physics education. The specific research questions and facets examined are:

4. What are the patterns in student use of Online Learning Modules (OLMs) in this course?
  - 1.1 What is the pattern of participation across the semester?
  - 1.2 How long do students stay logged onto the OLMs?
  - 1.3 When do students choose to complete the OLMs?

5. Why do/don't students engage with OLMs?
6. Is introducing the OLMs associated with improved learning and experiences?
  - 3.1 Do completing OLMs improve student learning?
  - 3.2 What are student opinions of the OLMs?

The intention is to share our research with practitioners, who are either considering blended learning and unsure of the student response, or those who have already implemented blended learning and may be exploring how to measure and analyse the student response.

### 5.3 Method

This paper presents a case study using a mixed methods approach, more particularly a mixed-model design (as described by Johnson and Onwuegbuzie (2004)). By combining quantitative and qualitative research approaches we can answer a broader “range of research questions because (we) are not confined to a single method” (Johnson & Onwuegbuzie, 2004). In this section, the context is explained through describing the student population, the form and purpose of the OLMs, and the methods that are used to analyse student participation, perceptions, and subsequent performance on an established physics concept test.

#### 5.3.1 *Implementing Online Learning Modules*

Sets of 12 OLMs were developed for a 1<sup>st</sup> year calculus-based physics course at the University of Sydney. The students undertaking the course were in their first semester of university. They had studied physics through to the end of their secondary education. The course was the “Regular” physics course as opposed to the “Advanced” course which consisted of high achieving students based on their grades in secondary education. In 2014, the cohort had 656 students who completed the final exam. For timetabling reasons the students were divided into five lecture streams (or section) with four different lectures covering identical content for three lectures per week.

The OLMs were designed as weekly exercises for students to complete in order to prepare for the upcoming week's lectures. Each week's module was divided into three brief sections,

- Information, where content was presented
- Questions, where students were asked questions related to the content
- Reflection, where students were prompted using metacognitive questions to reflect on their learning.

Figure 1 is a screenshot of the first module deployed using the universities eLearning platform “Learning Management System (LMS)”. More details on the development and content of the OLMs are described in Hill et al. (2015). This is not repeated in this paper as the response of students rather than the content of the OLMs is the focus of the investigation. A sample OLM can be found in Appendix 1.

The screenshot shows the LMS interface for The University of Sydney. The top navigation bar includes 'My Units of Study', 'eCommunities', 'Staff', and 'SEAMS'. A 'Question Completion Status' bar is visible. The main content area is titled 'Question 4' and is worth 10 points. The question text reads: 'Example of a free body diagram: There are two free body diagrams in the picture below the text, one for each basketball player. The man on the left is standing on the ground and therefore there is a 'normal' force ('n') from the ground on the man pointing upwards. The two forces balance out so he will experience no acceleration at this point. The man on the right has jumped in the air. The only force applying to him is the weight force downwards. Therefore we can calculate his acceleration using Newton's 2nd Law ( $F=ma$ )'. Below the text is an image showing two basketball players with their respective free body diagrams. The first player is standing on the ground with an upward arrow labeled 'n' and a downward arrow labeled 'W'. The second player is jumping in the air with a downward arrow labeled 'W'. The image is credited to 'Images courtesy of vectorolie at FreeDigitalPhotos.net'.

Figure 1: A screenshot of a component of an OLM offered to 1st year university physics students

The OLMs were designed to take 15 minutes with a recommended 30 minute time limit. They were available from 5pm on a Thursday until 10am on the coming Monday when the first lecture of the week occurred. Students were marked for participation, and completion of 11 of the 12 OLMs available through the semester resulted in the student being awarded 1% of the end of semester physics mark. (As this was a new and supplemental component of the course only 1% of the end of semester grade was allowed by the course organisers to be awarded for the OLMs.)

Students were informed of the OLMs in a variety of ways:

- (a) Through the standardised course outline provided online and in the first lecture of the course
- (b) Verbal explanation in the first lecture and hand-out explaining how to access the OLMs

- (c) Verbal reminders in lecture and laboratory classes during the first two weeks of semester
- (d) Weekly emails to students reminding them of their responsibilities for that week
- (e) Emails to students at time of deployment of the OLMs on four occasions; during the first week, at the beginning of each new topic area, and for the final OLMs.

### 5.3.2 *Measures of student engagement with the OLMs*

Student engagement with OLMs was measured in four main ways.

#### Tracking student participation in OLMs online

The LMS recorded the date, time and duration of every student attempt at an OLM. This allowed for most of research question 1 to be answered. We were also able to use these data to determine the number of OLMs completed by each student to answer research question 3 on student learning. The LMS data was transferred to SPSS and analysed by grouping and sorting.

#### Final module with reflection questions

The final OLM included the following reflection questions:

- (a) Likert Scale questions (of strongly agree, agree, neither agree nor disagree, disagree, strongly disagree)
  - a. The OLMs were helpful for learning physics this semester
  - b. The OLMs were relevant for learning physics this semester
  - c. The OLMs were demanding to complete
  - d. I put a lot of effort into completing the OLMs each week
- (b) Short answer response
  - a. What motivated you to complete the OLMs throughout the semester
  - b. Name one thing about the OLMs that was helpful for learning physics this semester

Student responses were coded and themes extracted.

#### Surveys and focus groups

The final module (described above) allowed for surveying of students who did regularly complete OLMs. However we wanted to also understand why students who were active participants in the course did not choose to participate in the OLMs. Therefore we surveyed a group of these students and participated in a staff-student liaison meeting to try and ascertain the perspective of non-participating students.

27 students who elected not to complete any OLMs responded to an additional survey administered during tutorials asking “Why did you not complete more OLMs this semester?” At a post-semester staff-student liaison meeting where students shared their experiences of the course in general, a 15 minute focus group was conducted seeking student experiences of the OLMs. Student comments were noted for triangulating with other data.

### Student assessment marks

Throughout the semester, the students completed a variety of assessments which contributed to their final mark and grade levels of high distinction, distinction, credit, pass and fail. We analysed the number of OLMs completed for each grade level.

Relevant for this investigation, in addition to the above assessments, on two occasions (as a pre-test and post-test) students completed the Force Motion Concept Evaluation (FMCE) (Thornton & Sokoloff, 1997) which is a test on mechanics concepts included in this course. The FMCE has been successfully used to evaluate the effectiveness of other teaching and learning innovations at this institution (Sharma, Johnston, Johnston, Varvell, Robertson, Hopkins, Stewart, Cooper, Thornton, 2010). This therefore provided a quantitative measure of whether the OLMs helped the students to understand physics better over the semester of instruction.

## **5.4 Results**

### *5.4.1 RQ1: What are the patterns in student use of OLM in this course?*

#### What is the pattern of participation across the semester?

Of the 656 who completed the final exam, 97% completed at least one module. Furthermore, 45.8% completed more than eight modules which was deemed as actively participating in the OLMs.

641 students completed the module in the first week and the number of students completing modules decreased across the semester (see figure 5.2). During the first week, and in the beginning of semester, there were more students enrolled in Regular Physics and more students participated in the OLMs. However, the number of students decreased after week 1. This decline in student enrolment and participation is common across various student learning opportunities (e.g. lectures and tutorials) and is not unique to the OLMs.

After the fifth OLM, the numbers dropped again. This module was available at the end of a week-long mid semester break. A decline is noticed in all aspects of the course. Some students

may have been away during the mid semester break, and for some, the break may have altered their regular study routine resulting in a failure to complete that week's OLM.

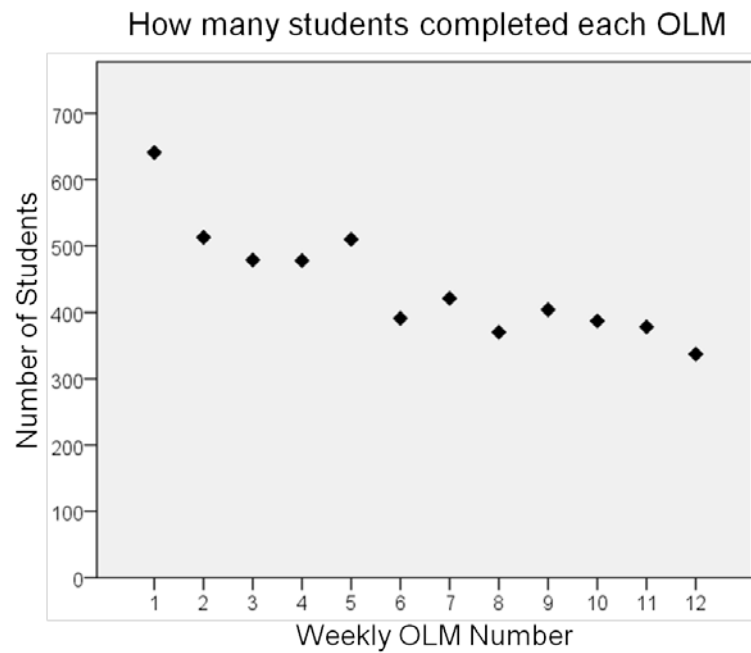


Figure 5.2: The number of students completing OLMs across the course of the semester.

How long do students stay logged onto the OLMs?

The modules were designed to take 15 minutes to complete. The average time across the semester was 14.9 minutes. Figure 5.3 shows a histogram of the distribution of time students spent on OLMs throughout the semester.

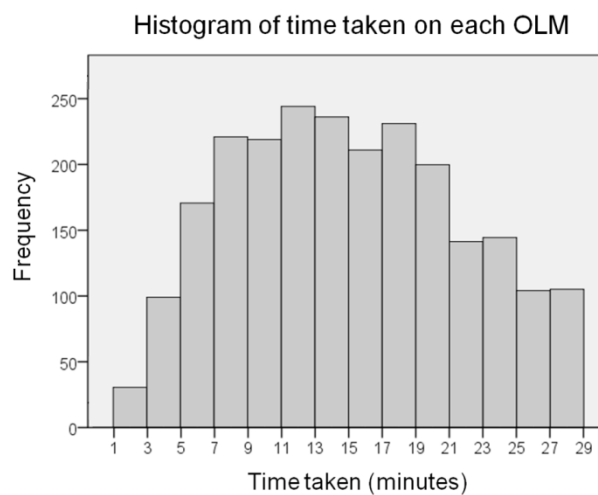


Figure 5.3: Histogram of time spent on 5101 OLM attempts across the semester excluding the week 13 reflection module which was intentionally shorter.

As figure 5.3 indicates there was a wide range of time spent on the OLMs. The data almost appears normal but a Kolmogorov-Smirnov reveal that it is not a normal distribution ( $p < 0.001$ ) While the intended time (and average time) was 15 minutes, many students took up to 30 minutes to complete the modules. It is likely that many students were making use of one of the affordances of online learning – that they can complete activities at their own pace based on their prior knowledge and learning capabilities.

When do students choose to complete the OLMs?

Another affordance of online activities is that students can complete learning exercises in their own time arranged around other activities. Therefore we may predict that students would complete the modules at all times throughout the four day period given to them each week. The histogram of when students actually completed the modules (split in two hour intervals) is presented in figure 5.4.

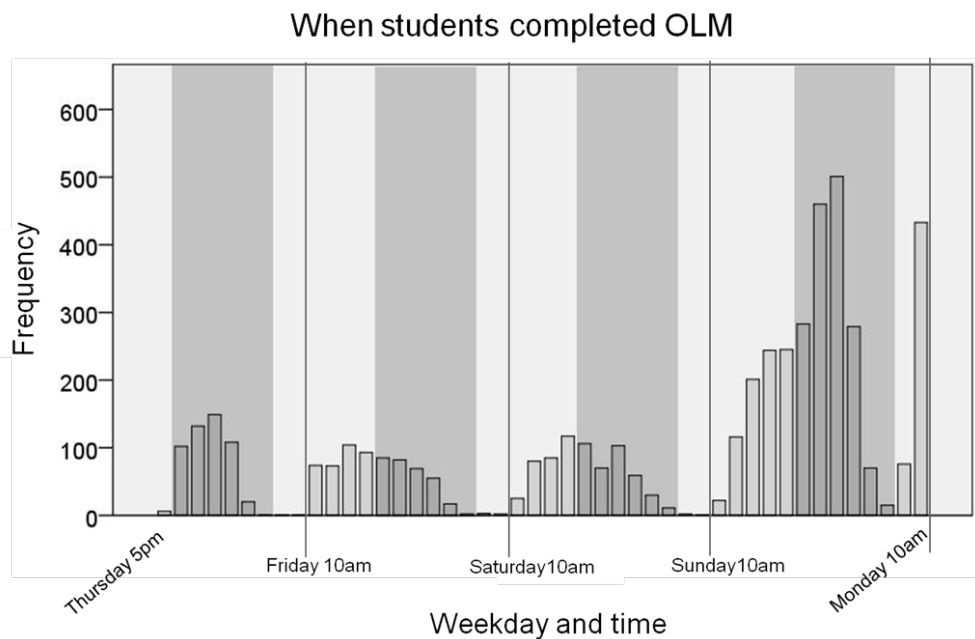


Figure 5.4: Histogram of when students chose to complete the OLMs between Friday 5pm and Monday 10am. The vertical single lines show 10am as the start of a new day of recording, and the shaded bars represent night time (6pm-6am).

There are three trends to notice from figure 5.4. Firstly, students did complete modules right across the weekend indicating that students did the modules when it most suited them. The second trend is that students typically completed the modules between 12pm midday and 3am the following morning suggesting students are willing to engage with online activities later in the night. The final trend is the most obvious, that the majority of students completed the modules immediately prior to the impending deadline of Monday morning, and therefore most students completed the module from Sunday midday onwards. Despite students having the



option to choose anytime on the weekend, 63.3% of all modules completed had the 30 minute duration expire after 10am Sunday (figure 5.5). As the semester went on, a lower percentage of students completed OLM on the Thursday (week 1 had 21%, week 12 had 6%) and more students completed OLM on the Sunday (week 1 had 49%, week 12 had 69%). The overall trend in students completing the OLMs later over the weekend is reflected in the higher standard deviations for the first and last days that the OLM were available.

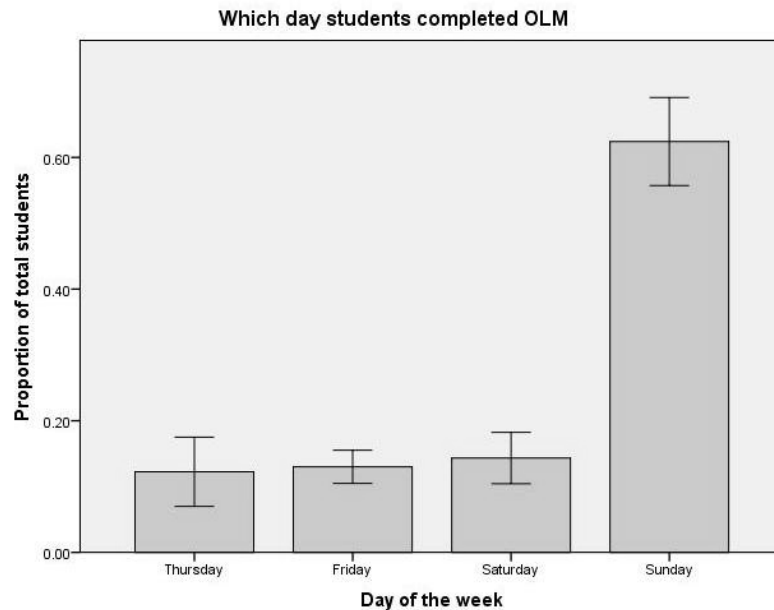


Figure 5.5: Which day students chose to complete OLMs. Categories extend from 10am of the particular day until 10am the next morning. Error bars represent 1 standard deviation of the proportion of students across the 12 weeks.

#### 5.4.2 RQ2: Why do/don't students engage with OLMs?

##### Why do students choose to complete OLMs?

326 students responded to the question “What motivated you to continue completing the online learning modules throughout the semester?” The student responses were qualitatively coded into one or more of six categories by one author, which was then validated by another author before together grouping the categories into three themes. These included Theme 1: Finding the OLMs helpful for learning (including categories 1a: Associating OLMs with the lectures, 1b: Referring to helpfulness, and 1c: Referring to learning in a positive), Theme 2: Wanting to attain the associated marks (category 2a: Associated marks), and Theme 3: Completing the modules was a normal part of the course (including categories 3a: Having an “Obligation” to complete the OLM, and 3b: referring to the OLMs as set work, or a normal exercise). The themes are summarised in table 5.1.

Table 5.1: Three identifiable themes to student answers of why they chose to complete the OLMs throughout the semester. Many student answers relate to more than one theme.

Theme	Responses that fit the theme	Representative example
<b>Theme 1: Found the OLMs helpful for learning</b>	61%	“The information gained and summarized by the online learning modules were very helpful in understanding the rest of the course”
<b>Theme 2: Wanted to attain the associated marks</b>	58%	“The 1% mark was easy to get by just completing them. For the little effort, it was worth it”
<b>Theme 3: Completing the modules was a normal part of the course</b>	19%	“It was part of the course”

61% of students indicated that they found the OLMs helpful and useful for learning. Some students felt that the OLMs gave a good overview about the next week’s lecture (“*The online learning modules provided a very good overview of what we would be learning in lectures and ESPECIALLY in tutorials that week... I would be prepared for the tutorials and be able to contribute to the workshops*”). In addition some students saw that the OLMs were a good revision tool (“*It helped me reflect on my work*”). Therefore many students did the OLMs because it helped them learn.

58% of students indicated that the marks associated with the OLMs were a key motivator. This is despite the total mark attainable only being 1% of the end of semester mark. This indicates that even such a small mark associated with an online activity can be enough to encourage high student participation. Finally 19% of student answers related to the perception that the OLMs were an ordinary part of first semester physics learning. The students were not told that this was a new initiative and so many just took it as a normal requirement.

#### Why do students choose not to complete the OLMs?

We surveyed 27 students who completed less than three OLMs as to why they didn’t complete any, or didn’t complete more OLMs throughout the semester. They were given space for an open ended response. The three most common reasons were that the students didn’t consider engaging in these online activities worthwhile (e.g. “*I wasn’t bothered*”, 8 responses), students forgot about the OLMs (e.g. “*I honestly forgot*”, 11 responses), and personal/logistical reasons (e.g. “*I did not complete the second half as my mother became ill*”). This highlights that students need to be reminded of the modules regularly, and effort needs to be made to remind them of why the modules are helpful and worthwhile. Only one student indicated technical problems which is positive when trialing a new technological activity. Interestingly two students didn’t like the deadline being on Monday with one remarking “*If it was (due on)*

Friday I would do them". These responses were important for evaluation in order to try and increase participation in following years.

#### 5.4.3 RQ3: Is introducing the OLMs associated with improved learning and experiences?

##### Do completing OLMs improve student learning?

There were two quantitative ways that we present here which can give a measure of student learning. The first is to compare student learning gains on a conceptual test, the FMCE (Thornton & Sokoloff, 1997), completed at the start and end of semester as pre and post tests. Students who completed more than eight OLMs (those who engaged with OLMs) were compared with those who completed less than four (non-participants of OLMs). The average results are presented in table 5.2.

Table 5.2: Mean scores and standard deviations on the FMCE raw scores (maximum score is 43) comparing students who engaged in OLMs with non-participants.

	<b>Students who engaged with OLMs (n=261)</b>		<b>Non-participants (n=53)</b>	
	Mean	$\sigma$	Mean	$\sigma$
<b>Pre-FMCE</b>	15.98	8.57	17.37	9.80
<b>Post-FMCE</b>	21.65	11.67	21.13	11.10

Non-parametric tests were used to compare the means as the distributions were found not to be normal (using the Kolmogorov-Smirnov test). Using independent-samples Man-Whitney U Tests, we found that there was no significant difference between the students who engaged with the OLMs and the non-participants for the Pre-FMCE ( $p=0.416$ ) or the Post-FMCE ( $p=0.830$ ). However, for both groups of students the Post-FMCE had a mean that was significantly higher than the Pre-FMCE (non-parametric Related-Samples Wicoxon Signed Rank Test,  $p<0.001$ ). Therefore there was improvement from both groups across the semester.

By calculating the normalised gain,  $\langle g \rangle$ , we are able to easily compare the increases in test scores between the two groups. It is a ratio of the actual gain to the maximum possible average gain for a group of students, i.e.,

$$\langle g \rangle = \% \langle G \rangle / \% \langle G \rangle_{\max} = (\% \langle S_f \rangle - \% \langle S_i \rangle) / (100 - \% \langle S_i \rangle) \text{ (Hake, 1998).}$$

Table 5.3 shows that the students who engaged with OLMs had a higher gain (.209) than the non-participants (.147) indicating that those who engaged in online learning had greater conceptual physics learning than their follow students. We note that the pre-FMCE mean is higher for the non-participants while their post-FMCE is no different to that of those who

engaged with OLMs. A similar pattern was found in a study in the same institution with students' engagement with tutorials (Sharma, Millar, & Seth, 1999; Sharma, Mendez, & O'Byrne, 2005).

Table 5.3: Learning gains for the FMCE for students who engaged with OLMs and non-participants.

<g>	<b>Students who engaged with OLMs (n=261)</b>	<b>Non-participants (n=53)</b>
<b>FMCE</b>	.209	.147

Another measure of the potential impact of the OLMs is comparing the level of student engagement with the OLMs, measured by how many modules were completed by students, and their end of semester physics mark (which is primarily an incorporation of exam, laboratory, and assignment marks). Figure 5.6 shows that the students who achieved high distinctions on average completed the most OLMs at  $10.7 \pm 1.4$  modules, while students who failed on average only completed  $4.1 \pm 3.8$  modules. As each grade level increases, so does the average number of OLMs completed. This is only a correlation and cannot be reported as a causal link, but when coupled with the results above, that greater engagement with OLMs resulted in greater learning gains, it is not surprising that the students who completed more modules, on average, achieved greater success in first semester physics overall. The relationship between OLM participation rates and student success in the course offers administrators another indicator to identify students who may be "at risk" of failing the course. Students with low or no OLM participation can be contacted by support staff in an effort to help them complete the semester.

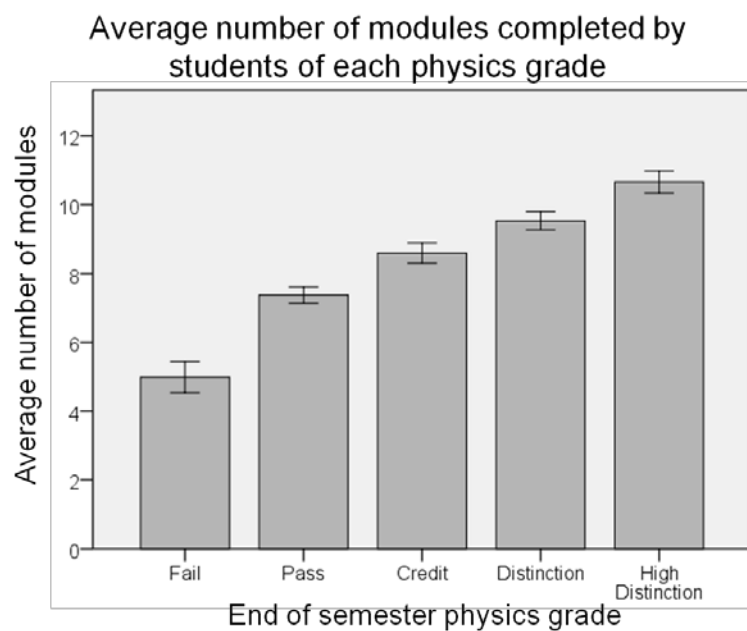


Figure 5.6: The average number of OLMs completed by students who attained each physics grade (error bars represent the standard error).

What are the student opinions of the OLMs?

During the final OLMs students were given an opportunity to reflect on a variety of aspects of the OLMs. Included here are likert responses and student comments on how the modules helped them in first semester physics. Figure 5.7 shows four histograms of the students' responses to the final OLM's reflection questions.

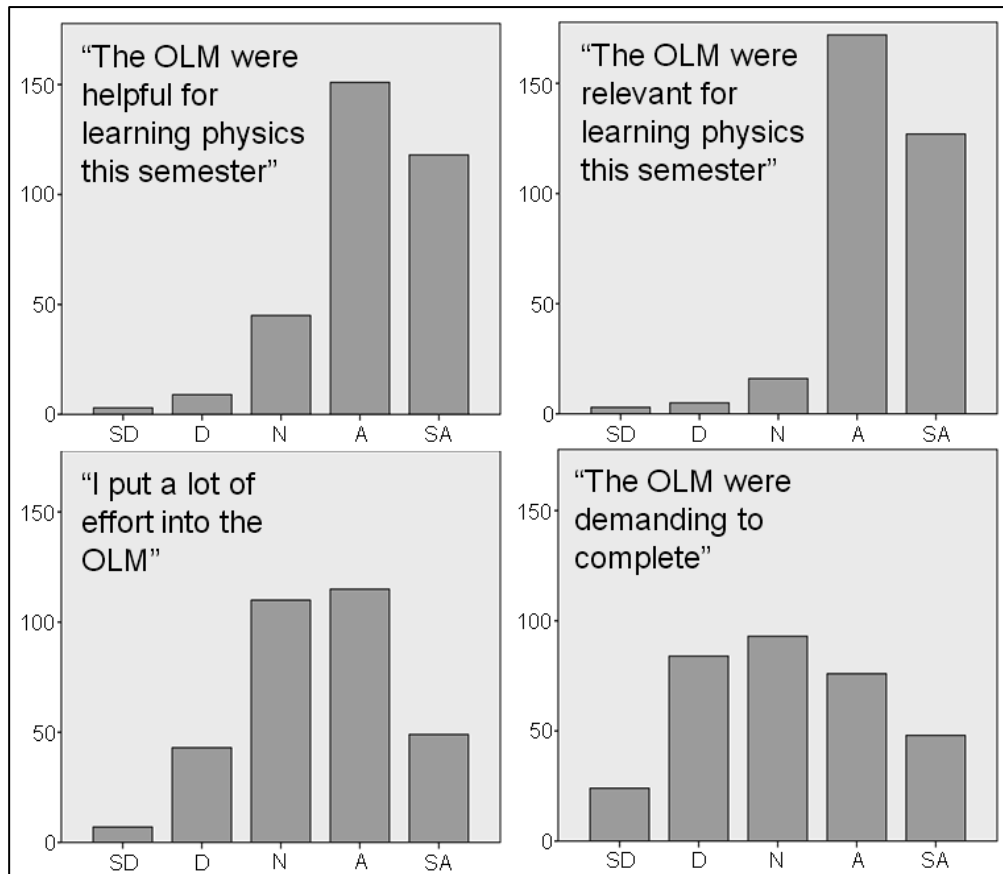


Figure 5.7: Histograms of student responses to reflection questions on the OLMs. Students could choose from a likert scale from *Strongly Disagree*, *Disagree*, *Neither Agree nor Disagree*, *agree*, to *Strongly Agree*.

It was intended through design that the first three questions would result in most students would “agree” or “strongly agree” and that the fourth question (“the OLM were demanding to complete”) would have a more even spread of student responses as the modules were not designed to be too demanding for students. Students on average found the OLMs helpful and relevant for learning physics. The majority of students (51%) either agreed or strongly agreed that they put a lot of effort into the OLMs but many students (34%) answered “*Neither Agree nor Disagree*” to this question. While we might have hoped that students had put more effort into the OLMs it is a positive result that students didn’t find the extra activity too demanding, but reported it’s helpfulness and relevance to the course.

As part of the final week’s module, the students were asked to “Name one thing about the Online Learning Modules that was helpful for learning physics this semester”. Thematic analysis (see Braun & Clarke (2006)) was used to understand and present the open-ended responses. 300 responses were obtained and one researcher identified six sub-themes using a bottom-up approach generating initial codes using a word-count method (see table 7 of Hill et al. (2015) for the word-count method results). This author proposed three overall themes, and a

fourth theme with two student responses stating that they did not find the OLMs helpful in any way. The other authors of the paper validated the analysis by using these now defined themes and sub-themes to categorise a selection of 60 responses (20%). They coded all but one of the responses in an identical way to the original analysis and so the themes are presented below. (The disagreement about the one particular response was resolved after a group discussion. Table 5.4 lists the three themes and six subthemes.

Table 5.4: The themes and sub-themes identified from the 300 online responses to the question "Name one thing about the Online Learning Modules that were helpful for learning physics this semester".

<b>Theme</b>	<b>Sub-theme</b>	<b>% of responses</b>
<b>1. OLMs prepared students for lectures and other learning.</b>	1a. The OLMs made learning in lectures more effective or efficient	44%
	1b. The OLMs assisted preparation for the week's learning (lectures, labs and tutorials)	28%
<b>2. OLMs improved student understanding of physics</b>	2a. The OLMs explained physics or facilitates learning and understanding	24%
	2b. The OLMs introduced physics content, ideas, or representations (graphs, equations or diagrams)	19%
<b>3. OLMs provided other benefits to learning physics</b>	3a. The OLMs encouraged regular physics participation	6%
	3b. The OLMs acted as a review (rather than preview) of the week's material	5%
<b>(4. The OLMs did not provide any benefit)</b>		<1%

Students recognised that completing the OLMs changed the way that they learnt physics [Theme 1]. Either they found physics lectures to easier to understand ("by completing the OLMs we are not completely clueless in lectures") or they felt that the OLMs helped them prepare for upcoming material. Therefore they found that the OLMs integrated well with the physics course. This statement is also supported by theme 3. Many students found that completing the OLMs encouraged regular participation in the physics course ("They made sure I did some physics work each week").

A final comment is made using comments from the bi-annual staff/student liaison meeting held at the end of each semester which contained a focus group reflecting on the OLMs and the physics course. Here is highlighted three most relevant student comments regarding the increased workload from the OLMs:

- Student A: “The quizzes (OLMs) are really helpful for the lecturers in the coming week”
- Student B: “The reflection questions are annoying. I know they say they are good for us, but... I don’t see the point. The really good part is the information and the questions”
- Student C: “There is not too much assessment/activities. It is good to keep motivated”

These three students consider the OLMs helpful (supporting the data obtained from the survey in the final OLM). One provided feedback that a portion of the weekly OLMs were frustrating and from their perspective, unhelpful but was still positive overall for the experience. Finally student C made a direct statement that despite the extra workload this was not a negative. The modules and other activities helped this student to keep motivated. This suggests that there is a limit to the amount of work we can ask of students, but introducing OLMs to a course already with lectures, laboratories, workshop tutorials and assignments has clearly not reached that limit.

## **5.5 Discussion**

In comparing voluntary participants and non-participants one must consider the issue that the participants are more likely to put extra effort into all aspects of their learning. While their improved performance from the pre-test to the post-test could be due to the intervention that they voluntarily participated in, it could also be due to their other efforts to learn physics across the semester. However, the results in this paper indicate a clear association between student performance and OLM participation and suggest that the OLMs may have been one of the differences in the post-test scores of the two groups.

The impact on student performance was only one of the questions that this paper set out to answer. Student participation was measured using data retained through the learning management system platform and engagement with the OLMs was considered through asking when and for how long did the students complete the modules and questioning student perceptions of the OLMs. As a result we have been able to provide practical insight into the



benefits of introducing research-based, integrated online learning activities relevant to both researchers and practitioners alike.

### *5.5.1 Implications for Research*

Lack (2013) rued the absence of much rigorous research into online learning. By comparing students who participated in more than eight OLMs (engaged students) with those who completed less than four (non-participants) we have demonstrated that engaging in a significant number of weekly pre-lecture OLMs in physics is associated conceptual learning gains across the semester. In addition students who attained higher end of semester results for the course on average had completed more OLMs. In addition, student perceptions indicated that they felt that the modules were helpful for learning physics, preparing themselves for lectures, and maintaining progress through the course indicating that the students felt that the implementation of blended learning has a clear positive impact on this first semester physics course.

For one of the first times, student participation was tracked over each weekend and across the semester. The results have shown that the majority of students did engage with the online component of blended learning and that there were some clear patterns in student use. This gives greater understanding of the student attitude towards blended learning and the actual impact rather than just assuming all students who complete all activities given to them regardless of their situations. On average students spent 15 minutes a week on the modules (as intended) but despite giving them almost four days to complete the modules (from Thursday evening until the Monday morning's lecture), 63.3% of modules were attempted in the last 24 hours, and the highest time period of module completion was 9-11pm on the Sunday evening. These results present us with a question: does blended learning allow for students to complete learning activities when it is most convenient for them (potential for greater engagement than face-to-face instruction) or does it simply change the time that students are working to the last 24 hours before the due date (same level of engagement)? That is – did students engage more by participating in an extra task simply because it was an extra task, or was it because the OLMs delivered this content in a format that was conducive to engagement (blended learning). In our course, students saw preparation for the coming week's lectures as a key benefit of the OLMs and therefore it is not surprising that the evening before classes were due to begin for the week would be a peak time in OLMs use as students prepared for the week ahead.

One limitation of the study was that time spent on the OLMs did not necessarily indicate the time that the students spent in front of their computers working through the OLMs. The times used to calculate the average time of 15 minutes was from when they began the module until the time that they submitted it. While OLM sessions that ran overtime were excluded as this

indicated that students had simply left their internet browser running, further research would improve the study by tracking clicks or cursor movements to ensure that during this time the students remained on task.

Further work could also be done in directly asking students why they completed the tasks at the times that they did and how the OLMs fitted into their everyday life. Students could also be asked how OLMs could be structured or delivered in order to make them engage even more.

### 5.5.2 *Implications for Teaching*

Practitioners are feeling pushed towards increasing the level online learning in their courses, whether from others in their institutions, or a conviction that it may benefit their students. Many may feel wary about how blended learning can fit with their situation and simply whether the students will participate in learning opportunities when they are placed online. Others may have implemented blended learning and are now looking for ways to measure the student participation and perceptions of the change and its impact on their performance. This paper analyses data retained through a learning management system to consider what blended learning looks like for the students.

This study demonstrates that students do engage in the online learning opportunities of a supplemental model of blended learning (Twig, 2003) in first year university physics. Vitaly important was incorporating research into both the design and the evaluation of the OLMs. We followed warnings and recommendations to ensure that the extra activity was not a burden and that the OLMs were well integrated with the course and student data supports this (Alammary et al., 2014). We echo these warnings of ensuring that any additional activity, especially presented through a different medium such as online learning, must be well integrated with the course and students must see the benefit to encourage high levels of participation and engagement.

In particular it needs to be decided whether the online activities are going to be lessons on their own or are designed to improve learning in other settings. By allowing the OLMs to be preparatory and well integrated with the lectures students were able to recognise that the modules helped them prepare and in fact changed the way that they learnt in lectures for the better (consistent with Day et al. (2004) and Moore (2014)).

As well as designing effective modules and convincing students of the educational value of participating in online learning there are a number of logistical factors to consider. Information given to students about online learning at the start of semester, and through the semester, needs to be clear and effective. Our observation is that the current generation of students prioritise

course activities when it contributes directly to their final mark. This explains why assigning a participation mark (even if it was only 1%) was effective in encouraging high completion rates (as shown by 58% of students indicating that this was part of the reason why they completed OLMs). In 2015 the institution will be applying standards-based assessment to the first year physics course where, in order to receive a particular grade, students must perform to a minimum standard in *all* learning assessments including laboratory classes, assignments, exams, and OLMs. So rather than 11 out of 12 modules constituting 1% of the physics mark, completion of 10 out of 12 modules will be required for students to attain a high distinction. This is expected to further increase student participation in the OLMs, which are deemed an essential component of the physics course.

Given that part of this is directed to practitioners considering implementing blended learning, we make a final comment reflecting on our experiences. When introducing an online component to a predominantly face-to-face course, especially for a large course, staff need to be available to reply to student emails within short time periods even over weekends to help with technical issues and other questions. Support from IT staff is critical in the start-up phase. As the inclusion of OLMs settles into a normal part of the course, such support needs to be sustained.

## **5.6 Conclusion**

This paper demonstrates integrating blended learning into a large first year university physics course. It was found that there was a high frequency of student engagement, despite a gradual decrease in participation across the semester. A high level of engagement was also found which according to students resulted in positive benefits to their learning in lectures and is associated with overall increases in conceptual understanding. Specifics of student participation such as time of day were tracked and reported on. By offering a rigorous investigation into the quality and frequency of student engagement in blended learning, this paper contributes to our understanding of blended learning and provides incentive and an example for educational designers to participate in blended learning in similar ways.

## **5.7 Appendix 1**

A sample of the OLMs can be found at the following link. Please note, it has been adapted into a worksheet format for easy viewing and therefore some features present in the online environment have been lost.

Online Learning Module: Free-body diagrams:

<http://www.physics.usyd.edu.au/super/RFS/Sample%20OLM.pdf>

## 5.8 References

- Alammary, A., Sheard, J., & Carbone, A. (2014). Blended learning in higher education: Three different design approaches. *Australasian Journal of Educational Technology*, 30(4).
- Beer, C., Jones, D., & Clark, K. (2009). The indicators project identifying effective learning: Adoption, activity, grades and external factors. Same places, different spaces. *Proceedings ascilite Auckland 2009*, 60-70.
- Black, G. (2002). A comparison of traditional, online, and hybrid methods of course delivery. *Journal of Business Administration Online*, 1(1), 1-9.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2), 77-101.
- Chen, Y., Wang, &, & Chen, N. (2014). Is FLIP enough? Or should we use the FLIPPED model instead? *Computers & Education*, 79, 16-27.
- Chen, Z., Stelzer, T., & Gladding, G. (2010). Using multimedia modules to better prepare students for introductory physics lecture. *Physical Review Special Topics-Physics Education Research*, 6(1), 010108.
- Craig, P., Wozniak, H., Hyde, S., & Burn, D. (2009). Student use of web based lecture technologies in blended learning: Do these reflect study patterns. *Same places, different spaces. Proceedings ascilite Auckland 2009*.
- Day, J. A., & Foley, J. D. (2006). Evaluating a web lecture intervention in a human-computer interaction course. *Education, IEEE Transactions on*, 49(4), 420-431.
- Day, J. A., Foley, J. D., Groeneweg, R., & Van der Mast, C. A. (2004). Enhancing the classroom learning experience with Web lectures.
- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410-8415.
- Georgiou, H., & Sharma, M. D. (2015). Does using active learning in thermodynamics lectures improve students' conceptual understanding and learning experiences? *European Journal of Physics*, 36(1), 015020.
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

- Harasim, L. (2000). Shift happens: Online education as a new paradigm in learning. *The Internet and higher education*, 3(1), 41-61.
- Hill, M., Sharma, M. D., Johnston, H. (2015). How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *Eur. J. Phys.* 36 (2015) 045019.
- Hood, M. (2013). Bricks or clicks? Predicting student intentions in a blended learning buffet. *Australasian Journal of Educational Technology*, 29(6).
- Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher*, 33(7), 14-26.
- Lack, K. A. (2013). Current status of research on online learning in postsecondary education. *Ithaka S+ R, zuletzt geprüft am*, 3, 2013.
- Lindstrøm, C. and Sharma, M. D. (2011) Self-Efficacy of First Year University Physics Students: Do Gender and Prior Formal Instruction in Physics Matter?, *Int. J. of Innovation in Science and Mathematics Education*, 19(2), 1-19.
- Lumsden, E. A. (1976). The effect of brief, pre-lecture quizzes on performance on regularly-scheduled tests, class participation, and student-evaluation of lectures. *Journal of Instructional Psychology*.
- McFarlin, B. K. (2008). Hybrid lecture-online format increases student grades in an undergraduate exercise physiology course at a large urban university. *Advances in Physiology Education*, 32(1), 86-91.
- Means, B., Toyama, Y., Murphy, R., Bakia, M., & Jones, K. (2009). Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies. *US Department of Education*.
- Moore, J. C. (2014). Efficacy of multimedia learning modules as preparation for lecture-based tutorials in electromagnetism. *arXiv preprint arXiv:1409.7682*.
- Neumann, D. L., & Hood, M. (2009). The effects of using a wiki on student engagement and learning of report writing skills in a university statistics course. *Australasian Journal of Educational Technology*, 25(3).
- Oncu, S., & Cakir, H. (2011). Research in online learning environments: Priorities and methodologies. *Computers & Education*, 57(1), 1098-1108.
- Pargas, R. P. (2006). Reducing lecture and increasing student activity in large computer science courses. Paper presented at the ACM SIGCSE Bulletin.
- Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education - Washington*, 93, 223-232
- Ruiz, J. G., Mintzer, M. J., & Leipzig, R. M. (2006). The impact of e-learning in medical education. *Academic medicine*, 81(3), 207-212.

- Seery, M. K., & Donnelly, R. (2012). The implementation of pre-lecture resources to reduce in-class cognitive load: A case study for higher education chemistry. *British Journal of Educational Technology*, 43(4), 667–677.
- Sharma, M. D., Johnston, I. D., Johnston, H., Varvell, K., Robertson, G., Hopkins, A., Stewart, C., Cooper, I., & Thornton, R. (2010). Use of interactive lecture demonstrations: A ten year study. *Physical Review Special Topics-Physics Education Research*, 6(2). doi: 10.1103/PhysRevSTPER.6.020119
- Sharma, M. D., Mendez, A., & O’Byrne, J. (2005) The relationship between attendance in Student-Centred Physics Tutorials and Performance in University Examinations, *International Journal of Science Education*, 27 (11) 1375-1389
- Sharma, M. D., Millar, R., & Seth, S. (1999) Workshop Tutorials: Accommodating student centred learning in large first year university physics classes, *Int. J. Sci. Ed*, 21, 839-859
- Stelzer, T., Brookes, D. T., Gladding, G., & Mestre, J. P. (2010). Impact of multimedia learning modules on an introductory course on electricity and magnetism. *American Journal of Physics*, 78(7), 755-759.
- Stelzer, T., Gladding, G., Mestre, J. P., & Brookes, D. T. (2009). Comparing the efficacy of multimedia modules with traditional textbooks for learning introductory physics content. *American Journal of Physics*, 77(2), 184-190.
- Swan, K. (2009). Introduction to the special issue on blended learning. *Journal of the Research Center for Educational Technology*, 5(1), 1-3.
- Thornton, R. K., & Sokoloff, D. R. (1997). Assessing student learning of Newton’s laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352.
- Twigg, C. A. (2003). Models for online learning. *Educause review*, 28-38.
- Utts, J., Sommer, B., Acredolo, C., Maher, M. W., & Matthews, H. R. (2003). A study comparing traditional and hybrid internet-based instruction in introductory statistics classes. *Journal of Statistics Education*, 11(3), 171-173.
- Wang, C.-H., Shannon, D. M., & Ross, M. E. (2013). Students’ characteristics, self-regulated learning, technology self-efficacy, and course outcomes in online learning. *Distance Education*, 34(3), 302-323.
- Wu, J., Tennyson, T., & Hsia, T. (2010). A study of student satisfaction in a blended e-learning system environment. *Computers & Education*, 55(1), 155-164)
- Zhao, Y., & Breslow, L. (2013). Literature Review on Hybrid/Blended Learning.

# **Chapter 6:**

## **How online learning modules can improve the representational fluency and conceptual understanding of university physics students**

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### **6.1 Abstract**

The use of online learning resources as core components of university science courses is increasing. Learning resources range from summaries, videos, and simulations, to question banks. Our study set out to develop, implement, and evaluate research based online learning resources in the form of pre-lecture online learning modules. The aim of this paper is to share our experiences with those using, or considering implementing, online learning resources. Our first task was to identify student learning issues in physics to base the learning resources on. One issue with substantial research is conceptual understanding, the other with comparatively less research is scientific representations (graphs, words, equations, and diagrams). We developed learning resources on both these issues and measured their impact. We created weekly online learning modules which were delivered to 1<sup>st</sup> year physics students at the University of Sydney prior to their first lecture of the week. Students were randomly allocated to either a *concepts stream* or a *representations stream* of online modules. The program was first implemented in 2013 to trial module content, gain experience and process logistical matters and repeated in 2014 in a course approximately 850 students. Two validated surveys, the Force and Motion Concept Evaluation (FMCE) and the Representational Fluency Survey (RFS) were used as pre-tests and post-tests to measure learning gains while surveys and interviews provided further insights. While both streams of online learning modules produced similar positive learning gains on the FMCE, the representations-focussed online learning modules produced higher gains on the RFS. Conclusions were triangulated with student responses which indicated that they have recognised the benefit of the online learning modules for their learning of physics. Our study shows that carefully designed online resources used as pre-instruction can make a difference in students' conceptual understanding and representational fluency in

physics, as well as make them more aware of their learning processes. In particular, the representations-focussed modules offer more advantages.

## **6.2 Introduction**

### *6.2.1 Online learning resources*

Online learning resources have been used for learning for over 40 years (Harasim, 2000). The phrase ‘blended learning’ is generally used when online learning resources ranging from collaborative activities to assessments are meaningfully integrated into courses with classroom instruction (Black, 2002; Ellis, Goodyear, Prosser, & O’Hara, 2006). With the development of robust technologies and reliable access, most university courses are moving towards some form of blended learning. A popular type of blended learning is pre-lecture online instruction (a form of flipped lecture) which allows for students to be better prepared for lectures (Chen, Stelzer, & Gladding, 2010; McFarlin, 2008; Stelzer, Gladding, Mestre, & Brookes, 2009) and the face-to-face lecture can further adopt the active learning strategies for physics education (Georgiou & Sharma, 2015; Mazur, 2009). Despite an apparent consensus that integrating online learning may be superior (Moreno & Mayer, 2004; Oncu & Cakir, 2011), researchers have pointed out the lack of rigorous efforts to demonstrate how such learning can be most effective in post-secondary education (Lack, 2013). This opens the opportunity for further research into the uptake of particular designs of online learning, acknowledging that there is considerable ongoing research already in the field. A call along these lines for Australian physics education was made in a national report some ten years ago (Sharma, Mills, Mendez, & Pollard, 2005).

This paper attempts to share how we designed an online learning resource and how we ascertained its learning effectiveness. The online resource is based on ‘blended learning’ in that online resource is meaningfully integrated. For this to occur, we had to identify student learning issues in physics to base the learning resources on. Students in science must learn both conceptual information as well as other scientific abilities, one of which is representational fluency, or the use of multiple representations in science (Etkina, Van Heuvelen, White-Brahmia, Brookes, Gentile, Murthy, Rosengrant, & Warren, 2006). This study looks at using online resources to teach well researched conceptual understanding, and less researched representational fluency.

### *6.2.2 Teaching scientific conceptual understanding online*

The study of the natural sciences at university requires students to learn a great volume of conceptual information. A typical first year physics course may cover concepts in the areas of



mechanics, thermal physics, waves and oscillations, electricity and magnetism, fluids, and quantum physics over just 26 weeks. The volume of information for students to learn, and the increasing diversity of students at university, has put pressure on practitioners to find alternative ways of teaching students science concepts, and using online resources to teach has been a popular solution (Chen et al., 2010; Lasry, Dugdale, & Charles, 2014; Moore, 2014; Seery & Donnelly, 2012; Stelzer, Brookes, Gladding, & Mestre, 2010; Stelzer et al., 2009). Amongst the literature there are a variety of methods including once-off online exercises, to almost whole courses delivered online. In this paper we draw on one particular example of using online learning to teach concepts before chemistry lectures (Seery & Donnelly, 2012). Seery and Donnelly (2012) implemented a series of 10 online learning (pre-lecture) resources based on key chemistry concepts to assist first year university students, finding marked improvements in student learning. Their particular style of online learning instruction was effective in teaching key concepts to first year science students. Hence we modeled our concepts stream of online learning modules on this paper to investigate whether there would be similar positive learning gains in physics, and also whether they would impact first year students' representational fluency.

Despite the vast array of research into systematic teaching of science concepts, there have been few attempts to investigate teaching of *representational fluency* throughout a semester in a university course, and none using weekly online learning modules.

### 6.2.3 *Multiple representations and scientific representational fluency*

Understanding and using multiple representations is an important skill in the sciences (Aldrich & Sheppard, 2000; Roth & Bowen, 2003) and in particular physics (Beichner, 1994; Britton, 2005; Dufresne, Gerace, & Leonard, 2004; Fredlund, Airey, & Linder, 2012). Etkina et al. (2006) lists this ("the ability to represent physical processes in multiple ways") as the first of seven "scientific abilities" that must be taught and assessed in introductory university physics (p1). Examples of multiple representations include visual representations (diagrams, maps, and flow charts) and symbolic representations (graphs, equations, and tables) (Gilbert, 2004). See figure 6.1 as an illustration (Redish, 2003).

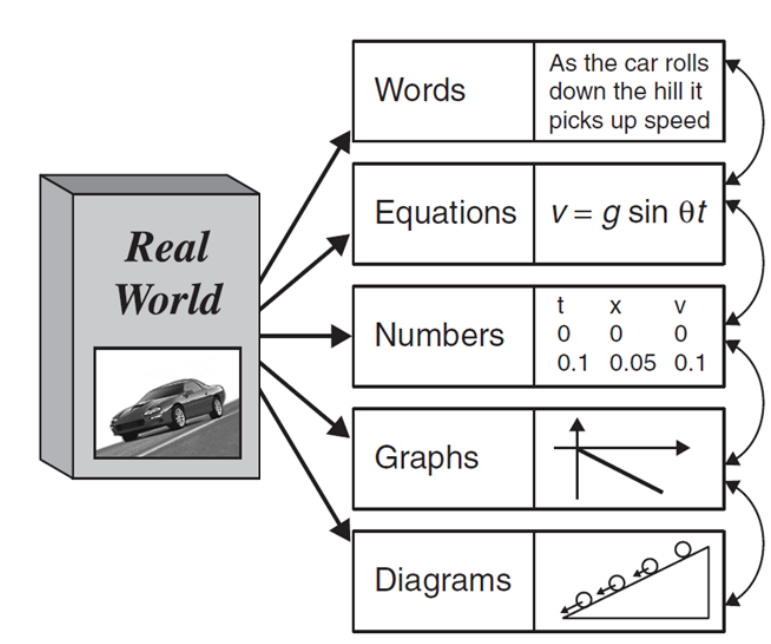


Figure 6.1: Multiple representations of a car rolling down a hill (figure adapted with permission from (Redish, 2003)).

Multiple representations portray relationships where they are not obvious (Bowen, Roth, & McGuinn, 1999; Goldman, 2003) and aid problem solving (Kohl & Finkelstein, 2007). *Representational Fluency* (Hill, Sharma, O'Byrne, & Airey, 2013; Nathan, Stephens, Masarik, Alibali, & Koedinger, 2002) describes collectively “the ability to work within and translate among representations” (p367) (Bieda & Nathan, 2009), using representations as experts do (Kohl & Finkelstein, 2005; Roth & Bowen, 1999), and learning new representations quickly (diSessa, 2004). The mark of a good student in physics is often that they can solve a variety of conceptually challenging problems and this requires fluency in a wide variety of representations to both understand the question and generate an appropriate solution (Dufresne et al., 2004).

Making meaning from various representations (semiotics) is conducted differently in various disciplinary discourses. This is often a problem for novice students separating the specialized, technical forms of representations from everyday meanings (Treagust & Chittleborough, 2001). This can easily be a barrier to participation in the discipline and Airey and Linder (2009) went so far as to say that fluency in a sufficient variety of specific representations may be a necessity for accessing a disciplines way of knowing. Instructors, and scientific textbooks use much more than the single mode of verbal communication assuming that students have the representational fluency to interpret the information (Lemke, 2005). Research indicates that this assumption is not valid as many novice students lack the representational skills and practices of experts or practicing scientists (Bowen, et al., 1999; Rosengrant, Van Heuvelen, & Etkina, 2009; Woolnough, 2000). In particular at the University of Sydney, first year regular physics students

appear to lack the representational fluency of more advanced students (Hill, Sharma, O'Byrne, & Airey, 2014).

Two questions then arise; first is representational fluency measurable? Second can we create a learning environment which demonstrably fosters the development of representational fluency? The first has been probed through the development and validation of the Representational Fluency Survey (Hill et al., 2014) akin to ways in which conceptual learning gains are measured through the Force and Motion Concept Evaluation (Thornton & Sokoloff, 1997) or the Mechanical Wave survey (Tongchai, Sharma, Johnston, Arayathanitkul, & Soankwan, 2009). The second question is the focus of this paper.

#### *6.2.4 Teaching scientific representational fluency online*

There is some research on instructional methods for improving university students' use of multiple representations (Hand & Choi, 2010; Kohl, Rosengrant, & Finkelstein, 2007b), but a scarcity on improving representational fluency to date to our knowledge. Kohl, Rosengrant, and Finkelstein (2007a) investigated whether explicitly teaching and explaining diagrams in physics or using diagrams often and authentically in a semester long program led to more effective use of diagrams. They found that at the end of semester, both approaches were equally effective with regards to student use of representations.

While we looked to chemistry for literature on teaching concepts online, a discipline with substantial experience teaching representations is mathematics. As a model for our representations-focussed instruction we considered a carefully designed and evaluated Maths Skills program used at La Trobe University, Melbourne, Australia (Jackson & Johnson, 2013). The Maths Skills program supports the development of mathematical skills amongst university science students as they progress through their semester long courses. Amongst the resources, structured topic worksheets with explicit headings directed students' metacognition towards understanding the purposes and relevance of the material, was found to be effective. We had discussions with this team and used elements of this structure.

#### *6.2.5 Purpose of the study*

The purpose was to develop two streams of research based online learning modules (OLM), a concepts-focussed stream and a representations-focussed stream. Then to investigate which stream would help students improve in two areas, their representational fluency (e.g. using graphs, words or equations), and conceptual understanding (e.g. a knowledge of concepts in mechanics), in order to make recommendations of the best use of online learning modules in university physics. Our specific research questions were:

1. How do we develop and implement representations-focussed OLM similar to concepts-focussed OLM?
2. Can we improve students' learning, (both conceptual understanding and representational fluency) through pre-lecture OLM?
3. Do students recognise the benefit of OLM for physics learning?

The sections below address each in sequence.

### **6.3 RQ1: Developing and implementing OLMs in first-year physics**

#### *6.3.1 Rationale*

The rationale aligns particularly with three of the studies discussed earlier. From Seery & Donnelly (2012), we adapted strategies for, 'priming' prior to lectures seeking to enhance understandings. The Concepts OLM emulated this by priming key concepts, while the Representations OLM primed key representations. From Kohl et al. (2007a) we adapted the "strongly directed" approach for the Representations OLM. This entailed explicitly identifying representations, their affordance and uses. In addition, emphasis was given on requiring students to observe, and enact translations between representations.

From Jackson and Johnson (2013) we adapted a specific uniform structure for all the OLM. Each weekly module had three sections consisting of:

1. Information, where content was presented directly to the students,
2. Questions, where internalisation of the content was fostered through prompting problems,
3. Reflection, where worth of the content was elaborated with metacognitive questions.

#### *6.3.2 Development*

The modules were developed iteratively involving trials with high school students in 2012 and ongoing consultation with lecturers and physics education experts, as shown in figure 6.3.

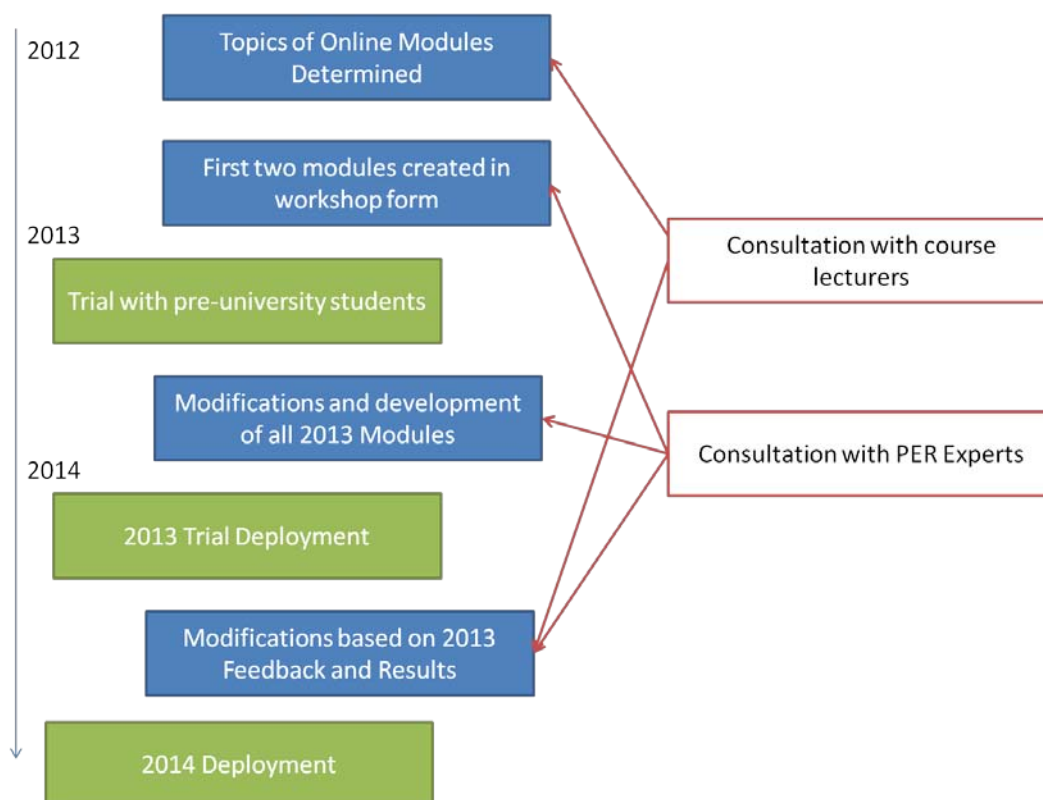


Figure 6.3: Flowchart of development process

A full trial deployment with students at university level occurred in semester 1, 2013. Refinements based on analysis of student responses were made prior to the 2014 deployment. In parallel, targeted consultation through workshops conducted with the wider academic community (Hill & Sharma, 2013; Hill, Sharma, & Johnston, 2013) assisted in fine tuning pedagogical aspects.

The final collection of Representations and Concepts OLMs used in semester 1, 2014 was therefore developed using a combination of student responses and expert and practitioner consultation. The results and analysis in this paper focus on the 2014 implementation. See table 6.1 for a list of OLM topics, and Appendix C for the full OLMs in worksheet form. There were minimal technical and administrative difficulties, and staff were familiar and comfortable in introducing and referring to OLM in their interactions with students.

Table 6.1: Topics for the areas of Mechanics, Thermal Physics, and Waves and Oscillations. All of the Representations OLM are highlighted as they all were relevant to the RFS. Five Concepts OLM are highlighted as these were from mechanics therefore relevant to the FMCE.

Week	Topic Area	Representations OLM	Concepts OLM
1	Mechanics	Free Body Diagrams	Understanding Tension & Friction
2		Equations of Energy	Kinetic & Potential Energy
3		Resolving Vectors	Momentum and Impulse
4		Representing Torque	Introduction to Torque
5		The Vector Cross Product	Understanding Angular Momentum
6	Thermal Physics	Linear Relationships & Proportionality	Linear Expansion & Specific Heat Capacity
7		Diagrams of Gases	Introduction to Ideal Gases
8		Work done by Gases	Thermal Physics Processes
9		Drawing Heat Engine	Heat Engines
10	Waves and Oscillations	Using Graphs to Describe Periodic Motion	Applications of Simple Harmonic Motion
11		The Wave Equation	Mechanical Waves
12		Reflection and Feedback	Reflection and Feedback

### 6.3.3 Delivery Platform

The modules were delivered using Sydney University's eLearning platform "Blackboard" which allowed for the modules to be completed by students on various devices including mobile tablets seamlessly within their learning management system. Figure 6.4 provides a screenshot of what the student would see in the week 1 Representations OLM.

The screenshot shows the University of Sydney OLM interface. At the top, there is a navigation bar with 'My Units of Study', 'eCommunities', 'Staff', and 'SEAMS'. Below this is a 'Question Completion Status' bar. The main content area displays 'Question 4' worth '10 points'. The question text reads: 'Example of a free body diagram: There are two free body diagrams in the picture below the text, one for each basketball player. The man on the left is standing on the ground and therefore there is a 'normal' force ('n') from the ground on the man pointing upwards. The two forces balance out so he will experience no acceleration at this point. The man on the right has jumped in the air. The only force applying to him is the weight force downwards. Therefore we can calculate his acceleration using Newton's 2nd Law ( $F=ma$ )'. Below the text is an image showing two basketball players with their respective free body diagrams. The player on the left is standing on the ground, with an upward arrow labeled 'n' and a downward arrow labeled 'W'. The player on the right is jumping in the air, with a downward arrow labeled 'W'. The image is credited to 'Images courtesy of vectorolie at FreeDigitalPhotos.net'.

Figure 6.4: A screenshot from the first week of OLM (Representations Stream). (Reproduced from figure 5.1)

#### 6.3.4 Integrating OLM into Regular Physics

The implementation occurred within the first year Regular Physics course across a 13 week semester with approximately 850 students. Historically, the course had three one-hour lectures, a one hour workshop tutorial per week, and eight, three-hour experimental laboratory sessions across the 13 weeks. Assessment is via laboratory work, assignments, tutorial participation and a final examination. The course had three modules: mechanics, thermodynamics, and waves and uses Young and Freedman (1996). Into this context we were to move towards flipped-lectures. The first step was to introduce pre-lecture online instruction and demonstrate its effectiveness before changing how the lectures themselves are taught.

Hence there were 12 OLM developed and deployed. They took 15-30 minutes to complete and could be done in multiple attempts, starting from the second week of the semester. The modules were available from 5pm on Thursday in the previous week and needed to be completed by 10am on Monday which coincided with the first physics lecture of the week. Completion of the modules was worth a nominal 1% of the final mark regardless of correctness of answers.

There were two streams of OLM, each priming work to be covered in the coming week's lectures; the Representations Stream comprised 12 modules focussed on representations, the

Concepts Stream comprised 12 modules focussed on concepts. Each student was randomly assigned to either the Representations or Concepts Stream for the semester.

## **6.4 RQ2: Can we improve students' learning (both conceptual understanding and representational fluency) through pre-lecture OLM?**

### *6.4.1 Measuring the impact of the OLM*

Students completed pre and post tests which were used for statistical testing and comparing learning gains. To answer research question 1, a conceptual survey, the Force & Motion Conceptual Evaluation (FMCE) (Thornton & Sokoloff, 1997) which has been used extensively at the institution was used. To answer research question 2, the, Representational Reasoning Fluency Survey (RFS) (Hill et al., 2014) was used (see Appendix A). The RFS was developed iteratively including examining validity and reliability, as described in (Hill et al., 2014). During the iterative development process student feedback and interviews, along with regular collaboration with an expert panel (including multiple individuals with over 30 years physics education experience), were used to confirm face and content validity. The version of the RFS used in this paper satisfied the criteria for standard statistical tests (difficulty index, point biserial coefficient and Cronbach's alpha).

Figure 6.5 illustrates the study design; structure of the intervention and data collection.



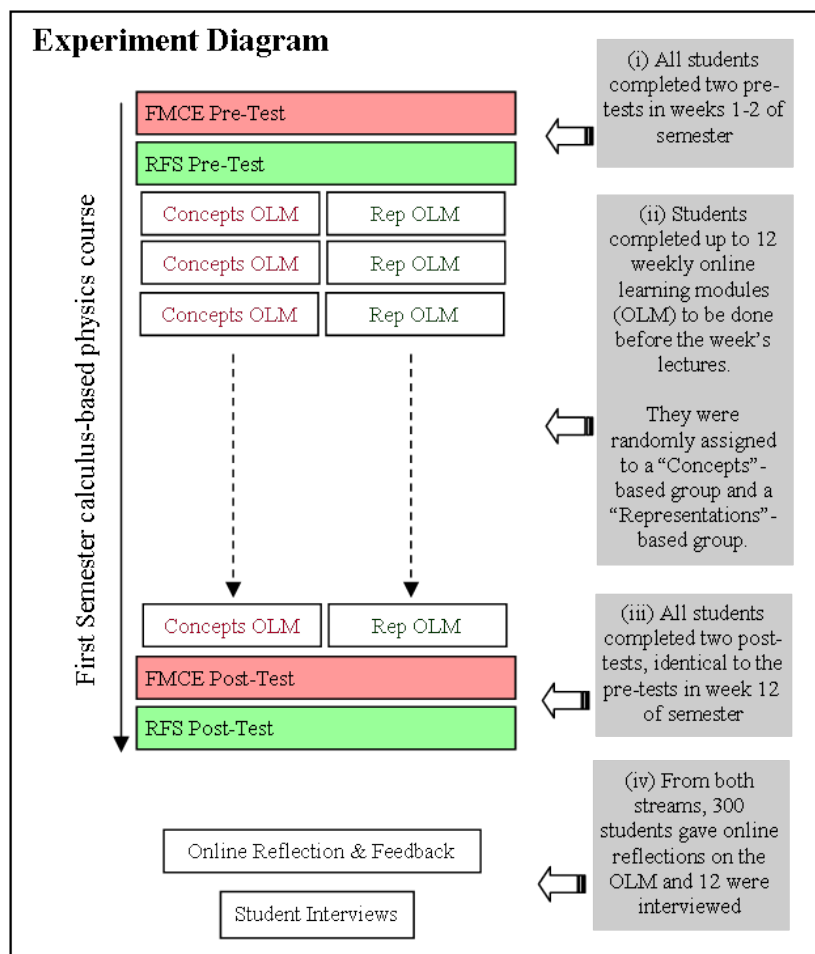


Figure 6.5: The sequence of data collection and deployment of the OLM streams in the study.

#### 6.4.2 Data collection

Students were randomly assigned to either the Concepts OLM or the Representations OLM. Students who met the following criteria have been included as participants in a particular OLM stream:

- completed either the FMCE or the RFS twice, as pre and post test.
- completed more than 8 of either Representations or Concepts OLM

Students who met the following criteria have been included as a non-participant in the OLM:

- completed either the FMCE or the RFS twice, as pre and post test.
- completed less than 4 modules.

One could argue that the OLM non-participants were more disengaged generally than those in the streams. This is not so. Our data indicate that these students chose to use different learning resources to the OLM and completed either the RFS or the FMCE twice. The non-participants persevered in labs, lectures and/or workshop tutorials till the end of the semester. In 2014, there were 406 students who were included in the final analysis, see table 6.2.

Table 6.2: The number of completed tests used for analysis divided by OLM Stream.

	<b>Representations OLM</b>	<b>Concepts OLM</b>	<b>Non participants</b>
<b>Pre &amp; Post FMCE</b>	137	124	53
<b>Pre &amp; Post RFS</b>	151	134	58
<b>Total sample size</b>	170	158	78

#### 6.4.3 What change in concept test (FMCE) results do the OLMs produce?

We modelled our program of Concepts OLM on the previous study from Seery and Donnelly (2012) who demonstrated improved conceptual learning. Do our Concepts OLM also produce benefits to conceptual learning? Do our Representations OLM which do not specifically target concepts also have a positive impact on learning concepts? Table 6.3 provides the mean scores and standard deviations for students from each OLM stream and the non-participants on the FMCE.

Table 6.3: Mean scores and standard deviations on the FMCE for each OLM stream and the non-participants.

	<b>Representations OLM (n=137)</b>		<b>Concepts OLM (n=124)</b>		<b>Non-participants (n=53)</b>	
	Mean	$\sigma$	Mean	$\Sigma$	Mean	$\sigma$
<b>Pre-FMCE</b>	16.23	8.39	16.01	8.81	17.37	9.80
<b>Post-FMCE</b>	21.53	12.46	21.87	11.49	21.13	11.10

The distributions were not normal when examined using Kolmogorov-Smirnov test for normality. Using independent-samples Mann-Whitney U Tests, we found no statistically significant difference between the distributions of pre test scores for the Concepts or Representations OLM ( $p=0.131$ ). No statistically significant differences were found when comparisons were made with non-participants (independent-samples Mann-Whitney U Tests,  $p=.295$ ). Therefore the conceptual understanding, as measured by the FMCE, was the same upon entry. Next we considered improvement across the course of the semester. Using non-parametric Related-Samples Wilcoxon Signed Rank Test we found a statistically significant increase in scores for both streams and the non-participants ( $p<0.001$ ). There was improvement across the course of the semester.

The question then arises, are the improvements of similar magnitudes or does one learning environment offer an advantage? We turn to learning gains, which are a measure of the “average normalised gain  $\langle g \rangle$  for a course as the ratio of the actual average gain  $\langle G \rangle$  to the maximum possible average gain, i.e.,

$$\langle g \rangle = \% \langle G \rangle / \% \langle G \rangle_{\max} = (\% \langle S_f \rangle - \% \langle S_i \rangle) / (100 - \% \langle S_i \rangle)$$
 (Hake, 1998)

Table 6.4 shows that the learning gains on the FMCE are the highest for the Concepts Stream, very closely followed by the Representations Stream and lowest for the non-participants.

Table 6.4: Learning gains for the FMCE for each OLM stream and the non-participants.

$\langle g \rangle$	<b>Representations OLM</b> (n=137)	<b>Concepts OLM</b> (n=124)	<b>Non-participants</b> (n=53)
<b>FMCE</b>	.198	.219	.147

In conclusion, these results indicate that both learning modules can improve student performance on a conceptual test. The Representations OLM produce gains almost to the same extent as the Concepts OLM and better than for non-participating students. Our results indicate that well designed representations instruction does facilitate conceptual understandings as it allows participation in disciplinary discourse (Airey & Linder, 2009) required for learning in lectures or any context.

#### 6.4.4 What change in representational fluency test (RFS) results do the OLMs produce?

Table 6.5 provides the mean scores and standard deviations on the RFS for the two streams and non-participants.

Table 6.5: Mean scores and standard deviations on the RFS for each OLM stream and the non-participants.

	<b>Representations OLM</b> (n=151)		<b>Concepts OLM</b> (n=134)		<b>Non-participants</b> (n=58)	
	Mean	$\sigma$	Mean	$\Sigma$	Mean	$\sigma$
<b>Pre-RFS</b>	8.330	3.68	7.910	3.31	7.380	3.60
<b>Post-RFS</b>	11.51	3.61	10.58	3.63	9.950	4.30

Student data for the RFS was compared in a similar manner to the FMCE. With the RFS pre test scores, no statistically significant differences were found between the distributions for the two streams and the non-participants. Again, comparing pre and post tests, both streams experienced a significant increase in mean scores ( $p < 0.001$ ) indicating improvement across the course of the semester.

Unlike the results for the FMCE however, when comparing the post tests, on average, students who were in the Representations OLM stream scored significantly higher on the post Representational Fluency Survey (Independent-samples Mann-Whitney U Test=0.011) than those from the Concepts Stream.

Considering RFS learning gains, the Representations Stream registered the highest gain, followed by the Concepts Stream and the non-participants, see table 6.6.

Table 6.6: Learning gains for the RFS for each OLM stream and the non-participants.

<b>&lt;g&gt;</b>	<b>Representations OLM (n=151)</b>	<b>Concepts OLM (n=134)</b>	<b>Non-participants (n=58)</b>
<b>RFS</b>	.329	.265	.242

In conclusion, on average both of the OLM streams and the non-participants improved their score on the RFS across semester 1 indicating that the combination of instructional methods did result in improved representational fluency. Both sets of OLM can be seen to be beneficial for learning representational fluency but the Representations Stream was most effective. These data show that the representational fluency of university students can be improved through Representations OLM. This successful result is pleasing, but not unexpected as it was targeted through meaningfully integrated blended learning using demonstrated methods such as the strongly directed approach of explicitly teaching representations (Kohl, et al., 2007a).

#### 6.4.5 *Interpreting Learning Gains*

The question now arises, how does this improvement compare with ‘normal practice’ or other teaching innovations? Here we seek to benchmark learning gains with earlier studies. Learning gains have been graphically represented, on a two-dimensional plot with the x-axis representing the pre-test scores and the y-axis the learning gains, see figure 6.6. Figure 6.6a is from an extensive study demonstrating that teaching methods employing interactive engagement strategies register higher learning gains than methods employing more traditional approaches (Hake, 1998). Figure 6.6b, from our institution, illustrates a similar finding, courses with Interactive Lecture Demonstrations (ILDs – where modified predict-observe-explain protocols are intermingled with peer instruction) register higher learning gains than more traditional lectures (non-ILD) (Sharma et al., 2010). Consistently studies reveal that particular teaching methods can result in medium gains versus traditional instruction which typically achieves lower gains. Figure 6.6c comprises of learning gains from the FMCE and 6.6d from the RFS from this study.

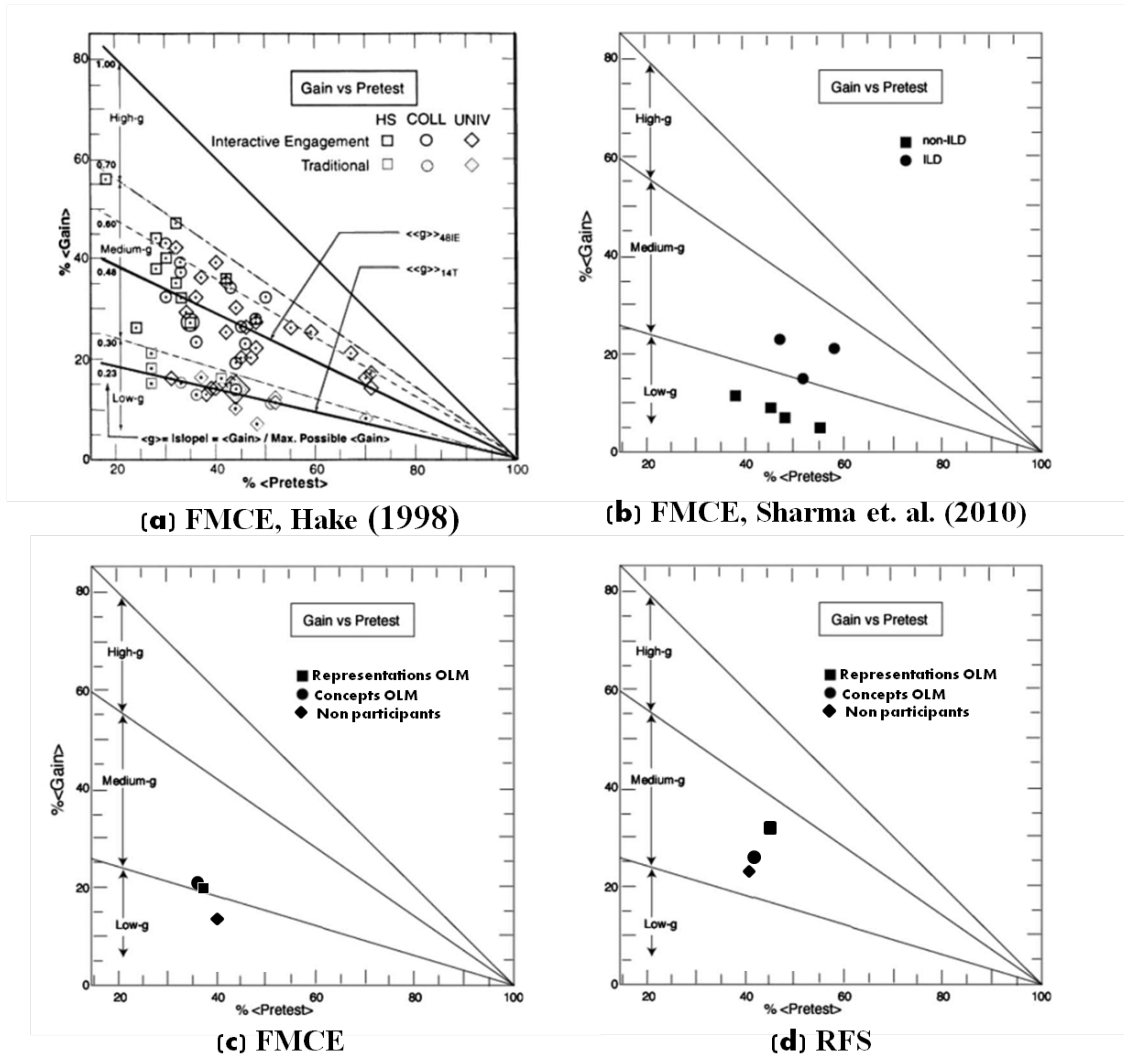


Figure 6.6: Gain plots of 2014 data for FMCE and RFS tests (c) and (d) and results from previous research using, as diagnostic tests, the Force Concept Inventory, Hake (1998) (a) and the FMCE, Sharma et. al. (2010) (b).

Noteworthy is that the non-participants registered low gains similar to students with non-ILD instruction as measured by the same test (FMCE) in previous years (comparing 6.6b and 6.6c). This establishes a baseline for our study. Both OLM streams resulted in higher gains for students on the FMCE (medium gains) than non-participants (low gains). In the case of the RFS all three streams fall within the range of medium gain, but again, the students who did complete modules experienced higher gains, with the Representations Stream achieving the highest gain.

## **6.5 RQ3: Do students recognise the benefits of OLM for physics learning?**

### *6.5.1 Data Collection and Analysis*

Student feedback was elicited upon completion of the final Week-13 module, and 12 students who completed the OLM were interviewed at the end of the semester (see sequence in figure 6.5). Student feedback was in the form of online responses to the following open ended question (n=300):

“Name one thing about the Online Learning Modules that was helpful for learning physics this semester”

Ten face-to-face, semi-structured interviews were conducted individually and one with two students. The interviews sought to probe ‘how the modules supported and or hindered learning?’ The students were selected using the quota sampling method to ensure representation of the student body. Each interview was 20-40 minutes in length, participant responses were audio recorded and transcribed by the interviewer to ensure maximum accuracy of both verbal and non-verbal responses.

The analysis of the open-ended responses and interview data occurred after all the data had been collected such that the researchers were immersed in all of the qualitative data while completing the analysis. Iterative coding identified emergent themes which were authenticated by triangulation through different analysis across the two data sources. The interview data provides rich descriptions of the emergent themes. There were three steps in the analysis.

1. A simple word count of the online responses identified popular words around which the emergent themes could be framed.
2. Systematic coding of online responses was used to formulate themes
3. The themes were validated by an expert and finalised by cross-checking with interview responses

### *6.5.2 Results*

Table 6.7 presents a word count of the most common words as well as examples of how the students used the words.

Table 6.7: Percentage of responses using variations of particular common words in answering the question "Name one thing about the OLM that was helpful for learning physics this semester" from both the Concepts and Representations Streams.

	Root word	Sample use of the word in context	Concepts (n=135)	Representations (n=165)
1a	Lecture	"It provided information that put <i>lecture</i> material into context"	46%	33%
1b	Prepare	"helped me <i>prepare</i> the material for the following week"	11%	6%
2a	Understand	"help me to reinforce the <i>understanding</i> of some basic understanding of physics"	17%	20%
2b	Concept	"giving an idea about the <i>concepts</i> we will learn the following week"	14%	7%
2c	Graph/Equation /Diagram	"it helped me to learn some useful <i>equations</i> beforehand"	0%	13%

While the OLM are one learning resource from many (including labs, lectures, tutorials and other online resources), table 6.7 illustrates that students recognised the strong connection between the OLM and lectures, and in particular improved learning in lectures. The five most common words in conjunction with coding led to three emergent themes with sub-themes, summarised in table 6.8. Each theme, elaborated below, displays that students do recognise the benefit of completing the OLMs for learning physics.

Table 6.8: The emergent themes and sub-themes from the 300 online responses to the question "Name one thing about the OLM that were helpful for learning physics this semester".

Theme	Sub-theme
<b>1. OLMs prepared students for lectures and other learning.</b>	1a. The OLMs made learning in lectures more effective or efficient
	1b. The OLMs assisted preparation for the week's learning (lectures, labs and tutorials)
<b>2. OLMs improved student understanding of physics</b>	2a. The OLMs explained physics or facilitates learning and understanding
	2b. The OLMs introduced physics content or ideas (concepts)
	2c. The OLMs introduced physics graphs, equations or diagrams (representations)
<b>3. OLMs provided other benefits to learning physics</b>	3a. The OLMs encouraged regular physics participation
	3b. The OLMs acted as a review (rather than preview) of the week's material

**Theme 1: The students found OLMs prepared them for lectures and other learning.**

Various comments from both streams revealed that the students felt that completing the OLMs changed the way they learnt. This was expressed in two ways, some felt that the lectures were easier to understand ("it helps me to understand more and more, much easier to follow the lectures" – Concepts Stream, "by completing the OLM we are not completely clueless in lectures" – Representations Stream [Theme 1a.]) Others felt more prepared for the upcoming material ("It gave me an idea what direction the lectures were heading in" – Concepts Stream, "It made me feel a little more comfortable as I was able to see the 'big ideas' that I would be learning in the following week" – Representations Stream [Theme 1b.]). In essence, these students recognised the purpose of the OLMs to help students "gain a basic understanding of each topic covered (as an) insight into the materials being covered for each following week" (Concepts Stream).

The observation of the students that completing the modules helped them "follow the lectures" (Concepts Stream), and "increase understanding of information during the lecture" (Representations Stream) is consistent with pre-lecture priming (Seery & Donnelly, 2012). The effectiveness of introducing representations to improve learning in lectures is explained by one student in particular: "The early introduction to the relevant formulas was extremely helpful as



then I was able to relate it to the content and make much more sense of what I was learning” (Representations Stream).

Theme 2: The students described the OLMs as directly teaching physics concepts or representations.

Around 19% of respondents commented that the modules improved their “understanding” of physics [Theme 2a.] Some students listed particular module topics such as “thermodynamics” (Concepts Stream) or “drawing ideal gasses” (Representations Stream), others spoke more generally about how “it sometimes explained things better than the lecturer does” (Representations Stream) [Theme 2a].

As table 6.7 shows, students from both streams reported that they learnt particular physics concepts from the OLM [Theme 2b.] (“It was useful in getting the initial idea of the concept which was being explained” – Representations Stream). However, only those from the Representations Stream (13%) mentioned graphs, equations/formulas or diagrams [Theme 2c.]. Here students recognised that it was an aspect of physics that was being introduced, “it gave simple hints on reading graphs” (Representations Stream). This was the main point of difference between student comments from the two module streams.

Theme 3: The students comment that the OLMs provided other benefits to learning physics.

The benefits described in this section were not part of the original intention of the OLM but are noteworthy for their potential impact on research into online learning. Students from both streams commented on OLM as a regular activity compelling them to actively participate in physics, impacting positively on their learning experience [Theme 3a.] (“They made sure I did some physics work every week” – Concepts Stream, “The compulsory evaluation of our learning each week was very helpful” – Representations Stream). Some students requested that OLM be given for *post-lecture* revision [Theme 3b.] (“rather than the online modules trying to prepare for the lectures, they felt like a more appropriate and encouraging reminder of the things mentioned in the lecture instead” – Concepts Stream). These students valued the OLM as a metacognitive reflective tool (“it forced me to do a quick mental summary of things I had learnt that week” – Concepts Stream) and as an “evaluation of our learning each week” (Representations Stream). Given the numbers of students who value the OLM for pre-lecture priming, whether to make them available afterwards, or for longer time periods is a challenging decision to make for educators.

Interview Responses

There was a greater difference between the streams in the interviews than in the online responses, however, the responses matched the themes identified in Table 6.8. Students who completed the Concepts Stream recognised the benefit of the almost flipped lecture approach.

*Initially for the first two or three weeks I thought they were pointless... but by doing the modules we do have a rough idea of what we are going to learn so when it ends up in lectures we know what the lecturer is telling us so we don't have to stop or pause it and ask him for every single time rather we can just move on with the class. (Concepts Stream) [Theme 1a.]*

They also believed that the modules played a role in priming prior knowledge, to optimise learning in lectures.

*Obviously you can't show up to a lecture and understand 100% what they are saying without some prior knowledge, so I feel that the online stuff did give me that prior knowledge that you needed. (Concepts Stream) [Themes 1a. and 2a.]*

Some students from the Representations Stream also recognised a shift in their “subconscious” attitudes towards lectures and were able to describe the metacognitive shifts that the modules facilitated.

*at a subconscious level it is working so you could maybe look at the lecture in new ways. (Representations Stream) [Theme 1].*

Furthermore, students recognised how priming explicit representations freed up cognitive space so more complex ideas could be understood in lectures.

*(The modules) told me about the graph and how it works... when they started talking about how it is to be applied and what it means, as opposed to being stuck with how it works and being behind, I already knew. (Representations Stream) [Theme 1a and 2c].*

Analysis of both the online responses and participant interviews illustrate how students were positive towards the OLM regardless of the focus on representations or concepts. In addition, they recognised that they were not stand-alone, but assisted learning in lectures [Theme 1]. In the case of the Representations Stream, it allowed for a particular barrier to learning to be lowered [Theme 2c.] which supports the quantitative findings that the Representations Stream

have the highest learning gains according to the representational (RFS) measure, and almost equally high learning gains as the Concepts Stream according to the conceptual (FMCE) measure.

## **6.6 Implications and further research**

### *6.6.1 Online resource development processes*

There were two notable factors in the success of the OLM at the University of Sydney. First was the research-based design; drawing on previous studies increased the likelihood of success of our move towards blended learning. We recommend that educators investigating blended learning consider the literature in (but not limited to) this paper and where possible, consult authors and educators attempting similar strategies.

The second factor was undertaking trials as shown in figure 6.3. The process of trialing physical worksheets in two high schools resulted in substantial changes which ensured that the modules were communicating what they were designed to communicate. The ideal would be to trial *online* modules on a small scale, but technological constraints prevented this. Hence, the first full implementation in 2013 is viewed as another trial. This study reports results from the 2014 deployment of the OLM as we consider this to be ‘going live’. The three year investment has resulted in an online learning resource that will need minimal, if any tweaks in the near future assuming that the syllabus is not altered. And we have evidence that the resource improves student learning and engagement. We see our study as an opportunity to analyze results and understand student learning and use of online resources even further. We recommend that educators consider trials prior to full deployment of learning resources.

### *6.6.2 Deployment and management strategies*

Reflecting on student participation and students’ comments (see research question 3), there are a number of lessons that can be learnt from our particular implementation of OLM in first year physics.

- (a) Offering 1% for completing 11 out of 12 OLM had some consequences:
  - a. A 1% incentive was sufficient to get most students completing the weekly online activities.
  - b. The OLM were awarded marks for participation rather than correct answers. This encouraged authentic participation and for students to take responsibility for their own learning. Students did not take advantage of the system.

- c. Clear communication is necessary as some students thought that by missing two OLM they were no longer able to attain any marks. The concept of pro rata marks needs to be stressed.
  - d. When marks are associated with any activity some students will seek clarification that marks have been awarded. A system needs to be in place to regularly monitor the online system and student emails. It is important to support students with access and completion issues as technical glitches can occur.
- (b) Communication of the purpose of the pre-lecture OLM was important for encouraging participation and managing student expectations
- a. Students were informed that the primary purpose of the OLM was to prepare for lectures. This was recognised by students as a helpful element of the OLM.
  - b. Students were reminded at the start of each new physics topic with a different lecturer (Thermal Physics, Oscillations and Waves) that the OLM would continue for these topics.
  - c. Students were not told that the OLM were an ‘innovation’ in this course. From the student perspective, the OLM (and blended learning) were simply a normal part of the course.
- (c) Making OLM available from 5pm Thursday until 10am Monday morning was appropriate for pre-lecture online activities
- a. An average of 15 minutes (student times typically ranged from 8-30 minutes) was appropriate. We saw significant changes in student learning. There was appreciation of the OLM rather than complaints.
  - b. Thursday until Monday morning gave the students enough flexibility but recognised that many students would complete the OLM at the last minute. Therefore giving a larger time window for students would be unnecessary.
  - c. Having access available over the weekend was necessary (as many students did the exercise on the Sunday) but also required periodic monitoring over the weekend to troubleshoot problems that inevitably arose.

### *6.6.3 Which is more beneficial for pre-lecture OLM: introducing physics representations or physics concepts?*

The results of research question 2 showed clearly that both streams of OLM were beneficial for student learning. Therefore we would encourage any tertiary science educator who is using completely classroom-based instruction to consider blended learning of pre-lecture instruction

with either representations or concepts. Both of the streams produced similar learning gains (*Representations*: 0.198, *Concepts*: 0.219) on the concept survey (FMCE), while those who elected not to complete the OLM but did participate in the course registered gains in the low range (0.147).

Despite this, for students to develop scientific representational fluency, the representations-focussed OLM were clearly more effective on the RFS (*Representations*: 0.329, *Concepts*: 0.265). In comparison, the gain for those who did not complete the OLM, was 0.242 is similar to the gain for the concepts stream. Therefore the results of this investigation would suggest that introducing representations through OLM is the better pre-lecture instruction option for student cohorts like the 1<sup>st</sup> year Regular physics students at the University of Sydney.

It is hoped that this result and implication can be used by other scientific disciplines too as while representational fluency here is nuanced for physics students, it is an interdisciplinary concept (Hill et al., 2014). Therefore educators in chemistry, biology, and environmental sciences could consider the representations that are taught and how they can best introduce them through blended learning or otherwise.

It could be suggested that the ideal instruction incorporates both concept-focussed and representation-focussed teaching. We would agree and argue that explicit representation-focussed instruction is often lacking in many scientific education settings. However, in the case of pre-lecture activities, where there is limited time in preparing for further teaching in lectures, this study demonstrates that representation-focussed instruction should be prioritized.

## **6.7 Conclusion**

The implementation of online pre-lecture learning modules in a first-year university calculus-based physics course resulted in improved learning gains on both conceptual and representational reasoning tests. Completing these modules, in addition to regular course instruction, increased student conceptual understanding and representational fluency greater than regular course instruction alone. Results over two years indicate that student representational fluency can be developed through targeted teaching strategies in particular explicitly introducing students to physics representations weekly throughout the semester. Furthermore, qualitative analysis supports the quantitative data and also shows that the students themselves recognise both intended and unintended benefits of OLM.

## 6.8 References

- Airey, J., & Linder, C. (2009). A Disciplinary Discourse Perspective on University Science Learning: Achieving Fluency in a Critical Constellation of Modes. *Journal of Research in Science Teaching*, 46(1), 27-49. doi: 10.1002/tea.20265
- Aldrich, F., & Sheppard, L. (2000). 'Graphicacy': the fourth 'R'? *Primary Science Review*, 64, 8-11.
- Beichner, R. J. (1994). Testing student interpretation of kinematic graphs. *American Journal of Physics*, 62(8), 750-762.
- Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637-650.
- Black, G. (2002). A comparison of traditional, online, and hybrid methods of course delivery. *Journal of Business Administration Online*, 1(1), 1-9. doi: <http://www.atu.edu/business/jbao/Spring2002/black.pdf>
- Bowen, G. M., Roth, W. M., & McGuinn, M. K. (1999). Interpretations of graphs by university biology students and practicing scientists: Toward a social practice view of scientific representation practices. *Journal of Research in Science Teaching*, 36(9), 1020-1043.
- Britton, S., New, P., Sharma, M. D., Yardly, D. (2005). A case study of the transfer of mathematics skills by university students. *International Journal of Mathematical Education in Science and Technology*, 36, 1-13.
- Chen, Z., Stelzer, T., & Gladding, G. (2010). Using multimedia modules to better prepare students for introductory physics lecture. *Physical Review Special Topics-Physics Education Research*, 6(1), 010108. doi: <http://dx.doi.org/10.1103/PhysRevSTPER.6.010108>
- diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, 22(3), 293-331. doi: 10.1207/s1532690xci2203\_2
- Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). *Solving Physics Problems with Multiple Representations*. Department of Physics & Astronomy and Scientific Reasoning Research Institute. University of Massachusetts.
- Ellis, R. A., Goodyear, P., Prosser, M., & O'Hara, A. (2006). How and what university students learn through online and face-to-face discussion: Conceptions, intentions and approaches. *Journal of Computer Assisted Learning*, 22(4), 244-256.
- Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy, S., Rosengrant, D., & Warren, A. (2006). Scientific abilities and their assessment. *Physical Review Special Topics-Physics Education Research*, 2(2), 020103.
- Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction. *European Journal of Physics*, 33(3), 657-666. doi: 10.1088/0143-0807/33/3/657

- Georgiou, H., & Sharma, M. D. (2015). Does using active learning in thermodynamics lectures improve students' conceptual understanding and learning experiences? *European Journal of Physics*, 36(1), 015020.
- Gilbert, J. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2, 16.
- Goldman, S. R. (2003). Learning in complex domains: when and why do multiple representations help? *Learning and Instruction*, 13(2), 239-244. doi: 10.1016/s0959-4752(02)00023-3
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.
- Hand, B., & Choi, A. (2010). Examining the Impact of Student Use of Multiple Modal Representations in Constructing Arguments in Organic Chemistry Laboratory Classes. *Research in Science Education*, 40, 16. doi: 10:1007/s11165-009-9155-8
- Harasim, L. (2000). Shift happens: Online education as a new paradigm in learning. *The Internet and higher education*, 3(1), 41-61. doi: [http://dx.doi.org/10.1016/S1096-7516\(00\)00032-4](http://dx.doi.org/10.1016/S1096-7516(00)00032-4)
- Hill, M., & Sharma, M. (2013). *Communicating like a physicist: teaching physics representations to high school students*. Paper presented at the Conference of the Australian Science Teachers Association, Melbourne, Australia.
- Hill, M., Sharma, M. D., & Johnston, H. (2013). *Developing representational skills through weekly online learning modules for first-year undergraduate physics students*. Paper presented at the Proceedings of The Australian Conference on Science and Mathematics Education (formerly UniServe Science Conference).
- Hill, M., Sharma, M. D., O'Byrne, J., & Airey, J. (2014). Developing and Evaluating a Survey for Representational Fluency in Science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 22(6), 22-42.
- Jackson, D. C., & Johnson, E. D. (2013). A hybrid model of mathematics support for science students emphasizing basic skills and discipline relevance. *International Journal of Mathematical Education in Science and Technology*, 44(6), 846-864.
- Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007a). Comparing explicit and implicit teaching of multiple representation use in physics problem solving. In L. McCullough, L. Hsu & P. Heron (Eds.), *2006 Physics Education Research Conference* (Vol. 883, pp. 145-148).
- Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007b). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics-Physics Education Research*, 3(1). doi: 01010810.1103/PhysRevSTPER.3.010108

- Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(1). doi: 10.1103/PhysRevSTPER.1.010104
- Kohl, P. B., Finkelstein, N. D. (2007). Expert and novice use of multiple representations during physics problem solving. In L. Hsu, C. Henderson & L. McCullough (Eds.), 2007 *Physics Education Research Conference* (Vol. 951, pp. 132-135).
- Lack, K. A. (2013). Current status of research on online learning in postsecondary education. *Ithaca S+ R, zuletzt geprüft am*, 3, 2013. doi: [http://apo.org.au/files/Resource/Ithaka-sr\\_OnlineLearningPostSecondaryEducation\\_May2012.pdf](http://apo.org.au/files/Resource/Ithaka-sr_OnlineLearningPostSecondaryEducation_May2012.pdf)
- Lasry, N., Dugdale, M., & Charles, E. (2014). Just in Time to Flip Your Classroom. *The Physics Teacher*, 52(1), 34-37.
- Lemke, J. (2005). Multiplying meaning. Reading science: Critical and functional perspectives on discourses of science, 87-114.
- Mazur, E. (2009). Farewell, lecture. *Science*, 323(5910), 50-51.
- McFarlin, B. K. (2008). Hybrid lecture-online format increases student grades in an undergraduate exercise physiology course at a large urban university. *Advances in Physiology Education*, 32(1), 86-91. doi: <http://dx.doi.org/10.1152/advan.00066.2007>
- Moore, J. C. (2014). Efficacy of multimedia learning modules as preparation for lecture-based tutorials in electromagnetism. *arXiv preprint arXiv:1409.7682*. doi: <http://arxiv.org/pdf/1409.7682v1.pdf>
- Moreno, R., & Mayer, R. E. (2004). Personalized messages that promote science learning in virtual environments. *Journal of Educational Psychology*, 96(1), 165-173. doi: <http://dx.doi.org/10.1037/0022-0663.96.1.165>
- Nathan, M., Stephens, A., Masarik, D., Alibali, M., & Koedinger, K. (2002). *Representational fluency in middle school: A classroom based study*. Paper presented at the Proceedings of the twenty-fourth annual meeting of the North American chapter of the International Group for the Psychology of Mathematics Education. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.
- Oncu, S., & Cakir, H. (2011). Research in online learning environments: Priorities and methodologies. *Computers & Education*, 57(1), 1098-1108. doi: <http://dx.doi.org/10.1016/j.compedu.2010.12.009>
- Redish, E. (2002). *Teaching Physics with the Physics Suite*. Maryland: University of Maryland Physics Education Research Group.
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2009). Do students use and understand free-body diagrams? *Physical Review Special Topics-Physics Education Research*, 5(1). doi: 10.1103/PhysRevSTPER.5.010108
- Roth, W. M., & Bowen, G. M. (1999). Of Cannibals, Missionaries, and Converts: Graphing Competencies from Grade 8 to Professional Science Inside (Classrooms) and Outside (Field/Laboratory). *Science, Technology and Human Values*, 24(2), 179-212.



- Roth, W. M., & Bowen, G. M. (2003). When are graphs worth ten thousand words? An expert-expert study. *Cognition and Instruction*, 21(4), 429-473.
- Seery, M. K., & Donnelly, R. (2012). The implementation of pre-lecture resources to reduce in-class cognitive load: A case study for higher education chemistry. *British Journal of Educational Technology*, 43(4), 667–677. doi: <http://dx.doi.org/10.1111/j.1467-8535.2011.01237.x>
- Sharma, M. D., Mills, D., Mendez, A., & Pollard, J. (2005). Learning outcomes and curriculum development in physics, A report on tertiary physics teaching and learning in Australia commissioned by the Australian Universities Teaching Committee.
- Stelzer, T., Brookes, D. T., Gladding, G., & Mestre, J. P. (2010). Impact of multimedia learning modules on an introductory course on electricity and magnetism. *American Journal of Physics*, 78(7), 755-759. doi: <http://dx.doi.org/10.1119/1.3369920>
- Stelzer, T., Gladding, G., Mestre, J. P., & Brookes, D. T. (2009). Comparing the efficacy of multimedia modules with traditional textbooks for learning introductory physics content. *American Journal of Physics*, 77(2), 184-190. doi: <http://dx.doi.org/10.1119/1.3028204>
- Thornton, R. K., & Sokoloff, D. R. (1997). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352.
- Treagust, D. F., & Chittleborough, G. (2001). Chemistry: A matter of understanding representations. *Advances in Research on Teaching*, 8, 239-267.
- Woolnough, J. (2000). How do Students Learn to Apply Their Mathematical Knowledge to Interpret Graphs in Physics? *Research in Science Education*, 30(3), 259-267.
- Tongchai, A., Sharma, M. D., Johnston, I. D., Arayathanitkul, K., & Soankwan, C. (2009). Developing, Evaluating and Demonstrating the Use of a Conceptual Survey in Mechanical Waves. *International Journal of Science Education*, 31(18), 2437-2457. doi: 10.1080/09500690802389605
- Young, H., & Freedman, R. (1996). *University Physics* (9th Edition ed.). Massachusetts: Reading.



## **Chapter 7:**

# **Discussion - Lessons learned regarding representational fluency**

This discussion considers three general questions regarding representational fluency. Each question is answered with implications for teachers and implications for research, as well as recommendations for the next step of work to be done on this question. The questions do not relate only to one paper; instead the answers and recommendations will be drawn from multiple papers in this thesis. Recall that the three questions presented in the introduction of this thesis were:

1. What is representational fluency?
2. What role does representational fluency play in physics learning?
3. How can students' development of representational fluency be facilitated?

### **7.1 What is representational fluency?**

#### *7.1.1 Summary Answer*

Representational fluency is the ability to work within and translate among representations used in a given discipline with ease. This thesis considered representational fluency of physics students and, as such, the representations requiring fluency were those specifically of the physics discipline.

#### *7.1.2 Discussion*

Representational fluency is an essential skill of physics students. It allows them to utilise the various representations in physics for communication, understanding, and problem solving. It is linked to content knowledge, or conceptual understanding, but can also be measured independent of content knowledge. The representational fluency of university physics students can be measured through the reliable, and valid, Representational Fluency Survey (RFS) (Hill, Sharma, O'Byrne, & Airey, 2014). This has never been attempted before in the literature.

The RFS, presented in Chapter 2, investigates representational fluency by probing the ability of students to solve representationally rich problems. The three tiers of the RFS indicate three facets of representational fluency (table 7.1). Each of these facets, to some degree, relates both to working within and translating among representations.

Table 7.1: The three tiers of the RFS

<b>Tier of the RFS</b>	<b>Facet of representational fluency</b>	<b>Relevant literature</b>
<b>Tier 1: Selecting the correct multiple choice answer</b>	The ability to discern information from a representation and manipulate it (mentally or otherwise) in order to solve a given problem. Always requires translating among representations.	(Bieda & Nathan, 2009; Gilbert, 2008; Kohl & Finkelstein, 2005; 2006; Nistal, Van Dooren, Clarebout, Elen, & Verschaffel, 2009; Shafir, 1999)
<b>Tier 2: Offering a scientifically congruent explanation in any representation</b>	The ability to generate scientifically congruent representations.	(Dufresne, Gerace, & Leonard, 2004; Roth, Bowen, & McGinn, 1999)
<b>Tier 3: Consistency between the chosen answer and the explanation</b>	The ability to use generated representations in meaningful ways towards a solution to a problem (regardless of whether the answer is correct).	(Bieda & Nathan, 2009; diSessa, 2004; Lesh, 1999)

Through administering the survey to 334 students at the University of Sydney the three tiers were validated as facets of representational fluency (Hill & Sharma, In Press). Furthermore, it also confirmed number of differences between groups of students who are considered to have a high level of representational fluency and those who have a low level of representational fluency. These were identified through analysing the results of the RFS and are consistent with previous research. On average, compared to cohorts with a low level of representational fluency, cohorts with a high level of representational fluency:

- use representations more often (Wu & Krajcik, 2006);
- use a greater variety of representations (diSessa, 2004; May, Hammer, & Roy, 2006; Tytler, Prain, Hubber, & Waldrip, 2013);
- use representations more closely aligned with accepted scientific practices (Roth & Bowen, 1999); and
- use a higher proportion of symbolic and visual modes of representation (consistent with Dufresne et al., 2004; J. Gilbert, 2004).

This had not previously been investigated collectively across multiple representations and is therefore a novel contribution of this thesis.

# Representational Fluency

The ability to work within and translate among representations used in a given discipline with ease

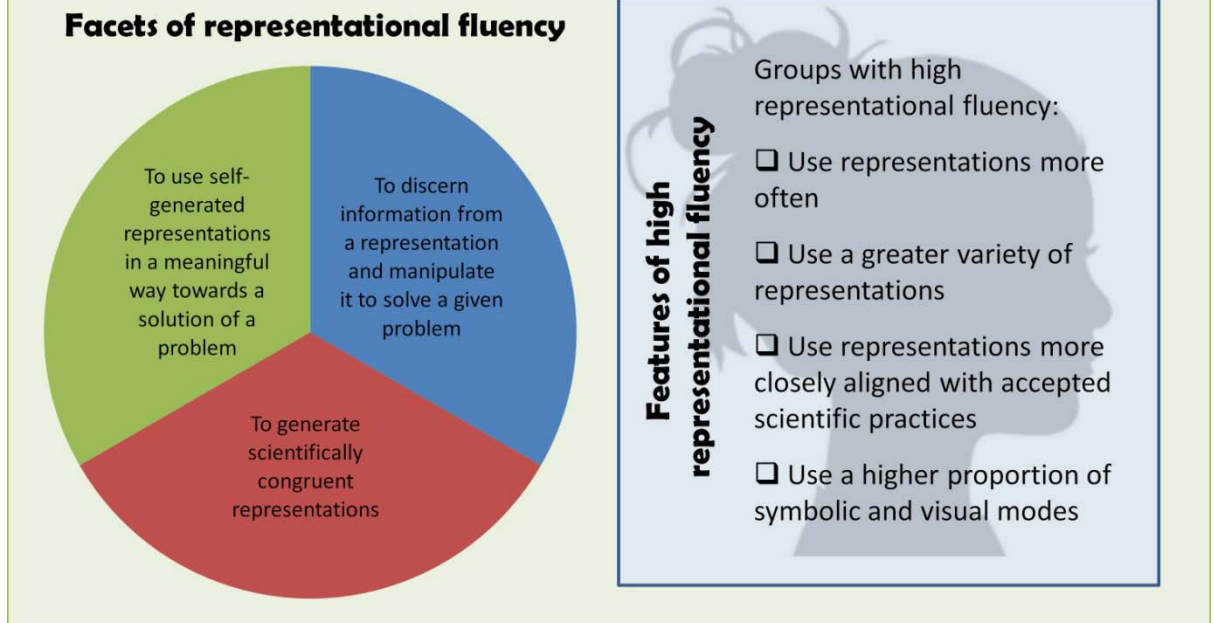


Figure 7.1: What is representational fluency?

### 7.1.3 Implications for Teachers

Educators have known for years that it is not simply the content but also the tools, methods, and ways of thinking to which students need to become accustomed. This research highlights a particular element of non-content, but discipline specific, facilitation of learning. Representational fluency gives a name to the skill that teachers recognise some groups of students have and others are still developing.

One implication is that teachers should look to deliberately support students as they develop representational fluency. Pre-service teachers would benefit from training in representational fluency and related pedagogy, resulting in teachers having a high level of representational fluency themselves and knowing how to facilitate representational fluency amongst their students.

In the classroom, and as part of instructional material, this research encourages teachers to be displaying the features of those with high representational fluency. Teachers may consider a incorporating representations to a greater extent and using a greater variety of representations in their teaching. Especially, teachers should not be afraid of drawing students towards symbolic

and visual modes of representations because using these modes are features of student groups with high representational fluency.

#### *7.1.4 Implications for Research*

The main implication for research into the question of what representational fluency is relates to how representational fluency can be measured. This has not been attempted before; instead some researchers have tried to measure the ability of students with one type of representation, or more commonly, measure student conceptual knowledge rather than representational use. The development of the RFS, a valid and reliable measure of representational fluency among university physics students, means researchers can now measure the representational fluency of students from different backgrounds, and after experiencing different forms of physics teaching.

Now that representational fluency has been defined, further research can either expand the RFS or develop new tools to measure representational fluency. This opens up the new possibility of research that can be pursued globally, and not only in the field of science. By measuring representational fluency (through the RFS or otherwise) instructional methods can be developed in order to facilitate representational fluency, as has been done in this thesis.

#### *7.1.5 Work to be done*

The RFS is not designed to be the final measure of representational fluency, not least because it is targeted at university physics students. Further research may include creating a larger pool of items to draw from, which would allow for variations of the RFS to be used with a wider variety of students. Modified versions could be designed for different age groups and for different disciplines within science.

Future work should also consider whether there are alternative means to testing the three identified facets of representational fluency in a survey that is easier to grade. The RFS is more difficult to grade than more commonly used multiple choice tests such as the FMCE or FCI. It may be possible to measure the same representational fluency as measured by the RFS with a multiple choice test, but that remains speculation at this stage.

## **7.2 What role does representational fluency play in physics learning?**

### *7.2.1 Summary Answer*

Representational fluency:

- is typically more developed for higher achieving cohorts of physics students;
- allows students to focus on content rather than the modes of communication and so changes the way that instructional materials, class learning, and the world around them is viewed; and
- allows communication in the classroom community and participation in the disciplinary discourse.

### 7.2.2 Discussion

The research in this thesis identified significant differences in the level of representational fluency between different groups of university physics students. Through trying to support students with low representational fluency in developing their representational fluency, it was seen that improved representational fluency changed the way that students learned in lectures and also resulted in improvements in conceptual understanding. Having high representational fluency, it appears, allows students to participate in the disciplinary discourse and therefore achieve greater benefit from physics instruction.

The results of the RFS reveal that representational fluency levels differ amongst the different levels of physics learning experience at the University of Sydney.

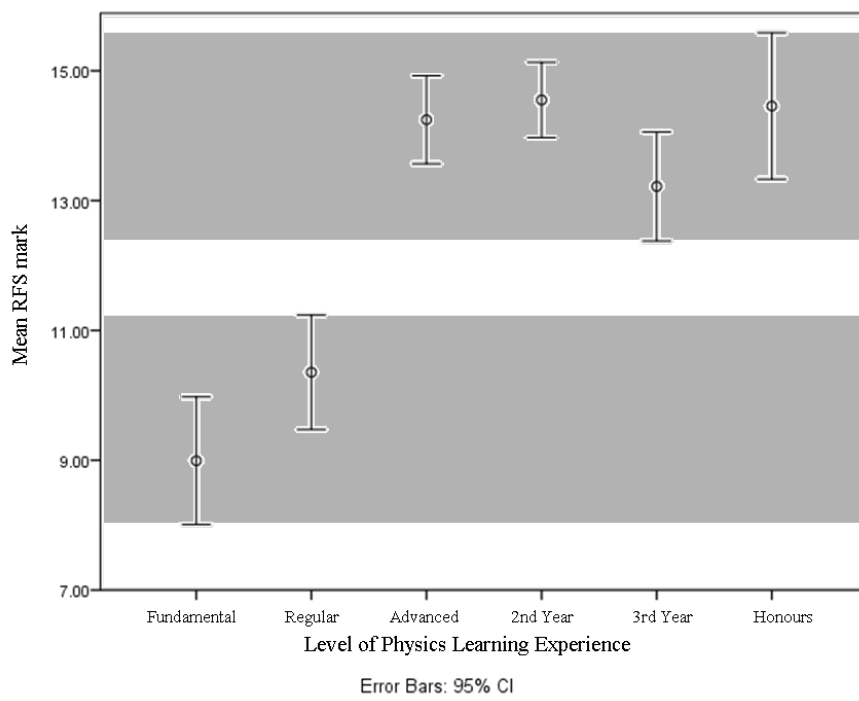


Figure 7.2: The mean RFS mark for the 6 levels of physics learning experience at the University of Sydney (Adapted from figure 3.2)

In particular, as seen in figure 7.2, the first year fundamental and regular students have, on average, a significantly lower level of representational fluency than the first year advanced students. The first year advanced students level of representational fluency is not significantly different from that of second year, third year, and honours/postgraduate students. During university instruction, more is expected of the first year advanced students than of the first year regular or fundamental students and these first year advanced students typically received higher marks on high school physics exams. While causation cannot be implied from this graph, one hypothesis is that students with high representational fluency may be able to learn physics more efficiently or effectively than students with low representational fluency. This hypothesis is supported by the further evidence outlined below.

The experiment reported in Chapter 6 details how representational fluency impacts student learning of physics concepts. During their first semester, students who received targeted, explicit, and integrated instruction on representational fluency had learning gains on a conceptual test comparable to students who received instruction focussed purely on physics concepts (Hill, Sharma, & Johnston, 2015).

Table 7.2: Learning gains for the FMCE (Force and Motion Concept Evaluation) for each OLM (Online Learning Module) stream and the non-participants. (from table 6.4).

<g>	Representations OLM (n=137)	Concepts OLM (n=124)	Non-participants (n=53)
FMCE	.198	.219	.147

While the learning gains for the students receiving conceptual physics instruction were 0.022 higher, the students learning about representations each week before class had greater conceptual learning gains than students who did not participate in the additional online instruction. On average, the students completing online learning modules focussed on representations had a gain 0.051 higher than students who did not participate even though there was no additional physics content taught in the representations stream. This indicates that developing students' representational fluency is an effective way for them to improve their ability to learn conceptual physics material.

Interview data and survey responses from students who participated in the weekly representations instruction provide some evidence why this might be the case. There was a clear trend of students from the representations stream indicating that the modules on representations improved the way that they learned in lectures. One student explicitly remarked that as a result of the instruction they would "look at the lecture in new ways". Rather than students needing to



focus on understanding representations in class, at the expense of focussing on the content, the pre-lecture representations instruction facilitated the lecture as a physics learning opportunity.

*(The modules) told me about the graph and how it works... when they started talking about how it is to be applied and what it means, as opposed to being stuck with how it works and being behind, I already knew. (Emphasis added)*

*– First year physics student*

Even the physics lecturers recognised the benefit of the pre-lecture instruction. This quote does not distinguish between students learning physics concepts and physics representations, but the lecturer believed that, in general, students conceptual understanding was improved by their involvement in pre-lecture instruction including the teaching of physics representations.

*I ran a set of... concept tests with clickers (a student response system) in this morning's lecture, and was pleasantly surprised at the outcome. For a start, attendance was up on the corresponding numbers last year - the 9am lecture is a good litmus test of student engagement. Secondly, their responses were quicker, and thirdly, a majority chose the correct answer... although the correct fraction varied from 55% to 95%.*

*I'm guessing that the... online learning modules may be having a positive effect on their engagement with the lecture material.*

*- Lecturer of first year physics*

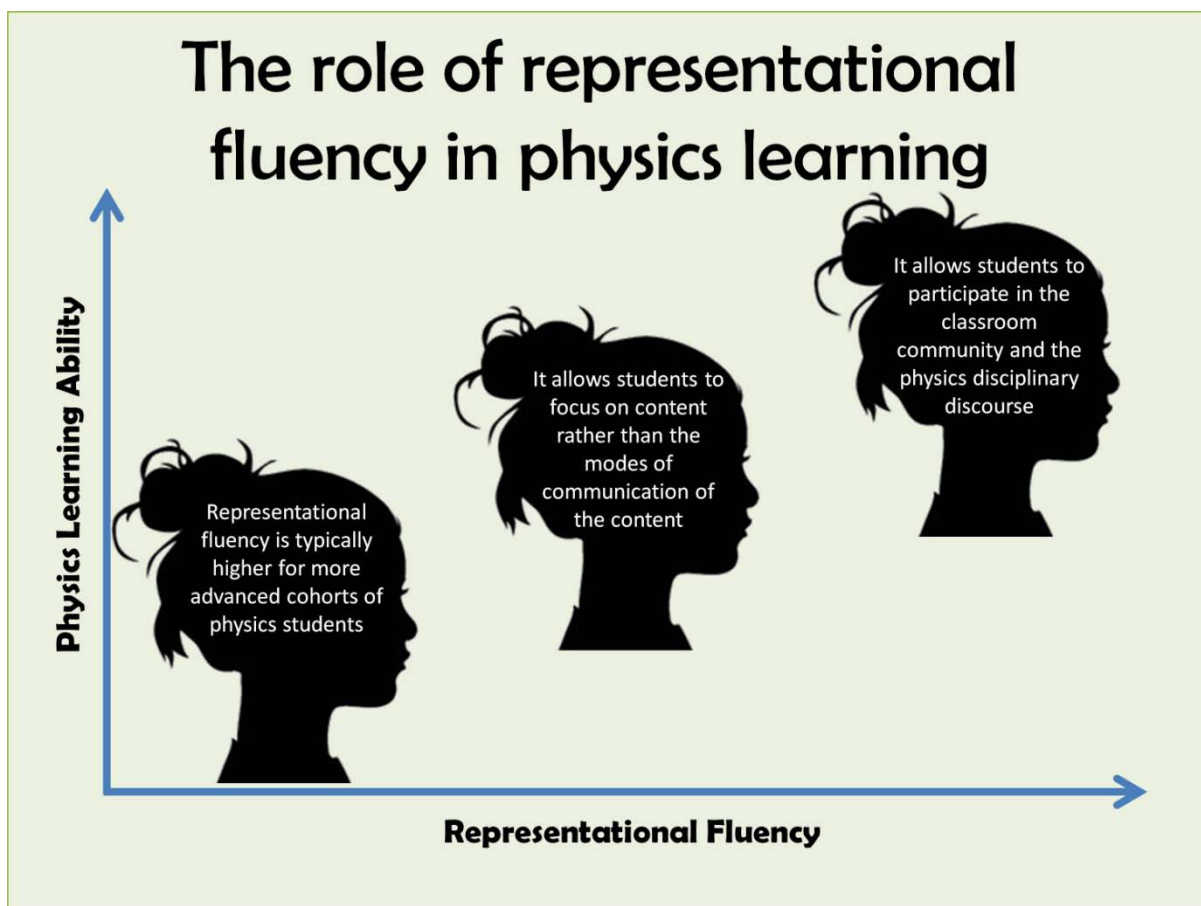


Figure 7.3: What role does representational fluency play in physics learning?

### 7.2.3 Implications for Teachers

One implication of this work is that the emphasis on developing representational fluency should be increased in curriculum documents, graduate attributes, or Threshold Learning Outcomes (TLOs). Currently, representational fluency underpins many of the science TLOs in Australia, but is only explicitly related to an outcome on communication: “4. Be effective communicators of science by: 4.1 Communicating scientific results, information, or arguments, to a range of audiences, for a range of purposes, and using a variety of modes.” Greater emphasis in such policies would lead teachers to see representational fluency as an outcome of science instruction facilitating life-long learning. It would also encourage continued engagement with developing science and the ability to communicate in the disciplinary discourse.

Furthermore, representational fluency should not only be seen as an end, but also as the means to the end of physics proficiency. If having a high level of representational fluency allows for greater participation in learning activities and improved outcomes in conceptual understanding, it follows that teachers need to strive to develop the representational fluency of their students for the sake of their physics learning. It would be wise for teachers to consider whether the level of representational fluency of their classes is appropriate for the level of physics instruction, and

avoid trying to teach physics concepts that are too advanced without supporting students to have the representational fluency they need to learn these difficult concepts.

#### *7.2.4 Implications for Research*

The first implication is obvious – if representational fluency is an important skill for physics students, how can physics instruction facilitate improvements in students’ representational fluency? This thesis provides some answers to this question in response to the third overarching question of this thesis: “How can students’ development of representational fluency be facilitated”. Because this is such a new idea, there remains substantial work to be done.

Research in this thesis suggests that having high representational fluency improves students’ learning of physics concepts. As a result, investigations can be done comparing the learning techniques of students based on their level of representational fluency. Researchers have already studied characteristics of effective students, and this can be compared to the characteristics of students with high representational fluency.

Research into effective physics pedagogy can now consider whether there should be variation in teaching techniques to students with low representational fluency compared with those with high representational fluency. Particularly due the large body of work demonstrating the effectiveness of inquiry in the classroom in science education, it may be that students who have high representational fluency benefit more from student centred, open inquiry tasks. This is an area of significant further research.

#### *7.2.5 Work to be done*

Even in the digital age, textbooks remain a crucial part of physics education in schools and universities. Teachers recognise that some students gain more benefit from reading the textbook than others, and therefore, some will seek answers in the textbook more often. This may relate to representational fluency. A topic for further investigation is examining how having high representational fluency changes the way that students engage with instruction such as, for example, physics textbooks.

## **7.3 How can students' development of representational fluency be facilitated?**

### *7.3.1 Summary Answer*

To facilitate the development of representational fluency, the use and affordances of representations should be taught explicitly (or with a strongly-directed approach), but integrated with course content. One method suitable for a university context is through weekly, representations-focussed, online learning modules.

### *7.3.2 Discussion*

Explicit teaching of representations can facilitate immediate change in student practices. This is also referred to as a “strongly-directed” approach to teaching representations (Kohl, Rosengrant, & Finkelstein, 2007). It involves making clear the representation, the conventions used in the discipline, and the representations' affordances (uses) as opposed to simply using representations correctly while teaching physics content. The benefit of explicit teaching of multiple representations was demonstrated in Chapter 4 in the development of representations-focussed worksheets for year 12 physics students. It was found that explicitly teaching free-body diagrams helped students to recognise often overlooked forces on everyday objects, such as an object's weight and the normal force when resting on a surface, and that explicitly teaching equations of energy led students to using more symbolic and visual representations in problem solving (a feature of students with high representational fluency identified in Chapter 3).

As a result, a framework for worksheet design (Figure 7.4) was published which can be used in various disciplines to teach students to use representations (Hill & Sharma, 2015).

Representations Worksheet	<b>Part 1: Information</b>		
	<b>What to master:</b> A list of up to 3 skills	<b>Why you need to know this:</b> Explaining how the skills can be helpful in physics	<b>How to master the skills:</b> Strongly directed/explicit instruction on how to use the representation
	<b>Part 2: Questions</b>		
	<b>Question 1R:</b> Question requiring representational use/thinking	<b>Question 2R:</b> Question requiring representational use/thinking	<b>Question 3: (Common Question)</b> Question appropriate to information from both worksheets
	<b>Part 3: Reflection</b>		
<b>How well do you think you know when and how to use <i>Representation</i>? (Likert)</b> Allows students and teachers to identify whether further work needs to be done in this area	<b>How helpful was this information for your study of physics this year? (Likert)</b> Helps students connect the instruction to the wider course as a whole		

Figure 7.4: The scaffold for representations-focussed worksheets developed in Chapter 4)

While these worksheets were shown to impact the ability of students to use particular representations relevant to the discipline (representational competence), whether these worksheets facilitate the ability to integrate representations or other aspects of representational fluency is to be determined.

Supplementary online learning modules (OLMs) were identified as an effective means of adding additional instruction to benefit a standard first year physics course (Hill, Sharma, & Xu, 2015). These were weekly, approximately 15 minute exercises for students to complete online in order to prepare them for the coming week's lectures. Chapter 5 illustrates how a large percentage of students engaged with this particular teaching format, and found it an effective part of their physics course. This indicated that the OLMs were an appropriate medium for university students (Chapter 5), and for investigating whether weekly representations instruction promotes representational fluency in students

Chapter 6 details how the representations worksheets of Chapter 4 were modified into the OLM format. An important feature of this implementation was that the 12 different representations taught were not taught in isolation. Instead each week's OLM was selected in consultation with the course lecturers to ensure that the students learned about the particular representation that would be most helpful for them in the coming week. They did not learn the representation on its own but were given information on the representation and were required to solve problems using the representation that were related to the upcoming week's study. In this way, the representation-focussed teaching was well integrated within the course.

The results show that students who completed the representations OLMs had the highest gains in representational fluency, as measured by the RFS, across the semester of university instruction (figure 7.5). The gains were  $g = .329$  which is towards the top of the medium-gain range. This was higher than students who completed OLMs based on physics concepts relevant to the course ( $g = .265$ ) and students who did not engage with the modules, or non-participants ( $g = .242$ ) though on average all students experienced medium gains in representational fluency (presumably due to their attendance at lectures).

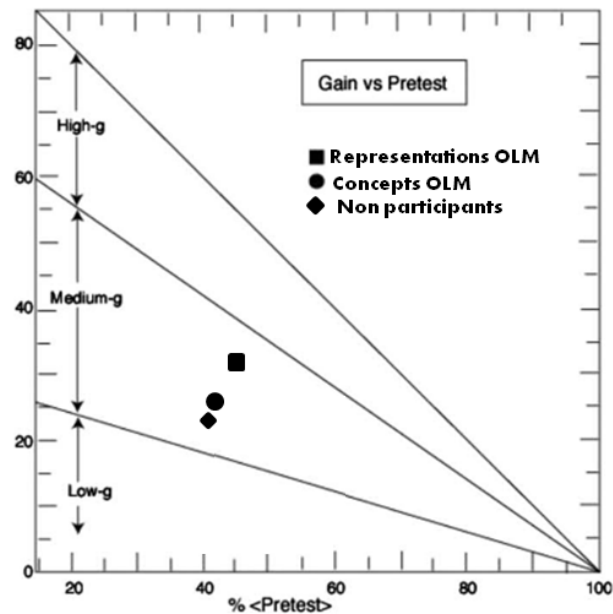


Figure 7.5: Learning gains on the RFS from students completing representations OLMs, concepts OLMs and students who elected not to participate in the OLMs. (6.6)

While this is almost certainly not the only way to teach representational fluency to university students (and may not even be the most effective way) it demonstrates that it is possible to deliberately teach students in a way that improves their representational fluency.

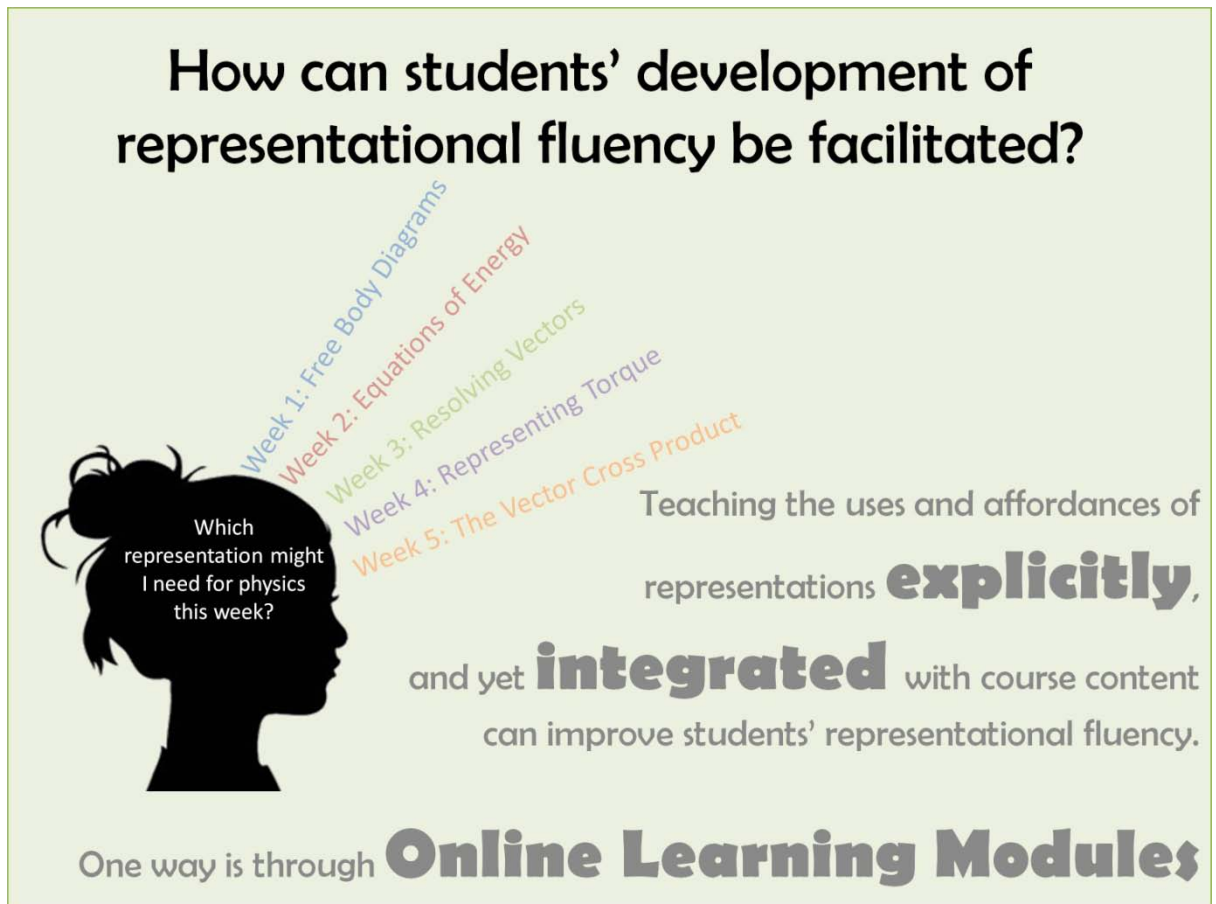


Figure 7.6: How can students' development of representational fluency be facilitated?

### 7.3.3 Implications for Teachers

The immediate implication for teachers is that this thesis has shown that improvements in a student's representational fluency can be facilitated through proper instruction. Teachers do play a role in developing the representational fluency of their students. This thesis has shown that this is possible and provided one way for representational fluency to be improved over the course of a semester of university-level instruction.

University course co-ordinators should consider whether a similar implementation of representations OLMs would be suitable for their student cohorts, in light of this thesis' demonstration of their effectiveness with the first year physics students at the University of Sydney.

If a similar implementation is not deemed suitable, perhaps for a secondary school context, teachers should consider how they can use the same principles to adapt a teaching strategy for their students. How to use representations should be explicitly taught, and taught in a way that is integrated with course material. One strategy may be introducing students to a particular representation or set of representations at the start of a lecture or class. This can be an explicit

teaching moment, and if the representations taught are also the ones that will be used heavily during the class, they will be well integrated with the course.

#### *7.3.4 Implications for Research*

One way of facilitating students' representational fluency has been presented in this thesis. This shows that teaching students to develop their level of representational fluency is an attainable goal. Therefore researchers should not see representational fluency as a predefined characteristic of proficient physics students, but rather a skill that can be developed.

Currently, research in representations targets a subset of representational fluency – particularly improving students' ability to use one particular representation. The value of this has been further demonstrated in this thesis where one representation was taught each week. Future research should consider whether there are effective ways to teach a variety of representations concurrently. Rather than simply trying to improve a student's graphicacy, can a single lesson aim to improve the way that students use both equations of motion, and graphs of motion? There is limited research in this area.

#### *7.3.5 Work to be done*

As education moves online there are both benefits and challenges. One challenge for science education is the change in the way students can communicate using representations through online mediums. With pen and paper students can draw diagrams, flow charts, graph, and write equations without any technological limitations. Online, students are constrained by the particular software they are using and their technical skills. While equations can be written on a computer, the manipulation and use of equations using technology is a difficult or at least unfamiliar skill when compared with writing equations on a physical piece of paper.

This was recognised as an issue when analysing student responses to questions in the OLMs. Their answers were online and therefore were restricted. There was a desire to analyse the representations that the students chose to use to solve the OLM problems using similar techniques to the analysis of the worksheets described in Chapter 4. The questions in the OLMs were intentionally written to facilitate allowing students' responses to show categorisation of the representations that they used, but so far, the analysis of these results is limited. This is something that will hopefully be continued in the future in conjunction with research into the benefit of the online environment for science education.

In conclusion, the results and analysis presented in the papers of this thesis (Chapters 2-6) have offered answers to the three questions surrounding representational fluency, provided



implications for teachers and researchers, and have led to further questions to be investigated. What is representational fluency, what role does representational fluency play in physics learning, and how can students' development of representational fluency be facilitated?

## 7.4 References

- Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637-650.
- diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, 22(3), 293-331. doi: 10.1207/s1532690xci2203\_2
- Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). Solving Physics Problems with Multiple Representations. Department of Physics & Astronomy and Scientific Reasoning Research Institute. University of Massachusetts.
- Gilbert, J. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2, 115-130.
- Gilbert, J. K. (2008). Visualization: An Emergent Field of Practice and Enquiry in Science Education. In J. K. Gilbert, R. Miriam & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (pp. 3-24): Springer.
- Hill, M., Sharma, M. D., O'Byrne, J., & Airey, J. (2014). Developing and Evaluating a Survey for Representational Fluency in Science. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International)*, 22(6), 22-42.
- Hill, M. & Sharma, M. D. (2015). Research-based worksheets on using multiple representations in science classrooms. *Teaching Science*, 61(3), 37-46.
- Hill, M., Sharma, M. D., Johnston, H. (2015). How online learning modules can improve the representational fluency and conceptual understanding of university physics students. *Eur. J. Phys.* 36 (2015) 045019.
- Hill, M., Sharma, M. D., Xu, Y. (2015). Pre-lecture online learning modules in university physics – Student participation, perceptions, and subsequent performance. Manuscript submitted for publication.
- Hill, M., Sharma, M. D., (In Press). Variation in students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students using the Representaitonal Fluency Survey. *Eurasia Journal of Mathematics, Science & Technology Education*
- Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(1). doi: 10.1103/PhysRevSTPER.1.010104

- Kohl, P. B., & Finkelstein, N. D. (2006). Student representational competence and the role of instructional environment in introductory physics. In P. Heron, L. McCullough & J. Marx (Eds.), *2005 Physics Education Research Conference* (Vol. 818, pp. 93-96).
- Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics-Physics Education Research*, 3(1). doi: 10.1103/PhysRevSTPER.3.010108
- Lesh, R. (1999). The development of representational abilities in middle school mathematics. *Development of mental representation: Theories and application*, 323-350.
- May, D. B., Hammer, D., & Roy, P. (2006). Children's analogical reasoning in a third-grade science discussion. *Science Education*, 90(2), 316-330.
- Nistal, A. A., Van Dooren, W., Clarebout, G., Elen, J., & Verschaffel, L. (2009). Conceptualising, investigating and stimulating representational flexibility in mathematical problem solving and learning: a critical review. *ZDM*, 41(5), 627-636.
- Roth, W., & Bowen, G. M. (1999). Of Cannibals, Missionaries, and Converts: Graphing Competencies from Grade 8 to Professional Science Inside (Classrooms) and Outside (Field/Laboratory). *Science, Technology and Human Values*, 24(2), 179-212.
- Roth, W. M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching*, 36(9), 977-1019.
- Shafir, U. (1999). Representational competence. In I. E. Sigel (Ed.), *Development of mental representation: Theories and applications* (Vol. xiii, pp. 371-389). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.
- Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (2013). *Constructing Representations to Learn in Science*: Springer.
- Wu, H. K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. *Journal of Research in Science Teaching*, 43(1), 63-95. doi: 10.1002/tea.20092

# **Appendices**

**Appendix A – The Representational Fluency Survey**

**Appendix B – Worksheets on physics concepts and representations for year 12 physics students**

**Appendix C – Online learning modules for first year university physics students**

**Appendix D – Relevant human ethics forms**



## **Appendix A**

### **The Representational Fluency Survey**

The Representational Fluency Survey (RFS) is a novel contribution to physics education research. It is designed to be used with university physics students in order to measure their representational fluency somewhat independent of their level of physics content or conceptual knowledge.

The test is designed to take a maximum of 30 minutes.

The journal article forming Chapter 2 describes the creation of the RFS and examines the validity and reliability of the test.

The journal article forming Chapter 3 demonstrates the use of the RFS to diagnose levels of representational fluency and to determine various characteristics of students with high representational fluency which allows for a more developed understanding of scientific representational fluency.

### RFS Instructions

There are seven questions.

Please answer each question, and please provide brief information which supports the answer you have chosen.

1

Acceleration versus time graphs for five objects are shown below. Acceleration is a measure of how velocity changes with time. All axes in the graphs have the same scale. Which object has the greatest change in velocity during the interval?

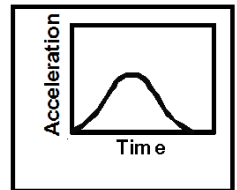
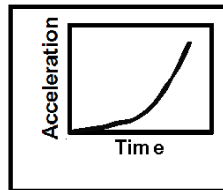
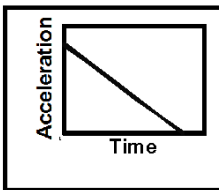
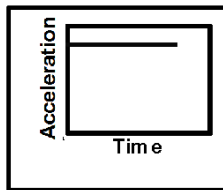
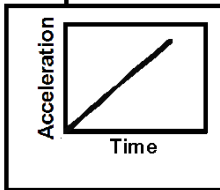
(A)

(B)

(C)

(D)

(E)



Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

2

A coin is tossed straight up into the air. After it is released it moves upwards, reaches its highest point and falls back down again. For each three points described below, choose one of the options A-G. If you think that none apply, write the letter J.

- A. The force is **down** and constant.
- B. The force is **down** and increasing.
- C. The force is **down** and decreasing.
- D. The force is **zero**.
- E. The force is **up** and constant.
- F. The force is **up** and increasing.
- G. The force is **up** and decreasing.

**Point 1:** The coin is moving upward after it is released:

Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

**Point 2:** The coin is at its highest point:

Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

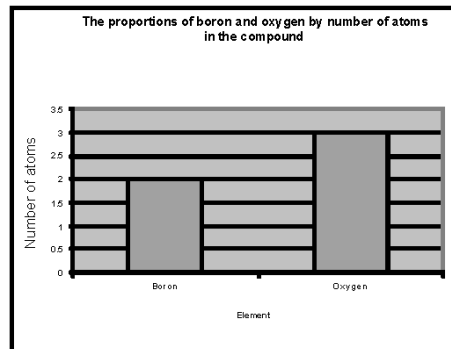
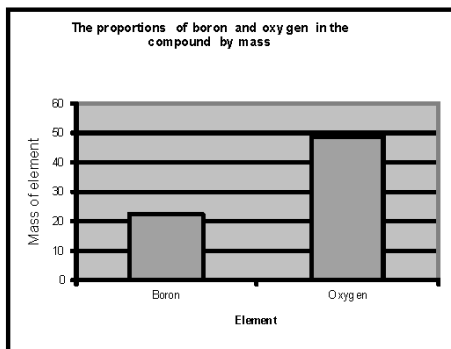
**Point 3:** The coin is moving downward:

Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

3

Boron and oxygen are the elements which make up the compound boric oxide.



What is the mass of an oxygen atom compared to a boron atom?

- (a) 0.5
- (b) 0.7
- (c) 1.5
- (d) 2.2

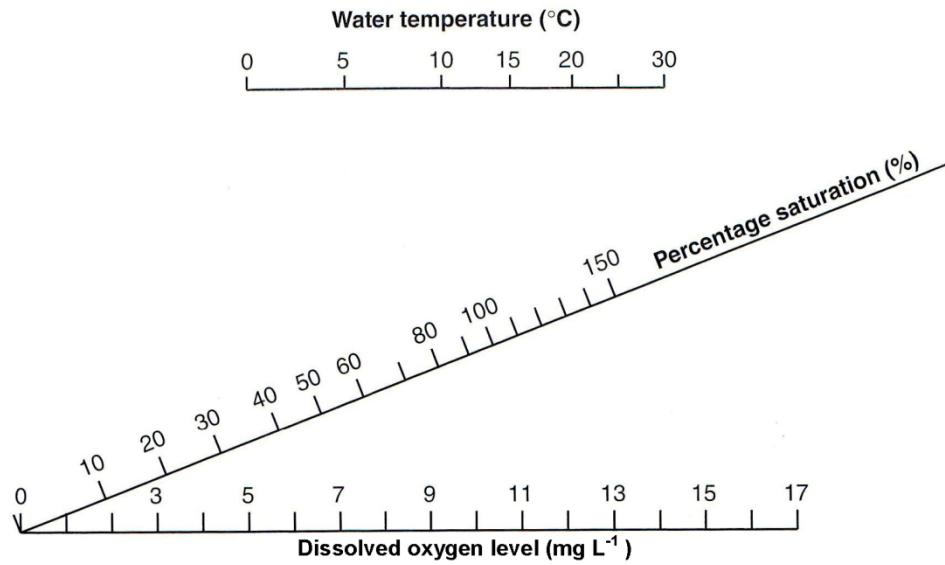
Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:



4

This nomogram shows the relationship between water temperature and the capacity of the water to hold dissolved oxygen (percentage saturation) at normal atmospheric pressure in a freshwater stream.



The stream had a 50% saturation level of dissolved oxygen when the dissolved oxygen level was 5 mg L<sup>-1</sup> and the water temperature was 15 °C.

Freshwater streams that are supersaturated with dissolved oxygen (greater than 100%) often experience excessive growth in aquatic plants.

At what minimum water temperature would this occur in the stream if it is dissolved oxygen level was 9 mg L<sup>-1</sup>?

- (a) 10 °C
- (b) 12 °C
- (c) 15 °C
- (d) 25 °C

Explain in words how to read information off this graph:

---



---



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5

A boy was competing in an orienteering tournament. He was initially stationary but accelerated at  $1.5 \text{ m/s}^2$  east for 2 seconds. He then maintained a constant speed in the same direction for another 30 seconds, before stopping suddenly upon reaching his first checkpoint.

A competitor started at the same point attempting to reach the same marker. She began stationary, accelerated at  $1 \text{ m/s}^2$  for 3 seconds, maintained a constant speed for 28 seconds before decelerating at  $1 \text{ m/s}^2$  for 3 seconds.

Given that they started at the same time, will the boy or the girl reach the checkpoint first?

Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

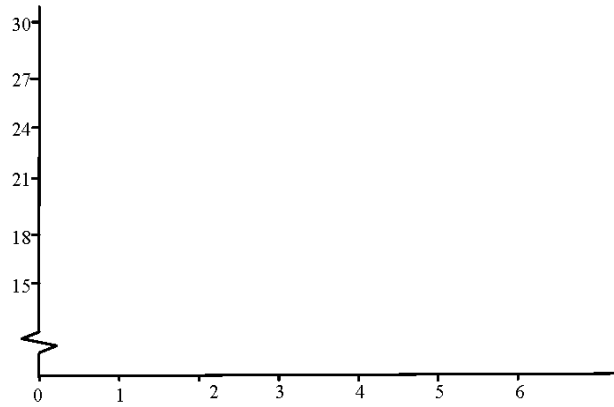
6

A student was measuring air temperature at different points around her house. She recorded the temperature and the distance from the open front door. Draw a simple graph in the space below which shows the relationship between temperature and distance from the door.

Distance from door (m)	1	2	4	5	6
Temperature (°C)	29	26	22	23	16

Title:

How temperature varies with distance from the front door of the house



Give information in the box below about the relationship between temperature and distance from the door:

7

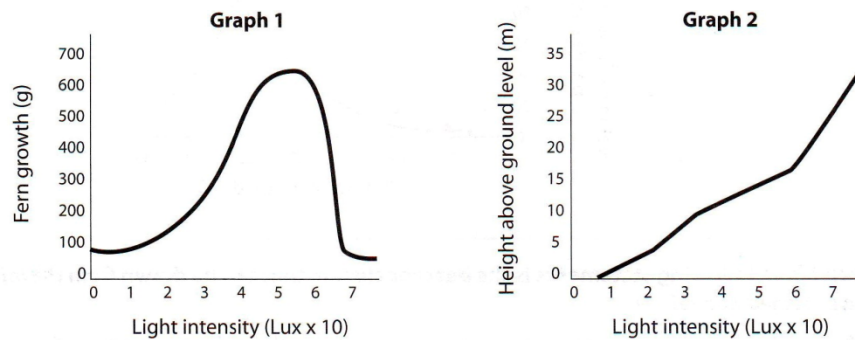
Different species of rainforest ferns require different levels of sunlight to survive. They obtain the required level of light as a result of their growth habit. The main types of ferns according to their growth habits are:

- Ground dwellers.
- Climbers, using the lower tree trunks to support their upward growth.
- Epiphytes that fasten onto the upper trunks and branches of trees.

The leaves (canopy) of the rainforest trees reduce the amount of light reaching the forest floor. The average height of the canopy trees is 25 metres above the ground, and the average depth of the canopy is 8 metres.

**Graph 1** below shows the effect of the intensity of sunlight on the growth (measured as mass increase) of a particular species of fern.

**Graph 2** below shows the variation in the intensity of sunlight in a rainforest against height above the forest floor.



From the information provided above, which of the following is the best description of the fern represented in **Graph 1**?

- (a) A ground dweller close to the base of trees
- (b) An epiphyte fastened onto the branches inside the canopy
- (c) An epiphyte fastened onto branches emerging above the canopy
- (d) A climber that grows to 10m up the trunk of the canopy trees
- (e) An epiphyte fastened onto tree trunks just below the main canopy

Answer: \_\_\_\_\_

Provide information supporting your answer or why you chose your answer:

There are no further questions. Please ensure you have provided information for each question.

## **Appendix B**

### **Worksheets on physics concepts and representations for year 12 physics students**

In order to investigate methods of facilitating student development of representational fluency, two sets of worksheets were created to be used with physics students in their final year of high school.

The development and use of these worksheets are described in the published paper included as Chapter 4.

There were four worksheets created, as detailed below, and each are included in this appendix.

The four worksheets. Two on the topic of forces, two on the topic of energy.

<b>Topic</b>	<b>Representations Worksheets</b>	<b>Concepts Worksheets</b>
Forces	Free-body diagrams	Tension and friction
Energy	Equations of energy	Kinetic and potential energy



## Part 1: Information

### What to master:

List the features of free body diagrams

Be able to explain why drawing free body diagrams is helpful

Be able to translate between the text of a problem and the corresponding free body diagram

### Why you need to know this:

- Free body diagrams allow you to:
  - Make sure you have taken into account all of the main forces affecting an object
  - Work out the total net force, by adding all the forces together, to work out the direction of motion from the force.
- Free body diagrams are a common problem solving technique in physics

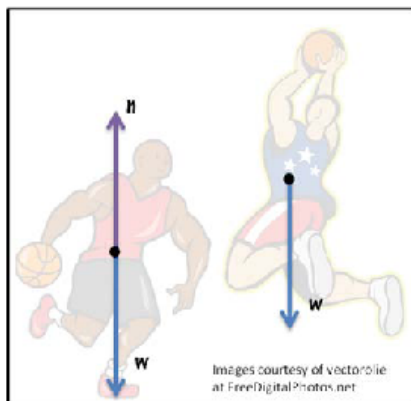
### How to master the skills:

*What is a free body diagram?*

The textbook for 1st year physics at the University of Sydney, University Physics, describes a free body diagram as “a diagram showing all the forces (magnitudes and directions) acting on the body” whose motion you are analysing by applying Newton’s laws.

*How to draw a free body diagram:*

1. Choose an object to be the focus of the diagram and represent it as a point or simple rectangle on the page.
2. Draw in all forces described in the question that apply to the object.
3. Check whether there are any forces missing, if the object is at rest, the forces should balance
4. Find if there are any unbalanced forces to work out the net force on the object



*Example of a free body diagram:*

There are two free body diagrams in the picture on the left, one for each basketball player.

The man on the right is standing on the ground and therefore there is a ‘normal’ force (‘n’) from the ground on the man pointing upwards. The two forces balance out so he will experience no acceleration at this point.

The man on the left has jumped in the air. The only force applying to him is the weight force downwards. Therefore we can calculate his acceleration using Newton’s 2nd Law— $F=ma$ .

## FORCES: Physics Representations

### Free Body Diagrams

#### Part 2: Questions

##### Question 1:

In your own words, explain why drawing a free body diagram may be helpful in solving a mechanics question in physics.

##### Question 2:

Draw the missing forces on these free body diagrams:

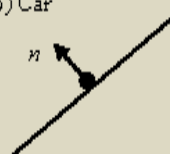
(a) Scuba diver



(a) A scuba diver remains stationary in the water 5m below the surface. There is a downward weight force on the scuba diver:

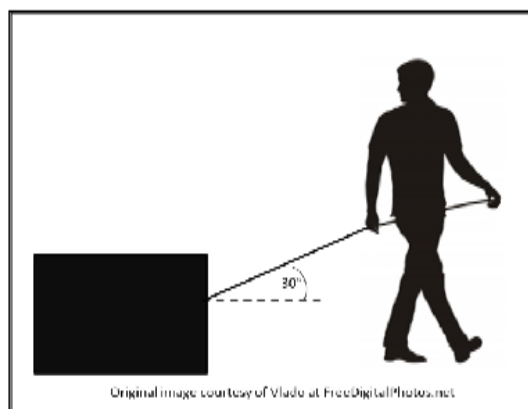
(b) A car accelerating up a hill has suddenly run out of petrol. There is a normal force on the tyres from the road pushing perpendicular to the slope of the hill:

(b) Car



##### Question 3:

Identify the main forces involved in this scenario pictured.



Write out the things you would do to solve the following problem: What is the force required to move along the floor the box with a mass of 80kg if the coefficient of static friction was 0.4?

I would...

## FORCES: Physics Representations

### Free Body Diagrams

#### Part 3: Reflection

For each of the following questions, circle the response that best answers the question for you

##### Reflection 1:

How well do you think you know when and how to use free body diagrams?

Not at all

Not very well

Average

Well

Very well

##### Reflection 2:

How important would you say free body diagrams are to new physics students?

Not at all

Not very important

Partly important

important

Very important

In two sentences explain your answer:

##### Reflection 3:

How helpful was this information for your study of physics this year?

Not at all

Not very helpful

Partly helpful

Helpful

Very helpful





### Part 1: Information

Key terms to know by the end of this session:

Weight

Tension

Friction

Coefficient of  
Kinetic Friction

Coefficient of  
Static Friction

### Why do you need to know these concepts?

These concepts are important in applying Newton's Laws in real life situations. For example, objects have mass, springs experience tension and objects will lose energy through friction.

### What you need to know:

*Weight* - Weight is the force exerted on an object by the Earth due to gravity. The weight force is equal to the object's mass multiplied by acceleration due to gravity (on Earth  $g=9.8\text{m.s}^{-2}$ )

#### Self-check quiz:

If an astronaut travels from Earth to the moon, where acceleration due to gravity is  $1/6$  of the value on earth, which will change?

- (a) Neither Weight or Mass
- (b) Weight
- (c) Mass
- (d) Both Weight and Mass

Correct answer at bottom of page

*Tension* - Whenever an object is hung or pulled by a rope, tension is the pulling force exerted by the rope on the object.

*Friction* - Friction is a force generated by the contact of objects. There are two types of friction. Static Friction is the force that resists movement when a stationary object experiences a force. If the net applied force is greater than the static friction then the object will begin to move. Kinetic Friction applies to moving objects. It is weaker than static friction. Kinetic friction is the force that slows down an object sliding across a surface or falling through the air.

Answer: (b). Mass is unchanged in different gravitational field, weight is mass times acceleration due to gravity so weight will change.

## FORCES: Physics Concepts

### Understanding Tension and Friction

#### Part 2: Questions

##### Question 1:

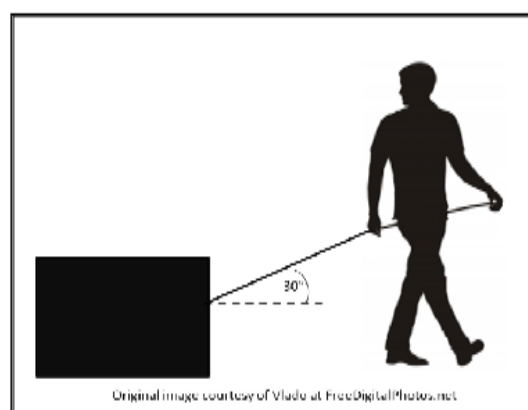
Describe how friction and tension may be important for solving problems in physics?

##### Question 2:

When moving a heavy object, such as a piano, explain why it can be harder to start moving, but easier to keep moving once it has started sliding across the floor.

##### Question 3:

Identify the main forces involved in this scenario pictured.



Write out the things you would do to solve the following problem: What is the force required to move along the floor the box with a mass of 80kg if the coefficient of static friction was 0.4?

I would...

## FORCES: Physics Concepts

### *Understanding Tension and Friction*

#### Part 3: Reflection

For each of the following questions, circle the response that best answers the question for you

##### Reflection 1:

How well do you think you know the concepts of weight, friction and tension?

Not at all

Not very  
well

Average

Well

Very well

##### Reflection 2:

How helpful was this information for your study of physics this year?

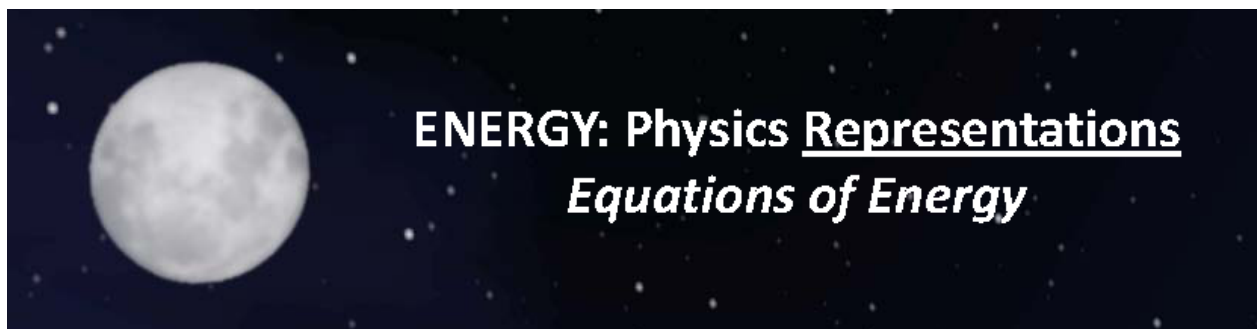
Not at all

Not very  
helpful

Partly  
helpful

Helpful

Very  
helpful



## Part 1: Information

### What to master:

Know the equations for kinetic and gravitational potential energy

Know how to use them for solving problems

Learn how to choose the most effective way to solve problems

### Why you need to know this:

- Choosing and using appropriate equations is an essential skill for problem solving in physics.
- The use of manipulation of equations assist in solving questions which require numerical responses.
- There are different types of equations suited to different problems and you need to know which to choose for which situation.

### How to master the skills:

#### Kinetic Energy

Kinetic energy is energy of motion. Every moving object has kinetic energy.

$$KE = \frac{1}{2}mv^2$$

#### Self check quiz:

Using the equation for kinetic energy, how many joules of kinetic energy does a 60kg man have when running at 17km/h?

- 8760 J
- 112363 J
- 1338 J
- 669 J

Answer at bottom of page

#### Potential Energy

Gravitational potential energy is due to an object's height above the ground. When it increases in height it takes energy storing it as gravitational potential energy, when it decreases in height the energy is converted from potential energy to another form, often kinetic energy.

$$\Delta U = mg\Delta y$$

#### Conservation of Energy

The law of conservation of energy states that "energy cannot be created or destroyed, it can only change in form. Therefore, as long as energy hasn't been converted to other forms such as sound or heat (from friction), in some problems the change in potential energy equals the change in kinetic energy.

$$\Delta KE = \Delta U$$

$$\Delta \frac{1}{2}mv^2 = \Delta mgh$$

Correct answer: d) 669 J

## ENERGY: Physics Representations Equations of Energy

### Part 2: Questions

#### Question 1:

(Follow the steps and show your working and answer in the box below)

You throw a 0.145kg baseball straight up in the air, giving it an initial upward velocity magnitude 20.0m/s. Use conservation of energy to find how high it goes, ignoring air resistance.

*Step 1:* Draw a diagram

*Step 2:* Calculate initial kinetic energy

*Step 3:* Apply conservation of energy – what is potential energy at the highest point?

*Step 4:* Use the potential energy equation to work out the height of the ball at the highest point

#### Question 2:

(Follow the steps and show your working and answer in the box below)

You throw a 0.145kg baseball straight up in the air, giving it an initial upward velocity magnitude 20.0m/s. Use equations of motion to find out how high it goes, ignoring air resistance.

*Step 1:* Draw a free body diagram to identify that the only force acting is gravity

*Step 2:* Choose the appropriate equation

$$v^2 = u^2 + 2as$$

$$s = ut + \frac{1}{2}at^2$$

*Step 3:* Substitute values into the equation to work out the height (distance travelled)

## ENERGY: Physics Representations

### Equations of Energy

#### Question 3:

Solve the following problem: For a roller coaster to make it around a vertical loop (see diagram) it must be going at a minimum speed based on the loop. If the loop is a circle with radius 15m, how fast must the roller coaster car be going at the bottom of the loop to make it around the whole loop?



Image used with permission from freemages.com

Please explain your method in solving the problem as you go, even if you are not sure how to solve it:

### Part 3: Reflection

For each of the following questions, circle the response that best answers the question for you

#### Reflection 1:

How well do you think you can choose the right set of equations to solve a physics problem?

Not at all

Not very well

Average

Well

Very well

#### Reflection 3:

How helpful was this information for your study of physics this year?

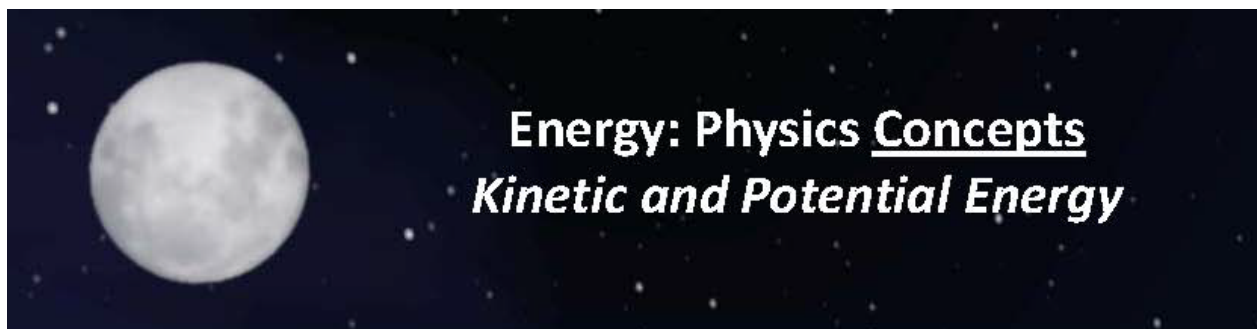
Not at all

Not very helpful

Partly helpful

Helpful

Very helpful



## Part 1: Information

### Key terms to know by the end of this session:

Kinetic energy

Gravitational potential energy

Elastic potential energy

Conservation of energy

Work

### Why do you need to know these concepts?

Concepts such as energy and work, together with the law of conservation of energy aid the understanding of motion. There are many forms of energy; here we focus on kinetic and gravitation and elastic potential energy.

### What you need to know:

#### *Types of Energy*

Kinetic energy is energy of motion. The faster an object moves, the more kinetic energy it has. Potential energy comes in various forms.

Gravitational potential energy is the energy an object has when at a height above the floor. As it falls, it loses potential energy.

Elastic potential energy is energy stored in a spring or another flexible object. You know when you release an object which is compressing a spring the object will shoot away from the spring. This is the elastic potential energy changing to kinetic energy.

#### *Conservation of energy*

The Law states that *energy is neither created or destroyed, it only changes form*. This means that when an ball is thrown in the air, it slows down (loses kinetic energy) as it gains height (gains potential energy). Energy is transformed from kinetic to potential energy.

#### *Work*

Work, in a physics context, is a description of the amount of energy transformed in a process. For example, the work done by gravity on a falling object is equal to the amount of energy transformed from gravitational potential energy to kinetic energy. Work can be done in the direction of motion (as in the previous example), but work can also be done opposite to the direction of motion.

## FORCES: Physics Concepts *Kinetic and Potential Energy*

### Part 2: Questions

#### Question 1:

Explain (in your own words) the difference between kinetic and potential energy

#### Question 2:

You throw a baseball straight up in the air, it moves vertically upwards, becomes stationary and then falls back to your hand at the same height as it left it. Which of the following statements are true (circle as many as apply).

(a) The kinetic energy is maximum at the top of the ball's trajectory

(b) Ignoring air resistance, all of the kinetic energy you give the ball turns into potential energy by the time the ball reaches its maximum height

(c) Potential energy increases, becomes zero at the top, then decreases as the ball falls

(d) According to conservation of energy the ball's speed leaving your hand will be exactly the same as the speed when it returns to your hand.



## FORCES: Physics Concepts Kinetic and Potential Energy

### Question 3:

Solve the following problem: For a roller coaster to make it around a vertical loop (see diagram) it must be going at a minimum speed based on the loop. If the loop is a circle with radius 15m, how fast must the roller coaster car be going at the bottom of the loop to make it around the whole loop?

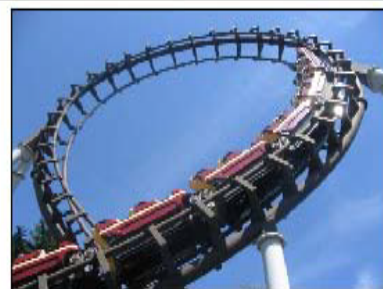


Image used with permission from freemages.com

Please explain your method in solving the problem as you go, even if you are not sure how to solve it:

### Part 3: Reflection

For each of the following questions, circle the response that best answers the question for you

#### Reflection 1:

How well do you think you know the concepts of Energy and Work?

Not at all

Not very well

Average

Well

Very well

#### Reflection 2:

How helpful was this information for your study of physics this year?

Not at all

Not very helpful

Partly helpful

Helpful

Very helpful



## Appendix C

### Online learning modules for first year university physics students

A total of 23 online learning modules (OLMs) were created as part of this research in order to investigate the question of how can we facilitate students to develop representational fluency. The investigation into the student response to completing OLMs is presented in Chapter 5 allowing for Chapter 6 to compare the relative effectiveness representations or concepts focussed modules.

There are two streams of modules including a representations-focussed stream (designed to introduce students to particular physics representations that would be relevant to their upcoming week's lectures) and a concepts-focussed stream (to introduce students to physics concepts before their lectures). Students at the university studying first year regular physics were randomly selected for participation in either stream.

Topics for the areas of Mechanics, Thermal Physics, and Waves and Oscillations. All of the Representations OLM are highlighted as they all were relevant to the RFS. Five Concepts OLM are highlighted as these were from mechanics therefore relevant to the FMCE.

Week	Topic Area	Representations OLM	Concepts OLM
1	Mechanics	Free Body Diagrams	Understanding Tension & Friction
2		Equations of Energy	Kinetic & Potential Energy
3		Resolving Vectors	Momentum and Impulse
4		Representing Torque	Introduction to Torque
5		The Vector Cross Product	Understanding Angular Momentum
6	Thermal Physics	Linear Relationships & Proportionality	Linear Expansion & Specific Heat Capacity
7		Diagrams of Gases	Introduction to Ideal Gases
8		Work done by Gases	Thermal Physics Processes
9		Drawing Heat Engine	Heat Engines
10	Waves and Oscillations	Using Graphs to Describe Periodic Motion	Applications of Simple Harmonic Motion
11		The Wave Equation	Mechanical Waves
12		Reflection and Feedback	Reflection and Feedback

## REPRESENTATIONS 1

## Online Learning Module - Week 1

### FREE-BODY DIAGRAMS

#### INFORMATION

**What to master:**

- List the features of free body diagrams
- Be able to explain why drawing free body diagrams are helpful
- Be able to translate between the text of a problem and the corresponding free body diagram.

**Why you need to know this:**

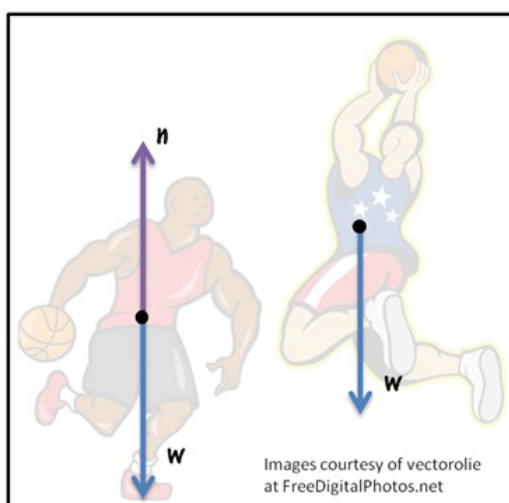
- Free body diagrams allow you to:
  - Make sure you have taken into account all of the main forces affecting an object
  - Work out the total net force, by adding all the forces together, to work out the direction of motion from the force.
- Free body diagrams are a common problem solving technique in physics.

**How to master the skills:***What is a free body diagram?*

The textbook for 1st year physics at the University of Sydney, University Physics, describes a free body diagram as “a diagram showing all the forces (magnitudes and directions) acting on the body” whose motion you are analysing by applying Newton’s laws.

*How to draw a free body diagram:*

1. Choose an object to be the focus of the diagram and represent it as a point or simple rectangle on the page.
2. Draw in all forces described in the question that apply to the object.
3. Check whether there are any forces missing, if the object is at rest, the forces should balance
4. Find if there are any unbalanced forces to work out the net force on the object

*Example of a free body diagram:*

There are two free body diagrams in the picture on the left, one for each basketball player.

The man on the left is standing on the ground and therefore there is a ‘normal’ force (‘n’) from the ground on the man pointing upwards. The two forces balance out so he will experience no acceleration at this point.

The man on the right has jumped in the air. The only force applying to him is the weight force downwards. Therefore we can calculate his acceleration using Newton’s 2nd Law ( $F=ma$ ).

REPRESENTATIONS 1

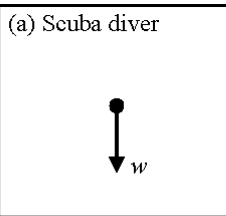
QUESTIONS

**Question 1:**

In your own words, explain why drawing a free body diagram may be helpful in solving a mechanics question in physics.

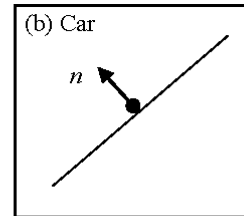
**Question 2:**

What forces are missing from these free body diagrams:



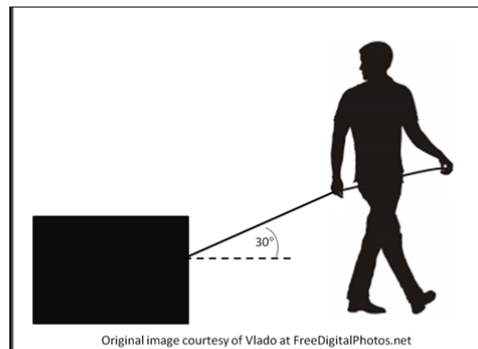
(a) A scuba diver remains stationary in the water 5m below the surface. There is a downward weight force on the scuba diver:

(a) A car accelerating up a hill has suddenly run out of petrol. There is a normal force on the tyres from the road pushing perpendicular to the slope of the hill:



**Question 3:**

Identify the main forces involved in this scenario pictured



Write out the things you would do to solve the following problem: What is the force required to move along the floor the box with a mass of 80kg if the coefficient of static friction was 0.4?

**REPRESENTATIONS 1**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know how and when to use free body diagrams well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding free body diagrams is important for new physics students”*?

Please explain your answer:

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

## REPRESENTATIONS 2

### Online Learning Module - Week 2 EQUATIONS OF ENERGY

#### INFORMATION

**What to master:**

- Know the equations for kinetic and gravitational potential energy
- Know how to use them solving problems
- Learn how to choose the most effective way to solve problems

**Why you need to know this:**

- Choosing and using appropriate equations is an essential skill for problem solving in physics.
- The use and manipulation of equations assist in solving questions which require numerical responses.
- There are different types of equations suited to different problems and you need to know which to choose for which situation.

**How to master the skills:**

*Kinetic Energy*

Kinetic energy is energy of motion. Every moving object has kinetic energy. The formula we can use to relate kinetic energy to mass (m) and velocity (v) of an object is below.

$$KE = \frac{1}{2}mv^2$$

**Self check quiz:**

Using the equation for kinetic energy, how many joules of kinetic energy does a 60kg man have when running at 10km/h?

- |     |       |
|-----|-------|
| (a) | 463J  |
| (b) | 231J  |
| (c) | 3000J |
| (d) | 83.3J |

Answer: (b). If you calculated a different answer, can you work out where you made the mistake?

*Potential Energy*

Gravitational potential energy is due to an objects height above the ground. When it increases in height it takes energy storing it as gravitational potential energy, when it decreases in height the energy is converted form potential energy to another form, often kinetic energy. The equation for the change in gravitational potential energy ( $\Delta U$ ) given as a function of mass (m), acceleration due to gravity (g) and change in height above ground ( $\Delta h$ ) is below.

$$\Delta U = mg\Delta h$$

## REPRESENTATIONS 2

### *Conservation of Energy*

The law of conservation of energy states that “energy cannot be created or destroyed, it can only change in form. Therefore, as long as energy hasn’t been converted to other forms such as sound or heat (from friction), in some problems the change in potential energy equals the change in kinetic energy.

$$\Delta KE = \Delta U$$

$$\Delta \frac{1}{2}mv^2 = \Delta mgh$$

You can see in the equation above that the mass (m) can be divided from each side of the equation to eliminate it.

### QUESTIONS

#### **Question 1:**

On a sheet of paper for your own use, follow the steps to solve the problem:

*You throw a 0.145kg baseball straight up in the air, giving it an initial upward velocity magnitude 20.0m/s. Use conservation of energy to find how high it goes, ignoring air resistance.*

Step 1: Draw a diagram

Step 2: Calculate initial kinetic energy

Step 3: Apply conservation of energy - what is the potential energy at the highest point?

Step 4: Use potential energy to work out the height of the ball from the highest point

#### **Question 2:**

On a sheet of paper for your own use, follow the steps to solve the problem:

*You throw a **0.90kg basketball** straight up in the air, giving it an initial upward velocity magnitude 20.0m/s. Use equations of motion to find out how high it goes, ignoring air resistance.*

Step 1: Draw a free body diagram identifying the only force acting as gravity

Step 2: Choose the appropriate equation, note that (s) is the distance travelled in the following equations

$$v^2 = u^2 + 2as$$

$$s = ut + \frac{1}{2}at^2$$

Step 3: Substitute values into the equation to work out the height (s).



REPRESENTATIONS 2

**Question 3a:**

Use a sheet of paper, and calculator if necessary to solve the following problem.

You can assume acceleration due to gravity ( $g$ ) is 9.8 metres per second per second.

For a roller coaster to make it around a vertical loop (see diagram) it must be going at a minimum speed based on the loop. If the loop is a circle with radius 15m, how fast must the roller coaster car be going at the bottom of the loop to make it around the whole loop?



Image used with permission from freeimages.com

Enter your answer in metres per second in the space below.

**Question 3b:**

Look at the sheet of paper you used to answer the previous question

*Whether or not you were able to get an answer, which of the following did you use in your attempt (Tick as many as apply)?*

- Equations of motion
- Equations of energy
- Conservation of energy
- A diagram
- Circle Geometry Equations

**REPRESENTATIONS 2**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1a:**

For some mechanics problems you can choose to use equations of motion, or conservation of energy. Can you think of a type of problem that is best suited for using equations of motion?

**Reflection 1b:**

Can you think of a type of problem that is best suited for using conservation of energy?

**Reflection 2:**

To what extent do you agree with the statement: “*I understand how to use equations of energy well*”?

Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
----------------	-------	----------------	----------	-------------------

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
----------------	-------	----------------	----------	-------------------

## REPRESENTATIONS 3

## Online Learning Module - Week 3

### RESOLVING VECTORS

#### INFORMATION

**What to master:**

- Know how to resolve vectors into vertical and horizontal components
- Know how to recombine vectors from vertical and horizontal components
- Know where to use this skill in physics

**Why you need to know this:**

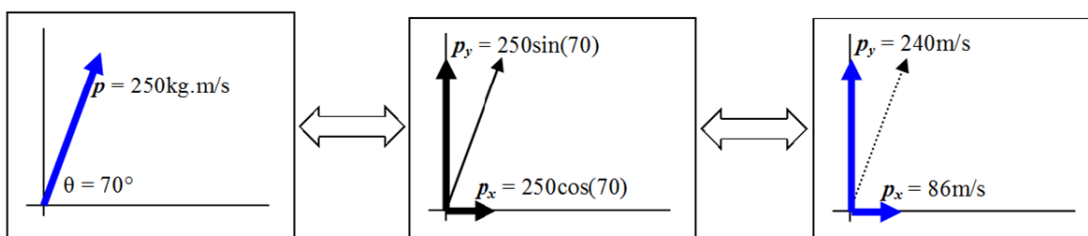
- Vectors are fundamental to the physical sciences. Examples of vectors include velocity, acceleration, force and momentum.
- In later years you will also use vectors to describe and work with fields (electromagnetic, gravitational).
- When solving mechanics problems, separating (or resolving) vectors into vertical or horizontal components is often one of the first steps to make problem solving easier.

**How to master the skills:**

*How to resolve a vector:*

There are multiple ways of describing a vector. Consider the momentum vector ( $p$ ):

As you can see, you can use trigonometry to *resolve* a momentum vector ( $p$ ) at an angle into two components, an x component ( $p_x$ ) and a y component ( $p_y$ ).



*When to use this skill:*

**Projectile motion:** When required to describe the motion of a falling or thrown object, resolving the velocity vector into two components first will help solve the problem (recall high school physics or Extension 1 Mathematics).

**Conservation of momentum:** Momentum is conserved, and we can interpret it as momentum is conserved *linearly*. Therefore, when objects collide at an angle, resolving vectors will assist in conservation of momentum problems.

**Forces at an angle:** When a force is applied neither directly vertically or horizontally but at an angle then resolving the force into the two components allow for separate calculations.

**Test your understanding:**

Write the formula for  $p_x$  and  $p_y$  in terms of " $p$ " and " $\theta$ ".

$$p_x =$$

$$p_y =$$

Answer:  $p_x = p \cos(\theta)$   
 $p_y = p \sin(\theta)$

REPRESENTATIONS 3

QUESTIONS

**Question 1:**

Can you work out how to get the magnitude of  $p$  (momentum) given  $p_x$  and  $p_y$ ? Write your answer in the box below.

**Question 2:**

A wagon is being pulled by a rope that makes a  $25^\circ$  angle with the ground. The person is pulling with a force of of 103 Newtons along the rope. Determine the *horizontal* and *vertical* components of the force vector.

**Question 3:**

Ensure you answer both parts (a) and (b) of the question.

A car is driving north with a momentum ( $p$ ) of 13,000 kg.m/s north. The car turns to be driving east with a momentum of 13,000 kg.m/s east.

- (a) Find the change in momentum of the car:
- (b) Explain the things you did to get to your answer:

**REPRESENTATIONS 3**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know how to resolve vectors well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding how to resolve vectors is an important skill for first year physics students”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

## REPRESENTATIONS 4

Online Learning Module - Week 4  
REPRESENTING TORQUE

## INFORMATION

**What to master:**

Representations of Torque

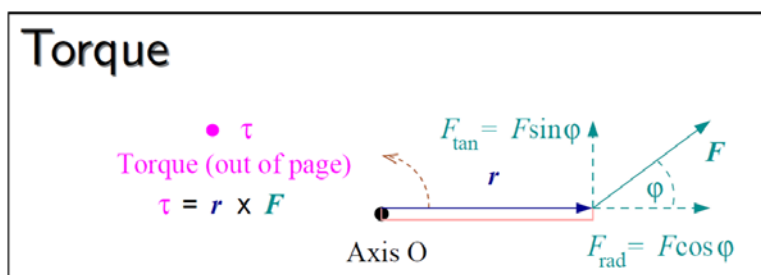
- Vector diagrams of torque
- The equations of torque
- Using the vector cross product to calculate torque

**Why you need to know this:**

So far, as we have discussed forces on objects we have only really considered forces affecting translational motion of objects. Depending on where the force acts on an object, there can also be rotational motion. Torque is the tendency of a force to cause a change in rotational motion of the body on which the force acts. If you understand the different ways to represent and calculate torque you can solve many more complex problems, particularly problems involving levers or objects rolling down inclined planes.

**How to master the skills:**Vector diagrams of torque

Consider the following diagram where a force ( $F$ ) is being applied at a distance ( $r$ ) from the pivot point of an object.



Note the following features in the diagram illustrating how both the *direction* and *location* of the force is important for calculating torque:

- 1) The force vector ( $F$ ) is resolved into tangential ( $F_{tan}$ ) and radial ( $F_{rad}$ ) components as only the force tangential to the direction of motion has any effect on the rotation.  $F_{tan} = F \sin(\phi)$
- 2) Consider the distance  $r$ , the greater  $r$  is the more effect the force will have on the rotation/torque ( $\tau$ ) of the object.  $\tau = r.F_{tan} = r.F \sin(\phi)$ .

This gives an equation for the magnitude of torque ( $\tau$ )

$$\tau = rF \sin(\phi)$$

## REPRESENTATIONS 4

Using the vector cross product to calculate torque:

You may have noticed on the diagram for the previous question that the vector equation for torque is:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

This equation involves the *vector cross product* of  $\mathbf{r}$  and  $\mathbf{F}$

Here is a quick lesson to remind you how to use the vector cross product.

Given vectors  $\mathbf{A} = A_x\mathbf{i} + A_y\mathbf{j} + A_z\mathbf{k}$  and  $\mathbf{B} = B_x\mathbf{i} + B_y\mathbf{j} + B_z\mathbf{k}$  where  $\mathbf{i}$ ,  $\mathbf{j}$  and  $\mathbf{k}$ , are orthogonal unit vectors. The vector  $\mathbf{C} = \mathbf{A} \times \mathbf{B}$  can be calculated as follows.

$$\begin{aligned} \vec{\mathbf{C}} &= C\hat{\mathbf{c}} = \vec{\mathbf{A}} \times \vec{\mathbf{B}} \\ &= (A_yB_z - B_yA_z)\hat{\mathbf{i}} + (A_zB_x - B_zA_x)\hat{\mathbf{j}} + (A_xB_y - B_xA_y)\hat{\mathbf{k}} \end{aligned}$$

Which is also defined as:

$$= AB \sin(\phi)\hat{\mathbf{c}},$$

Where  $\mathbf{c}$  is in the direction orthogonal to  $\mathbf{A}$  and  $\mathbf{B}$  and  $\phi$  is the angle between  $\mathbf{A}$  and  $\mathbf{B}$ .

Can you see how this compares to the formula for the magnitude of torque that we used in the previous information question shown again below for  $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ .

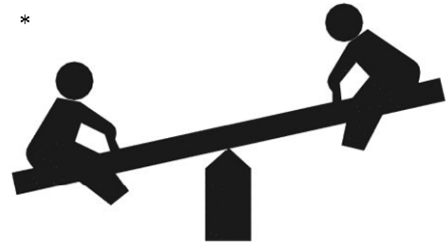
$$\boldsymbol{\tau} = rF\sin(\phi)$$

REPRESENTATIONS 4

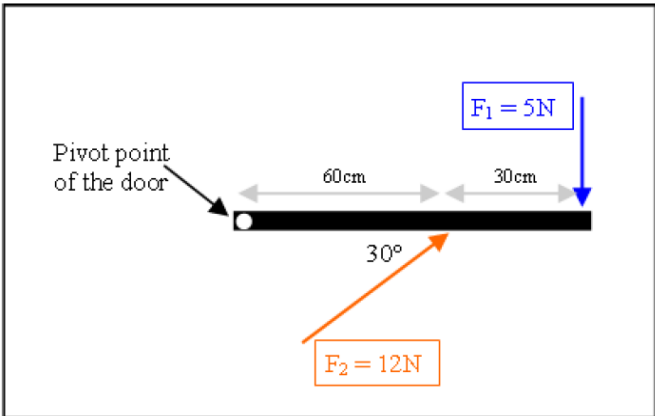
QUESTIONS

**Question 1:**  
 Unless  $r$  and  $F$  are perpendicular, there are always two angles between their directions that give the same torque for given magnitudes of  $r$  and  $F$ . Explain why. You may wish to draw a sketch for yourself to assist you as you write your explanation of the answer.

**Question 2:**  
 Two children are sitting on a see-saw (see picture below). One weighs 30kg and the other weighs 45kg. If the total length of the see-saw is 4m, is it possible for the children to balance the see-saw parallel to the ground by how far from the pivot point of the see-saw they sit? Explain why this is the case.



**Question 3:**  
 A particular door can open both ways and has a pivot point on the left hand side when pictured from above (see below). A person stands on one side trying to open the door clockwise. They push the door 90cm from the pivot point with a force of 5N perpendicular to the plane of the door.



Another person stands on the opposite side pushing with 12N, 60cm from the pivot point and at an angle of 30° from the door.

Which direction will the door turn? Your answer MUST include an explanation or working to show how you decided on a direction.

\* [https://www.dlswb.rmit.edu.au/toolbox/electrotech/toolbox1204/resources/03workshop/05hand\\_tools/02spanners.htm](https://www.dlswb.rmit.edu.au/toolbox/electrotech/toolbox1204/resources/03workshop/05hand_tools/02spanners.htm)



**REPRESENTATIONS 4**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know the concept of torque well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding torque is important for first year physics students”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

## REPRESENTATIONS 5

## Online Learning Module - Week 5

### THE VECTOR CROSS REVISITED

#### INFORMATION

**What to master:**

- Vector cross product calculations
- Visualising diagrams of the vector cross product
- Applying the vector cross product to *angular momentum* ( $L$ )

**Why you need to know this:**

We were introduced to the vector cross product in physics in the last week learning about *torque*

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

In the coming week we will be learning about *angular momentum* ( $L$ ) which is another vector quantity that can be calculated using the cross product.

$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

Here  $\mathbf{p}$  is the *momentum* of a section of mass of a system.

$$\mathbf{p} = m\mathbf{v}$$

Understanding concepts like angular momentum are difficult without being able to calculate, understand and visualise the cross product used to calculate  $L$ . Particularly difficult is being able to correctly identify the direction of angular momentum in various situations.

**How to master the skills:**

First, what is angular momentum?

Angular momentum ( $L$ ) describes momentum ( $\mathbf{p}$ ) operating at a distance ( $\mathbf{r}$ ) from an axis of rotation. It can be thought of as the rotational momentum of a system. Systems such as spinning bicycle wheels or rolling balls have angular momentum. There is also angular momentum for systems involving a particle moving past an object, though in this case, unless the particle is circling the object, the angular momentum is constantly changing. Angular momentum is defined as the cross product of the position vector from the origin of a mass ( $\mathbf{r}$ ) with the momentum of the mass ( $\mathbf{p}=m\mathbf{v}$ ).

Calculating the MAGNITUDE of the angular momentum vector

You may recall learning how to calculate the cross product in a Linear Algebra mathematics course. We also had a short introduction in the Online Learning Module last week. Recall:

$$\|\mathbf{A} \times \mathbf{B}\| = \|\mathbf{A}\| \|\mathbf{B}\| \sin(\phi)$$

or, using the variables used to calculate angular momentum

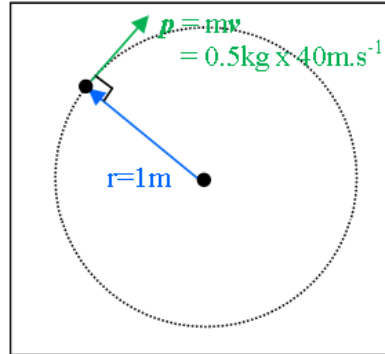
$$\|\mathbf{r} \times \mathbf{p}\| = \|\mathbf{r}\| \|\mathbf{p}\| \sin(\phi)$$

Here, the angle psi ( $\phi$ ), represents the angle between the vectors  $\mathbf{r}$  and  $\mathbf{p}$ .

## REPRESENTATIONS 5

Example 1:

Calculate the magnitude of the angular momentum of a ball with mass 0.5kg moving in a circle with radius 1m at a speed of  $40\text{m}\cdot\text{s}^{-1}$

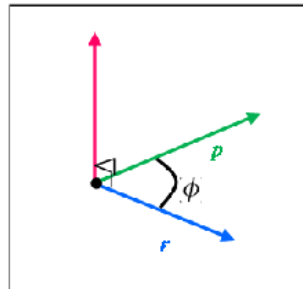


$$\|L\| = \|r \times p\| = r.m.v \sin(\phi)$$

$$\phi = 90^\circ, \text{ so } \sin(\phi) = 1. \|L\| = L = (1)(0.5)(40) = 20 \text{ kg}\cdot\text{m}^2/\text{s}$$

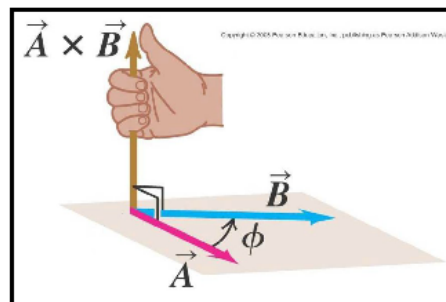
Determining the DIRECTION of angular momentum:

There are many ways of remembering the direction of the cross product. Consider the diagram of the cross product below.



How do you remember whether the *angular momentum* vector ( $L$ ) should be pointing up or down in the above picture?

In class you were shown the method of the *right hand grip* rule (pictured below) where the fingers of your **RIGHT** hand curl in the direction from  $A$  to  $B$  (if  $A \times B$ ), or in our case, the direction from  $r$  to  $p$ .



## REPRESENTATIONS 5

Example 2: Which direction does the angular momentum point if you consider a wheel of a bicycle if the bicycle is being ridden forwards?

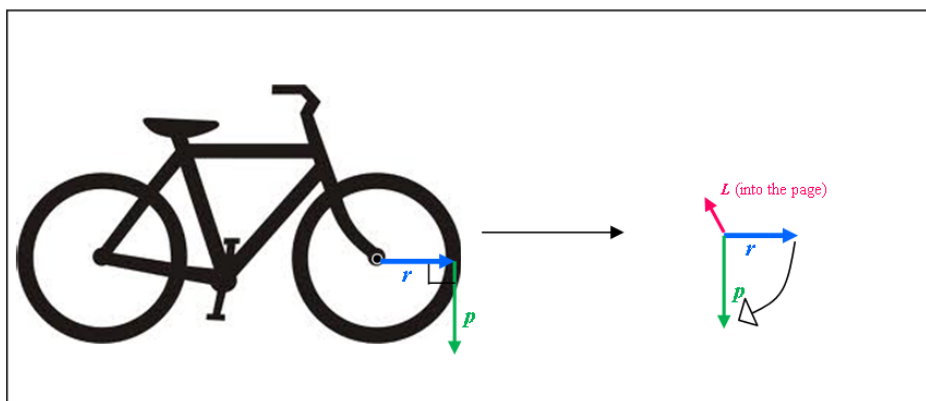
Step 1: Draw the wheel of a bike moving forward (whole bike pictured below)

Step 2: Draw on  $\mathbf{r}$  and  $\mathbf{p} = m\mathbf{v}$

Step 3: Re-draw  $\mathbf{r}$  and  $\mathbf{p}$  coming from the same point in order to visualise the cross product

Step 4: Use the right hand rule where fingers curl from  $\mathbf{r}$  to  $\mathbf{p}$  to determine the direction of  $\mathbf{L}$  with your thumb.

$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$



As you can see, the fingers of the right hand curl clockwise from  $\mathbf{r}$  to  $\mathbf{p}$ . Therefore  $\mathbf{L}$  points into the page and so for a bike moving forward the angular momentum is to the left of the bike for one wheel.

Warning: What would have happened if you didn't re-draw or visualise the vectors coming from the same point, rather used the right hand rule on the vectors on the bike? The fingers would have curled *anticlockwise* rather than *clockwise* giving the wrong direction for  $\mathbf{L}$ .

REPRESENTATIONS 5

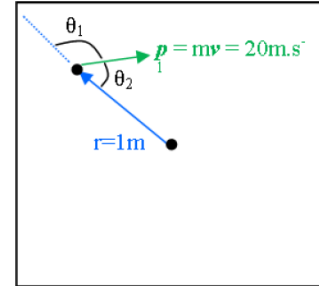
QUESTIONS

**Question 1:**

Considering the equation for the magnitude of Angular Momentum:

$$\|r \times p\| = \|r\| \|p\| \sin(\phi)$$

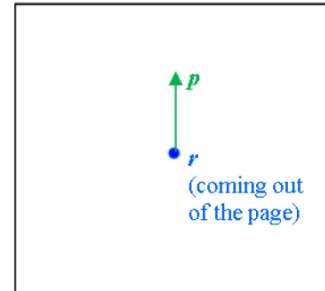
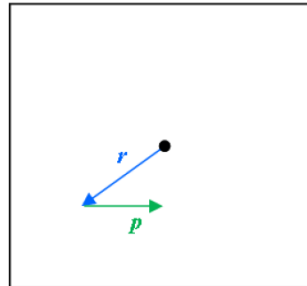
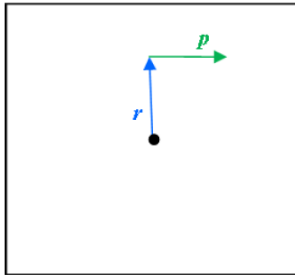
Can you explain why it doesn't matter if you use angles  $\theta_1$  or  $\theta_2$  from the following diagram when you try and calculate angular momentum of the system where a particle (0.5kg) is moving past the origin with a (a velocity of 40m/s in the direction pictured) with in your calculation of the angular momentum?



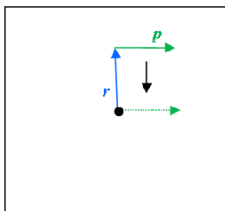
You do not need to calculate the answer.

**Question 2:**

Describe the *direction* of the angular momentum in the following three (3) diagrams:



**HINT:** Remember to translate the vectors so they originate from the same point (as seen below)



**Question 3:**

**Describe how you would teach someone to solve the following problem by explaining what the key things are that you would get them to do.**

The earth has a mass of approximately  $6 \times 10^{24}$ kg. It is orbiting the sun at 30,000 m/s, at a distance of  $149.6 \times 10^9$ m. Assuming the orbit is a perfect circle, and ignoring the rotation of the earth's about its own axis, what is the angular momentum of the earth rotating around the sun?

**REPRESENTATIONS 5**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I understand how to calculate and visualise the cross-product well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding how to calculate and visualise the cross-product is important for 1st year physics students”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

## REPRESENTATIONS 6

## Online Learning Module - Week 6

### LINEAR EXPANSION & SPECIFIC HEAT CAPACITY

#### INFORMATION

**What to master?**

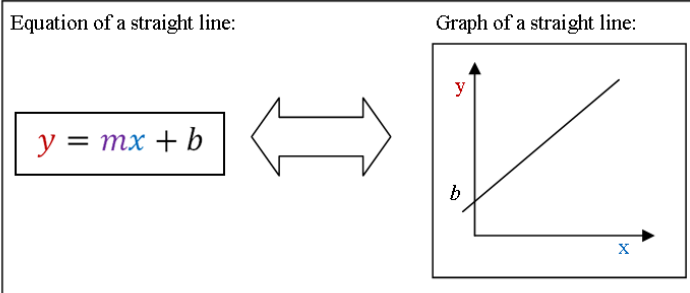
- Identify relationships that are linear from equations and graphs
- Use the fact that a relationship is linear to understand how properties of a system change and solve problems regarding the change.

**Why do we need to know this?**

- Many relationships in thermal physics are linear. These include concepts such as linear expansion and the specific heat capacity of different materials. Learning the skills of proportional reasoning will allow you to better understand the equations, graphs, diagrams and words that depict relationships in thermal physics.

Straight Lines depicted through equations and graphs:

The graphic below presents an equation and graph of a straight line relating some of the elements.



Questions (and answers) for consideration:

**Q: Why do we call this a linear relationship?**

A: It is linear as neither of the variables are squared (e.g.  $y=x^2$ ) so we can say that 'y' is proportional to 'x'. This means that increases in 'y' are *in step* with increases in 'x'. It is linear as there is a straight line on the graph.

**Q: What does the 'm' correspond to?**

A: m is the gradient of the line, it is also known as the constant of proportionality. We can say that 'y' is proportional to 'x' with constant of proportionality 'm'. A higher constant of proportionality (m) means that the change in 'y' is higher for a given change in 'x'. (Note: m is not the mass, m is a constant which can be a variety of physical constants or values as we will encounter in "Information #3".

**Q: How do you work out the gradient from the equation?**

A: Take the derivative of 'y' with respect to 'x':

$$\frac{dy}{dx} = \text{gradient} = m$$

**Q: How do you work out the gradient from the graph?**

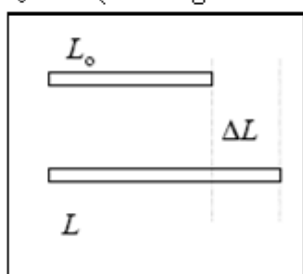
A: The gradient can be calculated by dividing the change in 'y' but the change in 'x' (rise over run):

$$m = \frac{\text{rise}}{\text{run}} = \frac{\Delta y}{\Delta x}$$

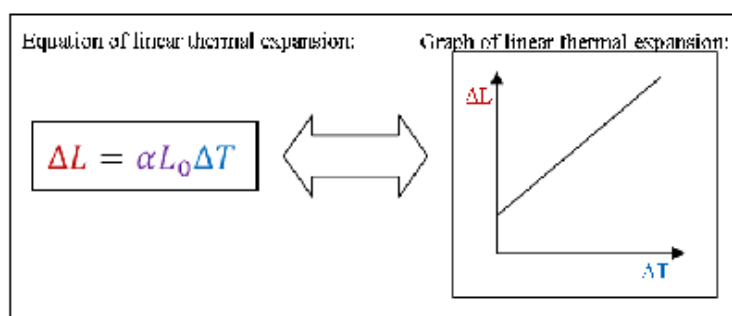
## REPRESENTATIONS 6

**Applications in Thermal Physics****#1 - Thermal Expansion**

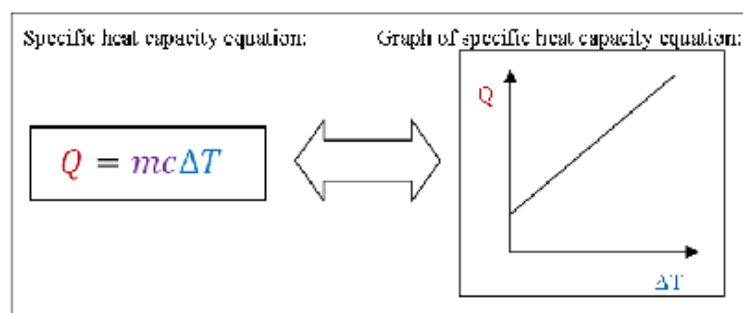
Thermal expansion is the term given to the property that objects get larger at higher temperatures. At a higher temperature, an object which was length  $L_0$  now has length  $L = L_0 + \Delta L$  (See diagram below).



The change in length ( $\Delta L$ ) can be found according to the following equation. Here alpha ( $\alpha$ ) is the *coefficient for linear expansion*. Note the gradient is not just alpha ( $\alpha$ ).

**#2 - Specific heat capacity**

The specific heat capacity ( $c$ ) is another constant found in a thermal physics linear relationship. Here,  $Q$  refers to the amount of heat transfer from or to a substance,  $m$  is the mass and  $\Delta T$  is the change in temperature. Note the gradient is not just the specific heat capacity ( $c$ ).





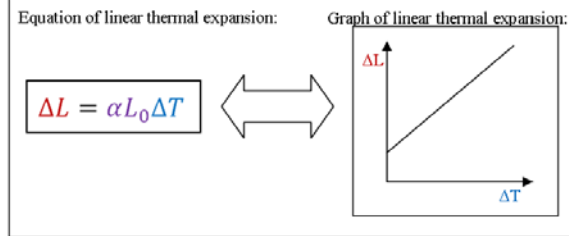
REPRESENTATIONS 6

QUESTIONS

**Question 1:**

Explain how you would find the coefficient of linear expansion ( $\alpha$ ) from the following graph: The equation is also pictured for you to remember the relationship.

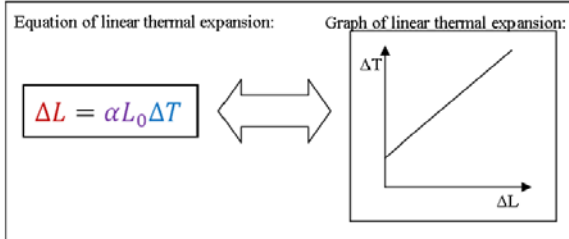
*You do not need to actually find the answer (there are no numbers on the graph so you can't find it), only explain how you would find it.*



**Question 2:**

There is a new graph pictured below. After checking the variables on each axis carefully, explain how you can find the coefficient of linear expansion ( $\alpha$ ) from the following graph .

*You do not need to calculate it, you only need to explain how to find it from the graph.*



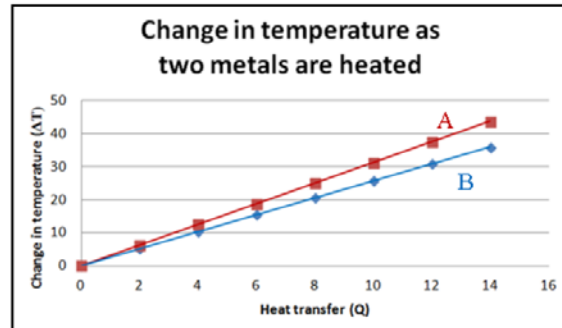
**Question 3a:**

The specific heat capacity ( $c$ ) of copper is 0.39 kJ/kg.K, and the specific heat capacity of germanium is 0.32 kJ/kg.K.

An experiment was done where heat was transferred to two blocks with the same mass of germanium and copper and the temperature change was measured. The results are plotted on the following graph .

Looking at the following graph, *explain* which line (A or B) represents copper and which line represents germanium

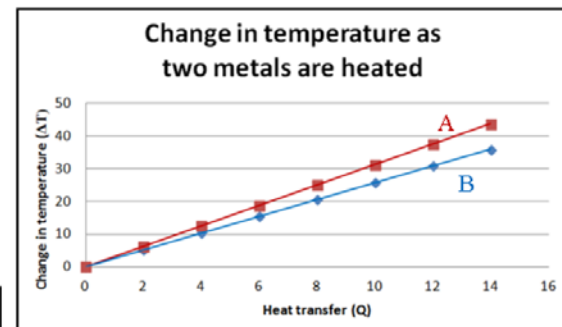
*Ensure that you explain your answer.*



**Question 3b:**

If the experiment was to continue and more heat was to be added to the metals. Would the change in temperature for copper be the same when the heat change is from 52-54 kJ as when the heat change is from 0-2 kJ?

*Briefly explain your answer.*



**REPRESENTATIONS 6**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: “*I understand linear relationships well*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Please explain why understanding linear relationships is important for 1st year physics students.

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

REPRESENTATIONS 7

Online Learning Module - Week 7  
DIAGRAMS OF GASES

INFORMATION

**What to master?**

Be able to draw diagrams to visualise properties of an ideal gas.

**Why do we need to know this?**

Individual molecules of a gas are impossible to see with the naked eye. Drawing representational diagrams can help you understand what is occurring with the gas and the processes that are involved. This will allow you to avoid making common mistakes when it comes to considering ideal gases.

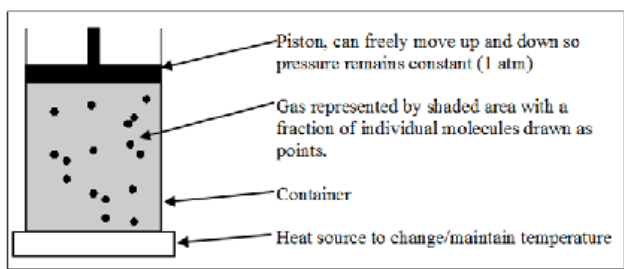
**How to master the skills?**

Introducing the ideal gas equation:

When considering an ideal gas (a gas with a large number of molecules and a number of other assumptions that will be detailed in upcoming lectures) the following relationship has been determined experimentally. This is known as the ideal gas equation.

<p>Here:                  p = pressure                  V = volume of the gas in a container                  n = number of moles of gas                  R = Universal Gas Constant (<math>R=8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}</math>)                  T = temperature (in Kelvin - must be absolute temperature)</p>	$pV = nRT$
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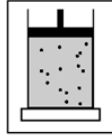
Introducing an ideal gas diagram:



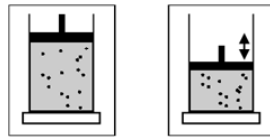
**REPRESENTATIONS 7**

Relating the diagram to the variables of the equation of state of the ideal gas:

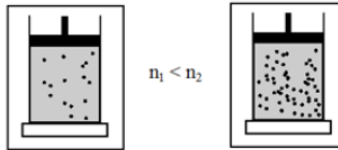
**Pressure:** Can be measured by the force from the gas on the piston. If the piston is free to move, the force will always be 1 atmosphere (or  $1.01 \times 10^5$  Pa).



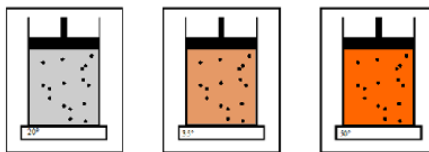
**Volume:** Related to the space taken up by the gas. Changing the position of the piston changes the volume.



**n = number of moles:** More molecules means more moles. If more gas is depicted by more dots in the container.



**Temperature:** There are various conventions for depicting temperature. These include changing the colour or shade of the gas, writing the temperature on the heat source assumed to be in equilibrium with the gas or drawing velocity vectors on the gas molecules (not pictured).



REPRESENTATIONS 7

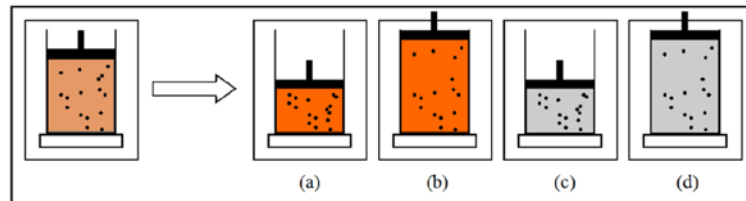
QUESTIONS

**Question 1:**

An ideal gas is in a container with a piston free to move up and down to maintain constant pressure (pictured on the left). The gas is heated resulting in an increase in temperature. Which of the following diagrams could represent the gas after the increase in temperature?

$$pV = nRT$$

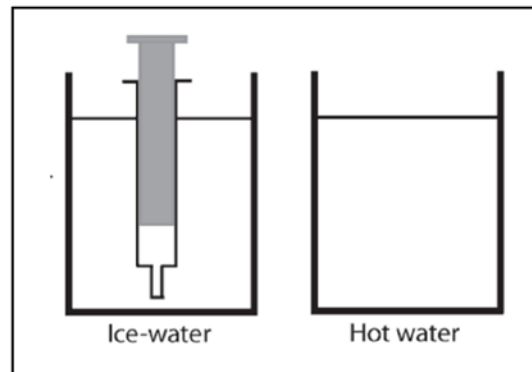
Please circle your response below



**Question 2:**

For questions 2a, 2b and 2c use the following information:

A syringe that contains an ideal gas and has a frictionless piston of mass  $M$  is moved from a beaker of cold water to a beaker of hot water. Answer the following questions and consider that the syringe reaches thermal equilibrium with hot water.



**Question 2a:**

How does the gas temperature change?

- A. Increase
- B. Decrease
- C. No Change

**Question 2b:**

How does the gas pressure change?

- A. Increase
- B. Decrease
- C. No Change

**Question 2c:**

How does the gas pressure change?

- A. Increase
- B. Decrease
- C. No Change

**REPRESENTATIONS 7**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I understand how to draw diagrams to visualise properties of an ideal gas well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

Please explain why understanding how to draw diagrams to visualise properties of an ideal gas is important for 1st year physics students.

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

## REPRESENTATIONS 8

## Online Learning Module - Week 8

### WORK DONE BY GASES

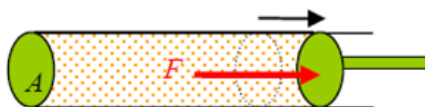
#### INFORMATION

**What to master?**

- Be able to determine the work done by a gas under certain conditions using equations
- Be able to determine the work done by a gas under certain conditions using a graph
- Be able to correctly identify whether work done by a gas is positive or negative

**Why do we need to know this?**

When the state of an ideal gas changes, it undergoes a thermodynamic process eg increasing pressure and decreasing in volume at a constant temperature. As part of the process, work can be done by the gas/system on the surroundings (positive work) or work can be done from the surroundings on the gas (negative work). Due to its arbitrary nature, whether the work done by the gas is positive or negative can often be confusing for physics students.



Work is defined as:

$$W = \int_{r_1}^{r_2} F \cdot dr$$

The force of the gas on the piston of area A is:

$$F = pA$$

Substituting into the definition of work gives:

$$W = \int_{r_1}^{r_2} F \cdot dr = \int_{x_1}^{x_2} (pA) \cdot dx = \int_{x_1}^{x_2} p \cdot d(xA) = \int_{V_1}^{V_2} p \cdot dV$$

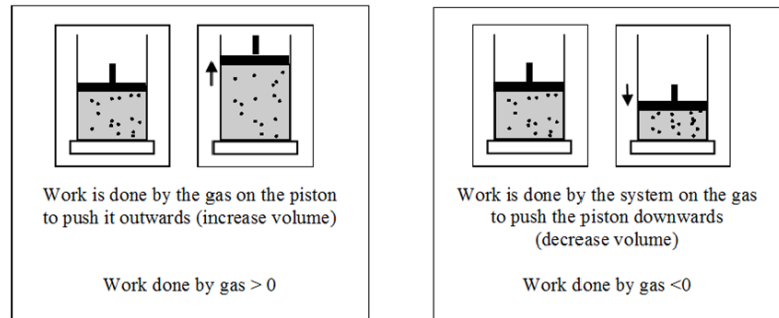
The formula for calculating work done by a gas on its surroundings is the pressure integrated over the change in volume.

$$W = \int_{V_1}^{V_2} p \cdot dV$$

If  $V_2 > V_1$  (the gas is expanding) then the work done by the gas/system is positive.

If  $V_2 < V_1$  (the gas is contracting) then the work done by the gas/system is negative.

**REPRESENTATIONS 8**



From the definition of work done by a gas you may be able to work out how to calculate work from a pressure-volume (P-V) graph. Comparing it to the definition of displacement used to calculate displacement from a Velocity-Time graph:

Work in terms of pressure and volume

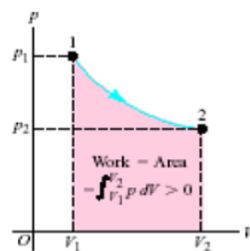
$$W = \int_{V_1}^{V_2} p \cdot dV$$

Displacement in terms of velocity and time

$$x = \int_{t_1}^{t_2} v \cdot dt$$

Just as displacement is the area under the line for a velocity-time graph, work done by a gas is the area under the line for P-V graph.

An increase in volume means that work is positive:



A decrease in volume means that work done is negative:



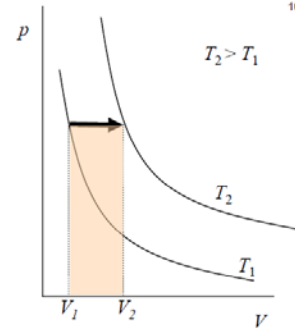


REPRESENTATIONS 8

QUESTIONS

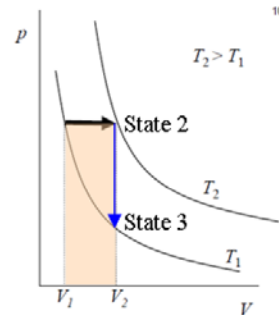
**Question 1:**

Isothermal lines can be drawn on a PV diagram (see below). These are lines of constant temperature. If an ideal gas starts at a point on  $T_1$  and while maintaining constant pressure is heated and moves to  $T_2$ , explain how to determine how much work the gas has done on the surroundings.



**Question 2:**

Considering the same diagram, the gas now reduces in temperature ( $T_2$  to  $T_1$ ) and while maintaining a constant volume (follows the blue line from "State 2" to "State 3"). Explain how much work does the gas do on its surroundings for the process from state 2 to state 3 (along the blue line).



**Question 3:**

For questions 3a and 3b use the following information:

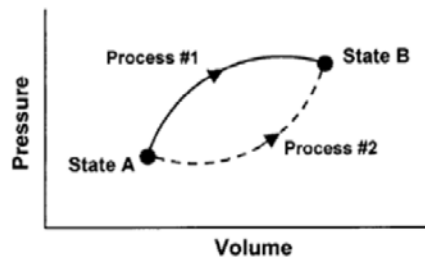
A P-V diagram represents a system consisting of a fixed amount of ideal gas that can undergo two different processes in going from state A to state B through Process #1 and Process #2.

**Question 3a:**

Complete the following sentence using the below options:

Work done by the gas in Process #1 is \_\_\_\_\_ than Process #2.

- (a) Greater than
- (b) Less than
- (c) Equal to



**Question 3b:**

Explain how you chose the answer to the previous question in 1-2 sentences:

**REPRESENTATIONS 8**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: "I know how to calculate work done by a gas well"?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Explain why "Being able to calculate work done by gases is important for first year physics students"?

**Reflection 3:**

To what extent do you agree with the statement: "*This information will be helpful for my study of physics this semester*"?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**REPRESENTATIONS 9**

**Online Learning Module - Week 9  
DRAWING HEAT ENGINES**

**INFORMATION**

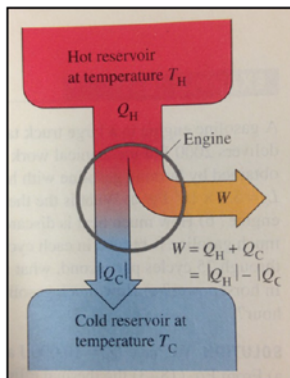
**What to master?**

- Interpreting schematic diagrams for heat engines
- Drawing basic schematic diagrams for heat engines
- Understanding how efficiency relates to heat engine diagrams

**Why do we need to know this?**

Heat engines are systems where work is produced as a result of thermal processes. Generally one wants the efficiency of the engine to be maximised. There are a set of simple schematic diagrams which allow us to best visualise the process of a heat engine and therefore draw conclusions about the efficiency of the engine.

**How to master the skills:**

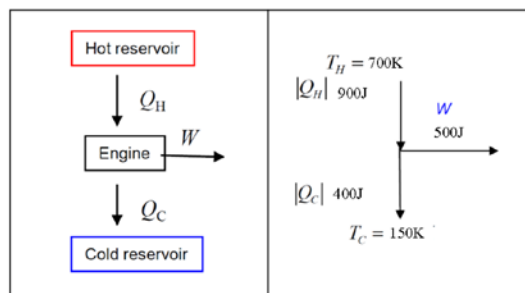


Diagrams of heat engines:

Every heat engine takes heat from a hot reservoir and expel heat to a cold reservoir. The heat that is not expelled is transformed into work.

Consider the diagram to the left. Notice how in this diagram the hot reservoir is depicted in red indicating a higher temperature and the cold reservoir is blue. You can see from the circle in the middle that the engine involves taking heat energy ( $Q_H$ ), expelling heat energy ( $Q_C$ ) and the difference is the work ( $W$ ).

The diagram above not always practical to draw so we can simplify in either of the following two ways:



*In an exam, you would want to draw a diagram like one of these, probably the one on the right, rather than the full colourful diagram with the block arrows above.*

Understanding how to use diagrams:

The efficiency of a heat engine is defined as:

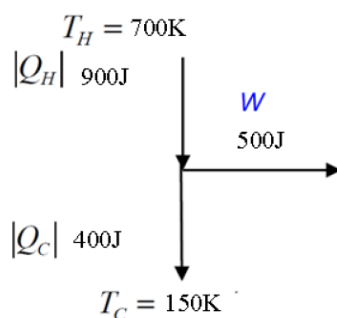
## REPRESENTATIONS 9

Understanding how to use diagrams:

The efficiency of a heat engine is defined as:

$$e = 1 - \left| \frac{Q_C}{Q_H} \right|$$

Can you see how given a diagram of a heat engine, it is easy to interpret the efficiency of the heat engine?

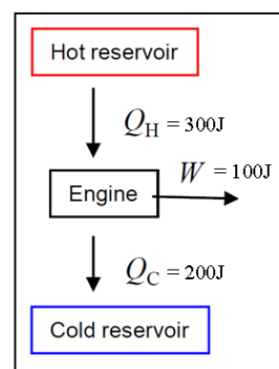


## QUESTIONS

**Question 1:**

Calculate the efficiency of the heat engine (as a percentage) represented by the following diagram.

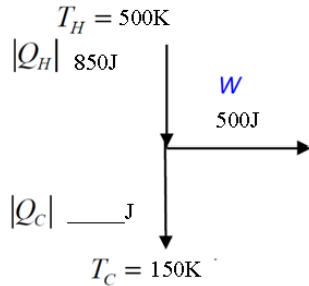
- A. 30.0%
- B. 33.3%
- C. 50.0%
- D. 66.6%
- E. 70.0%



REPRESENTATIONS 9

**Question 2:**

Calculate the amount of waste (in joules) that this engine produces:



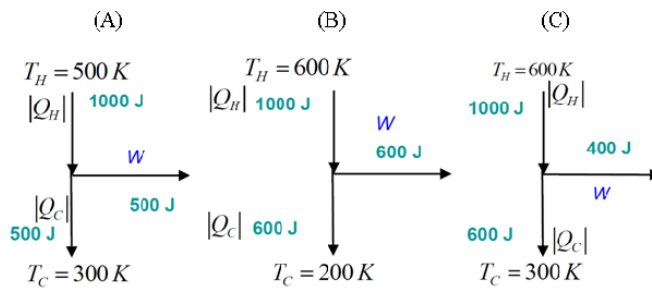
**Question 3a:**

A hybrid petrol-electric car has a higher efficiency than a petrol-only car because it recovers some of the energy that would normally be lost as heat to the surrounding environment during braking.

If the efficiency of a typical petrol-only car engine is 20% what efficiency (as a percentage) could be achieved if the amount of heat loss during braking is halved?

**Question 3b:**

There are three diagrams of heat engines below. Please circle the options you think are feasible as heat engines:



**REPRESENTATIONS 9**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: "I know how to draw and understand heat engine diagrams well"?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Explain why "Being able to draw and understand heat engine diagrams is important for first year physics students"?

**Reflection 3:**

To what extent do you agree with the statement: "*This information will be helpful for my study of physics this semester*"?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

## REPRESENTATIONS 10

## Online Learning Module - Week 10

## WHICH GRAPHS TO USE TO DESCRIBE PERIODIC MOTION?

## INFORMATION

**What to master?**

- Understand the difference between displacement-time graphs and displacement-displacement diagrams of periodic motion.
- Identify benefits of using displacement-time graphs and displacement-displacement diagrams of periodic motion
- Be able to translate between a displacement-time graph and displacement-displacement diagram.

**Why do we need to know this?**

To understand periodic motion, (including Simple Harmonic Motion and periodic waves) often graphs are drawn. Graphs can help visualise the problem, work out features of the problem and help the process of generating the correct answer. Typically you will always want to draw a graph to help you in a waves/oscillations question (and sometimes also draw a free-body diagram) but the type of graph you choose to draw will give you different information, which may or may not be helpful in getting to the answer.

**How to master the skills:**Displacement-Time versus Displacement-Displacement - Both can be helpful when considering travelling waves:

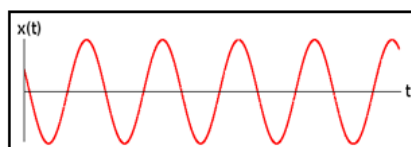
The two types of graphs that you will typically encounter are displacement-time and displacement-displacement. The obvious way to tell the difference is by looking at how the axes are labelled.

You will notice that sometimes the two diagrams can look very similar. If this was describing one transverse wave (such as a wave on a rope when someone flicks it up and down fast) then the displacement-time is a graph which shows the position of one part of the rope over a long period of time, but the displacement-displacement diagram shows the positions of many parts of the rope at one instant in time.

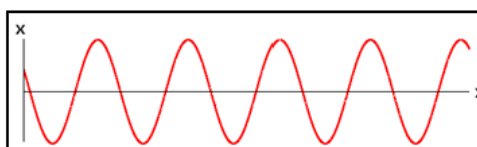
Consider, if you were to take a photograph of someone flicking a rope would that be best described as a displacement-time graph or a displacement-displacement diagram?

(Remember, that a photograph is just one instant in time.)

the mass at various times:



Displacement-time



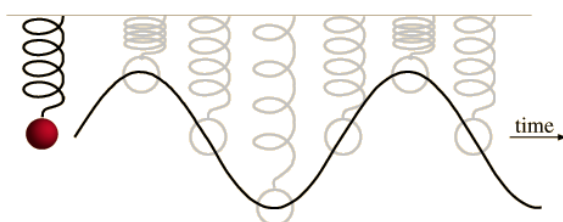
Displacement-displacement

## REPRESENTATIONS 10

### When displacement-time graphs are more helpful - Simple Harmonic Motion and Oscillations:

A good example of simple harmonic motion is a mass suspended from the ceiling by a spring oscillating up and down.

For this situation, a displacement-displacement diagram would not provide much helpful information as there is only one direction of motion, therefore there is no horizontal movement. The diagram would simply be a vertical line. For simple harmonic motion, it is best to express the motion with a displacement-time graph which indicates the position of the mass at various times:



### When displacement-displacement diagrams may be more helpful:

Later in the course you will encounter standing waves. These are waves which remain in a constant position and can be seen sometimes when someone is shaking a rope up and down and the other end of the rope is attached to the wall. Using a skipping rope is an example of a standing wave. To work out how many wavelengths are present in a standing wave for a length of rope, we would draw a displacement-displacement diagram. This is also true for drawing standing pressure waves in musical instruments.



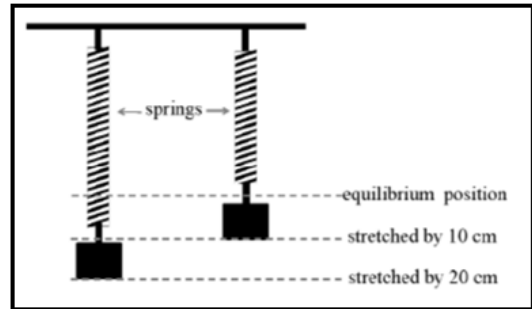


REPRESENTATIONS 10

QUESTIONS

**Question 1:**  
Which graph (displacement-displacement or displacement-time) would you want to be given if you were trying to work out the vertical velocity of one part of a rope that was experiencing a wave passing along it. Explain your answer in 1-2 sentences.

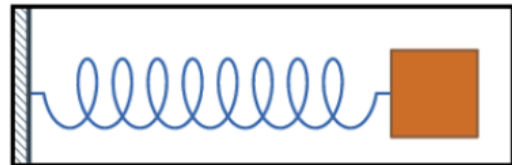
**Question 2:**  
Two equal masses are attached to separate identical vertical springs next to one another (see diagram below). One mass is pulled so its spring stretches 20 cm and the other pulled so its spring stretches only 10 cm. The masses are released simultaneously.



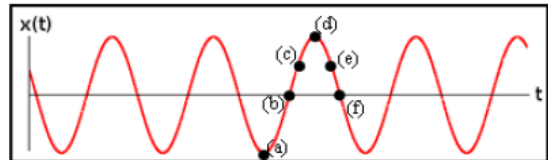
Which mass passes the equilibrium position first? Explain the steps you took, or things you did, to get to your answer.

**Question 3:**  
*For questions 3a and 3b use the following information:*

Consider a mass oscillating horizontally on a spring:



A displacement - time graph for the spring is pictured with 6 points on the graph marked (a)-(f):



**Question 3a:**  
Circle the letters that correspond to the points position(s) where the horizontal acceleration of the block is zero?

A
B
C
D
E
F

**Question 3b:**  
Circle the letters that correspond to the points position(s) where the potential energy of the block is maximum?

A
B
C
D
E
F

**Question 3c:**  
Circle the letters that correspond to the points position(s) where the kinetic energy of the block is maximum?

A
B
C
D
E
F

**REPRESENTATIONS 10**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: “I know how to use different graphs to understand oscillations and waves well ”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Explain why "Knowing how to use different graphs to understand oscillations and waves is important for first year physics students "?

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

## REPRESENTATIONS 11

## Online Learning Module - Week 11

### THE WAVE EQUATION

#### INFORMATION

**What to master?**

- Understanding the wavefunction
- How to derive the wave equation
- How to use the wave equation

**Why do we need to know this?**

The wave equation is an expression that defines a propagating wave. It applies to many different types of waves and different propagating mediums. The wave equation allows calculations of the speed of a wave and allows computational physicists to create models of waves. In class you will be using waves defined by the wave function to draw a model of waves in different constraining situations such as in a hollow tube.

**How to master the skills:**Understanding the wavefunction:

A wavefunction is simply an expression for the displacement of an oscillating particle with respect to position and time. The equation for a generic wave function  $y(x,t)$  is shown below.

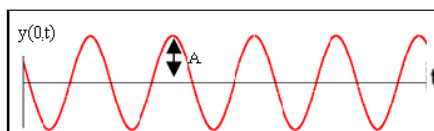
$$y(x, t) = A \sin(\omega t - kx)$$

There are a few properties to note:

- A - amplitude, the maximum distance that a particle is displaced
- $\omega$  - angular frequency,  $\omega = 2\pi f$  where  $f$  is the frequency
- k - wavenumber,  $k = 2\pi/\lambda$  where  $\lambda$  is the wavelength

The wavefunction is a function with two variables, therefore the displacement of the particles can be plotted on both a displacement-displacement ( $y-x$ ), and a displacement-time ( $y-t$ ) graph by setting the other variable to zero. Both are sinusoidal, there are just different constants,  $\omega$  and  $k$ .

As an example, by setting  $x=0$ , the wavefunction can be graphed on the following  $y-t$  graph:



Deriving the wave equation: (Note: You may want to follow this derivation with a pen and paper for yourself)

Consider the wavefunction from the previous question:

$$y(x, t) = A \sin(\omega t - kx)$$

## REPRESENTATIONS 11

To derive the wave equation, we would like to compare the transverse acceleration of the oscillating particles with the curvature of the wave.

STEP 1: Finding the acceleration of the oscillating particles.

$$y(x, t) = A \sin(\omega t - kx)$$

Take the derivative of  $y(x, t)$  with respect to time:

$$y(x, t) = A \sin(\omega t - kx)$$

$$\therefore \frac{\partial y(x, t)}{\partial t} = \omega A \cos(\omega t - kx)$$

Take the derivative with respect to time again:

$$\therefore \frac{\partial^2 y(x, t)}{\partial t^2} = -\omega^2 A \sin(\omega t - kx)$$

$$\therefore \frac{\partial^2 y(x, t)}{\partial t^2} = -\omega^2 y(x, t)$$

STEP 2: Find the curvature of the wave.

$$y(x, t) = A \sin(\omega t - kx)$$

Take the derivative of  $y(x, t)$  with respect to  $x$ :

$$y(x, t) = A \sin(\omega t - kx)$$

$$\therefore \frac{\partial y(x, t)}{\partial x} = -k A \cos(\omega t - kx)$$

Take the derivative with respect to  $x$  again:

$$\therefore \frac{\partial^2 y(x, t)}{\partial x^2} = -k^2 A \sin(\omega t - kx)$$

$$\therefore \frac{\partial^2 y(x, t)}{\partial x^2} = -k^2 y(x, t)$$

STEP 3: Combine the two expressions to get the wave equation.

Divide the acceleration by the curvature:

$$\frac{\frac{\partial^2 y(x, t)}{\partial t^2}}{\frac{\partial^2 y(x, t)}{\partial x^2}} = \frac{\omega^2}{k^2} = v^2$$

Where  $v = \omega/k$

Rearranging gives the wave equation:

$$\frac{\partial^2 y(x, t)}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y(x, t)}{\partial t^2}$$

How to use the wave equation:

The wave equation can be used to derive formulas to calculate the speed of a wave in a particular medium. If you can generate expressions for the acceleration of particles (from the restoring force) and the curvature of the wave you can substitute these into the wave equations to get new expressions for the speed of the wave. You may not have to do this yourself, but it is important to know where these expressions come from.

## REPRESENTATIONS 11

## QUESTIONS

**Question One**

What is the amplitude, angular frequency and wavenumber of the wave described by the following expression:

$$y(x, t) = 2.5\text{cm} \sin(500\text{s}^{-1} t - 0.25\text{cm}^{-1} x)$$

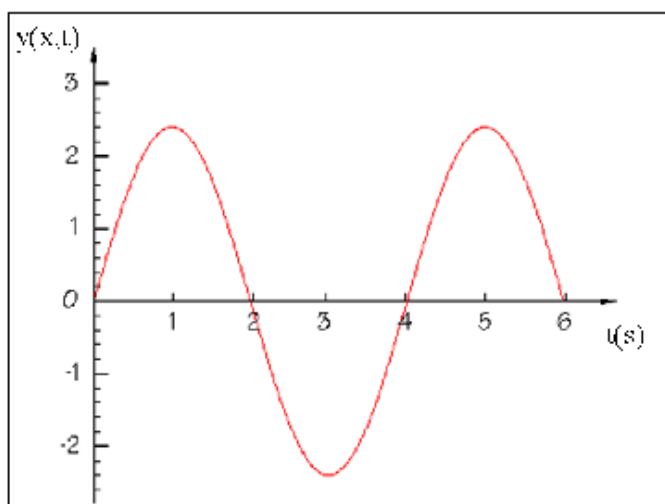
**Question Two**

Explain in 2-3 sentences, as if to a fellow first year physics student, what is meant by a mechanical wave.

You may use any combination of words, numbers or descriptions of graphs or equations.

**Question Three**

What information can you provide about the graph below:



You may use any combination of words, numbers or descriptions of graphs or equations.

**REPRESENTATIONS 11**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: “I understand the wave equation well ”?

**Reflection 2:**

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Explain why "Understanding the wave equation is important for first year physics students"?

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

COMMON MODULE

Online Learning Module - Week 12  
REFLECTION

The following questions are designed to allow the University to get feedback on the effectiveness of the online learning modules. Please complete the following.

**Question 1:**

To what extent do you agree with the statement:

"The online learning modules were *helpful* for learning physics this semester"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 2:**

Name one thing about the online learning modules that was helpful for learning physics this semester? (If applicable)

**Question 3:**

To what extent do you agree with the statement:

"The online learning modules were *relevant* for learning physics this semester"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 4:**

To what extent do you agree with the statement:

"The online learning modules were *demanding* to complete"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 5:**

To what extent do you agree with the statement:

"I put a lot of *effort* into the online learning modules each week"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

COMMON MODULE

**Question 6:**

What motivated you to continue completing the online learning modules throughout semester?

**Question 7:**

What other resources did you use to complete the online learning modules (if any):

**Question 8:**

Please write 1-2 sentences explaining whether you think it is important for physics students to be fluent with physics communication tools such as graphs, equations and diagrams.

**Question 9:**

What was the first language that you spoke as a child?

**Question 10:**

To further investigate the helpfulness of the online learning modules we would like to interview some students to learn more of their experiences. A movie ticket and other treats will be provided should you be willing to be interviewed and all interviews will be conducted at the University. If you are willing to be interviewed please write a suitable time period in the space below, otherwise leave it blank.

Consider:

- During Week 13 or StuVac
- During the second week of exams (The week starting Monday 24/6/13)
- During Week 1-2 of Semester 2.

Thank you for giving feedback on the online learning modules.

We wish you all the best preparing for your Semester 1 exams and encourage you to make the most of final opportunities to learn such as visiting the physics duty tutoring sessions, attending week 13 workshops and downloading and completing past exam papers.

If you have any final comments about the online learning modules please write them below.



CONCEPTS 1

Online Learning Module - Week 2  
UNDERSTANDING TENSION AND FRICTION

INFORMATION

**Key terms to know by the end of this session:**

- Weight
- Tension
- Friction
  - Coefficient of Kinetic Friction
  - Coefficient of Static Friction

**Why do you need to know these concepts?**

These concepts are important in applying Newton's Laws in real life situations. For example, objects have mass, springs experience tension and objects will lose energy through friction.

**What you need to know:**

*Weight* - Weight is the force exerted on an object by the Earth. The weight force is equal to the object's mass multiplied by acceleration due to gravity (on Earth  $g=9.8\text{m.s}^{-2}$ )

*Self-check quiz:*

If an astronaut travels from Earth to the moon, where acceleration due to gravity is 1/6 of the value on earth, which will change?

- (a) Neither Weight or Mass
- (b) Weight
- (c) Mass
- (d) Both Weight and Mass

Answer: (b). Mass is unchanged in different gravitational fields.

*Tension* - Whenever an object is hung or pulled by a rope, tension is the pulling force exerted by the rope on the object.

*Friction* - Friction is a force generated by the contact of objects. There are two types of friction. Static Friction is the force that resists movement when a stationary object experiences a force. If the net applied force is greater than the static friction then the object will begin to move. Kinetic Friction applies to moving objects. It is *weaker* than static friction. Kinetic friction is the force that slows down an object sliding across a surface or falling through the air.

CONCEPTS 1

QUESTIONS

**Question 1:**

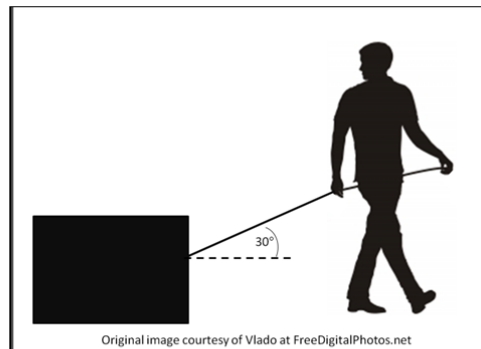
Describe how friction and tension may be important for solving problems in physics?

**Question 2:**

When moving a heavy object, such as a piano, explain why it can harder to start moving, but easier to keep moving once it has started sliding across the floor.

**Question 3:**

Identify the **main** forces involved in this scenario pictured



Write out the things you would do to solve the following problem: What is the force required to move along the floor the box with a mass of 80kg if the coefficient of static friction was 0.4?

**CONCEPTS 1**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know the concepts of weight, friction and tension well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding the concepts of weight, friction and tension are important for new physics students”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**CONCEPTS 2**

**Online Learning Module - Week 2  
KINETIC AND POTENTIAL ENERGY**

**INFORMATION**

**Key terms to know by the end of this session:**

Kinetic Energy	Conservation of energy
Gravitational potential energy	Work
Elastic potential energy	

**Why do you need to know these concepts?**

Concepts such as energy and work, together with the law of conservation of energy aid the understanding of motion. There are many forms of energy; here we focus on kinetic and gravitational and elastic potential energy.

**What you need to know:**

Types of energy:

*Kinetic energy* is energy of motion. The faster an object moves, the more kinetic energy it has.

Potential energy comes in various forms.

*Gravitational potential energy* is the energy of a system when an object is at a height above the floor. As it falls, it loses potential energy.

*Elastic potential energy* is energy stored in a spring or another flexible object. You know when you release an object which is compressing a spring, the object will shoot away from the spring. This is the elastic potential energy changing to kinetic energy.

Conservation of energy:

This law states that energy is *neither created or destroyed, it only changes form*. This means that when a ball is thrown in the air, it slows down (loses kinetic energy) as it gains height (gains potential energy). All kinetic energy is transformed to potential energy, provided that we assume that there is no air resistance.

Work:

Work, in a physics context, is a description of the amount of energy transformed in a process. For example, the work done by gravity on a falling object is equal to the amount of energy transformed from gravitational potential energy to kinetic energy. Work can be done in the direction of motion (as in the previous example), but work can also be done opposite to the direction of motion.

*Tension* - Whenever an object is hung or pulled by a rope, tension is the pulling force exerted by the rope on the object.

*Friction* - Friction is a force generated by the contact of objects. There are two types of friction. Static Friction is the force that resists movement when a stationary object experiences a force. If the net applied force is greater than the static friction then the object will begin to move. Kinetic Friction applies to moving objects. It is *weaker* than static friction. Kinetic friction is the force that slows down an object sliding across a surface or falling through the air.

## CONCEPTS 2

### QUESTIONS

**Question 1:**

Explain the difference between kinetic and potential energy.

**Question 2:**

You throw a baseball straight up in the air, it moves vertically upwards, becomes stationary and then falls back to your hand at the same height as it left it. Which of the following statements are true (tick as many as apply).

- The kinetic energy is maximum at the top of the ball's trajectory
- Ignoring air resistance, all of the kinetic energy you give the ball turns into potential energy by the time the ball reaches the maximum height
- Potential energy increases, becomes zero at the top, then decreases as the ball falls
- According to conservation of energy and ignoring air resistance, the ball's speed leaving the hand will be exactly the same as the speed when it returns to your hand.

**Question 3a\*:**

Use a sheet of paper, and calculator if necessary to solve the following problem.

You can assume acceleration due to gravity ( $g$ ) is 9.8 metres per second per second.

For a roller coaster to make it around a vertical loop (see diagram) it must be going at a minimum speed based on the loop. If the loop is a circle with radius 15m, how fast must the roller coaster car be going at the bottom of the loop to make it around the whole loop?



Image used with permission from freeimages.com

Enter your answer in metres per second in the space below.

**Question 3b:**

Look at the sheet of paper you used to answer the previous question

*Whether or not you were able to get an answer, which of the following did you use in your attempt (Tick as many as apply)?*

- Equations of motion
- Equations of energy
- Conservation of energy
- A diagram
- Circle Geometry Equations

**CONCEPTS 2**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1a:**

For some mechanics problems you can choose to use equations of motion, or conservation of energy. Can you think of a type of problem that is best suited for using equations of motion?

**Reflection 1b:**

Can you think of a type of problem that is best suited for using conservation of energy?

**Reflection 2:**

To what extent do you agree with the statement: “*I understand the concepts of energy and work well*”?

Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
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Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
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**CONCEPTS 3**

## Online Learning Module - Week 3

### MOMENTUM AND IMPULSE

**INFORMATION**

**Key terms to know by the end of this session:**

Momentum  
Impulse

**Why do you need to know these concepts?**

These are specific physics terms which are very helpful in calculating the forces and motion in various situations. Momentum and impulse are particularly important when considering *collisions* of objects.

**What you need to know:**
Momentum ( $p$ )

- $p = mv$  (units are kg.m/s)
- Momentum is the product of mass and velocity
- By substituting into Newton's second law we find  $F = dp/dt$ . This indicates that the greater the change of momentum (for example in a collision) the greater the force.

**Test your understanding:**

How fast does a 46g golf ball need to be travelling to have the same momentum as a 2.7kg bowling ball rolled at 7.0m/s?

Answer: 410m/s (2 significant figures)

Impulse ( $J$ )

- There are two main different expressions of momentum
  - one in terms of forces applied,
  - one in terms of change of momentum.
- You can choose which equation to use depending on what information is given in the problem.

<i>Force applied</i>	<i>Change in momentum</i>
$J = F\Delta t$	$J = \Delta p$

- Impulse is a property of *interaction*
  - If there is no external force, there is no impulse which means the momentum doesn't change. This is the concept of conservation of momentum.

**CONCEPTS 3**

**QUESTIONS**

**Question 1:**

Explain the difference between momentum and impulse in 1-2 sentences.

**Question 2:**

Using the words “momentum” and “impulse” can you explain why catching a cricket ball may hurt more than catching a table tennis ball?

**Question 3:**

Ensure you answer both parts (a) and (b) of the question.

A car is driving north with a momentum ( $p$ ) of 13,000 kg.m/s north. The car turns to be driving east with a momentum of 13,000 kg.m/s east.

- (a) Find the change in momentum of the car:
- (b) Explain the things you did to get to your answer:



**CONCEPTS 3**

<b>REFLECTION</b>				
<p>Research indicates that reflecting on your learning can improve your understanding of physics subject matter.</p>				
<p><b>Reflection 1:</b>                      To what extent do you agree with the statement: <i>“I know the concepts of momentum and impulse well”</i>?</p>				
Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
<p><b>Reflection 2:</b>                      To what extent do you agree with the statement: <i>“Understanding the concepts of momentum and impulse are important for first year physics students”</i>?</p>				
Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree
<p>Please explain your answer:</p>				
<div style="border: 1px solid black; height: 60px; width: 100%;"></div>				
<p><b>Reflection 3:</b>                      To what extent do you agree with the statement: <i>“This information will be helpful for my study of physics this semester”</i>?</p>				
Strongly Agree	Agree	Neither A or D	Disagree	Strongly Disagree

<b>CONCEPTS 4</b>
-------------------

## Online Learning Module - Week 4 INTRODUCTION TO TORQUE

### INFORMATION

#### Key terms to know by the end of this session:

Torque

Angular Acceleration

Moment of Inertia

#### Why do you need to know these concepts?

So far as we have discussed forces on objects we have only really considered forces affecting translational motion of objects. Depending on where the force acts on an object, there can also be rotational motion. Torque is the tendency of a force to cause a change in rotational motion of the body on which the force acts. If you understand torque you can solve many more complex problems, particularly problems involving levers or objects rolling down inclined planes.

#### What you need to know:

Consider opening a door. Not only do you need to apply a force to the door, but where you apply the force is important. Think about whether it is easier to push open a door by putting pressure close to the hinges, in the middle of the door or close to the handle?

It is 'easier' to push a door open far from the hinges, but pushing or pulling the door close to the hinges may not work at all. This is because *torque* is a maximum when the force is applied at a maximum distance from the pivot point of the object to be rotated.

#### *Calculating Torque*

Torque can be found by multiplying the tangential\* force by the radial distance from the point of rotation to the location where the force is applied.

\*Tangential force is the component of the force that is perpendicular to the radial distance. Pushing a door perpendicular to the plane of the door will allow it to open whereas pushing towards the hinges will not generate any turning force (*torque*).

#### *Newton's Laws and Torque*

Recall that by Newton's first law that there is only *acceleration* of an object if there is an unbalanced *force* on the object. We can find the analogous relationship when considering rotational motion. There is only *rotational acceleration* of an object if there is an unbalanced *torque* on the object.

$$\mathbf{F} = m\mathbf{a}$$

Recall Newton's 2nd law:

This equation describes how the *acceleration* is proportional to the *force* applied.

Analogously, *angular acceleration* is proportional to *torque*. This time, the relevant equation does not have the *mass* of the object ( $m$ ) in it, rather a new property called *moment of inertia* ( $\alpha$ ). The moment of inertia is a rotational property of a body which depends on the distribution of mass around the axis of rotation. You will learn more about the moment of inertia in this week's lectures.

**CONCEPTS 4**

**QUESTIONS**

**Question 1:**

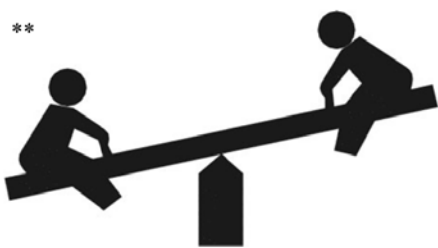
Construction workers use spanners (see picture below) to tighten and loosen nuts. Explain using the words "Force" and "Torque" why spanners help to loosen a tight nut that needs to be unscrewed.



\*

**Question 2:**

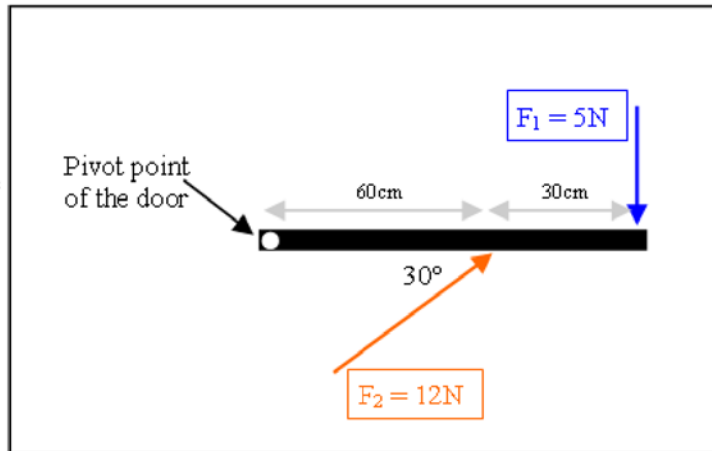
Can you explain why two children on a see-saw (picture below) with different masses can balance the see-saw to be parallel with the ground by sitting at different positions on the see-saw?



\*\*

**Question 3:**

A particular door can open both ways and has a pivot point on the left hand side when pictured from above (see below). A person stands on one side trying to open the door clockwise. They push the door 90cm from the pivot point with a force of 5N perpendicular to the plane of the door.



Another person stands on the opposite side pushing with 12N, 60cm from the pivot point and at an angle of 30° from the door.

Which direction will the door turn? Your answer MUST include an explanation or working to show how you decided on a direction.

\* [https://www.dlsweb.mit.edu/toolbox/electrotech/toolbox1204/resources/03workshop/05hand\\_tools/02spanners.htm](https://www.dlsweb.mit.edu/toolbox/electrotech/toolbox1204/resources/03workshop/05hand_tools/02spanners.htm)  
 \*\* <http://www.johncammish.co.uk/?p=2132>

**CONCEPTS 4**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know the concepts of torque well”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding torque is important for first year physics students”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

## CONCEPTS 5

## Online Learning Module - Week 5

### UNDERSTANDING ANGULAR MOMENTUM

## INFORMATION

**Key terms to know by the end of this session:**

Angular momentum

Conservation of angular momentum

Gyroscope

**Why do you need to know these concepts?**

Just as *torque* describes *forces* causing rotation, *angular momentum* describes *momentum* operating at a distance from an axis of rotation. Once you understand what *angular momentum* is, then you can apply the *law of conservation of angular momentum* which explains physical phenomena such as how gyroscopes are used as well as being a helpful tool in solving problems involving rotating bodies.

**What you need to know:**

Angular Momentum Recall the definition of momentum ( $\mathbf{p} = m\mathbf{v}$ ). This means that momentum is high for heavy, fast moving objects. Angular momentum can also be high for heavy, fast moving objects, but angular momentum also takes into account the distance of the mass from the axis of rotation.

Below is the formula for angular momentum ( $L$ ) where  $\mathbf{p} = m\mathbf{v}$ :

$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

Therefore,  $L$  is proportional to the distance from the rotational axis ( $r$ ), the mass of the object ( $m$ ) and the velocity ( $v$ ). You can use the definition of the cross product to calculate the angular momentum when given these values in a problem.

Angular momentum of rotating bodies Using the definition of angular momentum from above, we can then work out equations to describe angular momentum of not just orbiting objects, but objects such as a spinning top that rotate about a central axis. This requires integrating for multiple masses ( $m$ ), at multiple displacements from the axis of rotation ( $r$ ). Consider the equation below:

$$L = I\omega$$

This equation introduces two terms that you have hopefully already encountered in lectures:

- "I" is the moment of inertia which varies depending on the size, shape, distribution of mass and rotation of the body.
- $\omega$  is the angular velocity (the rate of change of the angle with time)

Conservation of Angular Momentum: Just as linear momentum is conserved in a system with no external forces, there is a corresponding rule for conservation of angular momentum. This time, however, angular momentum is conserved not when there are no external *forces*, rather when there are no external *torques*.

system, should the gyroscope be changed in orientation there must be a large change in angular momentum elsewhere in the system so a mechanism to turn a small, fast-rotating gyroscope can guide a much larger object.

**CONCEPTS 5**

**Gyroscopes** A gyroscope is a device for measuring or maintaining orientation, based on the concept of angular momentum. It is a spinning wheel with a very high angular momentum in which the axle is free to assume any orientation. Although this orientation does not remain fixed, a very high torque is required to change its direction. Therefore, the gyroscopes orientation remains nearly fixed, regardless of the mounting platform's motion

Applications of gyroscopes include inertial navigation systems such as in the Hubble telescope, or to maintain direction in tunnel mining.

Gyroscopes can also be used for the stabilization of flying vehicles like radio-controlled helicopters. The high angular momentum means that if the gyroscope forms part of a

**QUESTIONS**

**Question 1:**

Explain the difference between conservation of momentum and conservation of angular momentum.

**Question 2:**

The important property of a gyroscope is that it has high angular momentum. Why is this the case?

**Question 3:**

**Describe how you would teach someone to solve the following problem by explaining what the key things are that you would get them to do.**

The earth has a mass of approximately  $6 \times 10^{24}$  kg. It is orbiting the sun at 30,000 m/s, at a distance of  $149.6 \times 10^9$  m.

Assuming the orbit is a perfect circle, and ignoring the rotation of the earth's about its own axis, what is the angular momentum of the earth rotating around the sun?

**CONCEPTS 5**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I know the concept of angular momentum well”*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

To what extent do you agree with the statement: *“Understanding the concept of angular momentum is important for first year physics students”*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

Please explain your answer:

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

## CONCEPTS 6

### Online Learning Module - Week 6 LINEAR EXPANSION AND SPECIFIC HEAT CAPACITY

#### INFORMATION

**Key terms to know by the end of this session:**

- The coefficient of linear expansion
- Specific heat capacity

**Why do you need to know these concepts?**

Objects change when heat energy is added or removed. For example, when heat energy is added to an object, it expands according to the coefficient of linear expansion. However, adding heat does not change all objects in the same way, the "specific heat capacity" relates the amount of heat change with the change in temperature of the object.

Coefficient of linear expansion ( $\alpha$ ):

How does a change in temperature affect the dimensions of a system? The answer lies in the coefficient of linear expansion ( $\alpha$ ) defined by the following formula.

$$\alpha = \frac{\text{change in length}}{\text{initial length} \times \text{change in temperature}}$$

If an object will experience a large change in length due to a temperature change (for a given initial length) it will have a large coefficient of linear expansion. The table below has the coefficient of linear expansion for various materials.

Material	$\alpha$ [ $\text{K}^{-1}$ or $(\text{C}^\circ)^{-1}$ ]
Aluminum	$2.4 \times 10^{-5}$
Brass	$2.0 \times 10^{-5}$
Copper	$1.7 \times 10^{-5}$
Glass	$0.4\text{--}0.9 \times 10^{-5}$
Invar (nickel-iron alloy)	$0.09 \times 10^{-5}$
Quartz (fused)	$0.04 \times 10^{-5}$
Steel	$1.2 \times 10^{-5}$

Specific heat capacity ( $c$ ):

Some of you may be familiar with the concept of specific heat capacity depending on what subjects you did at high school. The specific heat capacity ( $c$ ) of a material of a particular mass is the measure of the heat energy transfer to the object ( $Q$ ) required to increase the temperature ( $T$ ) by one degree.

$$c = \frac{1}{\text{mass}} \times \frac{\text{heat energy}}{\text{change in temperature}} = \frac{1}{m} \frac{Q}{\Delta T}$$

The heat capacity is large for materials such as water, and small for metals such as iron and copper. This means that it takes a lot more heat energy to increase the temperature of water than to heat up iron or copper of the same mass.

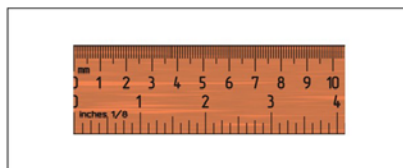


## CONCEPTS 6

### QUESTIONS

**Question 1:**

There is a picture of a ruler to the right. If it was to be heated enough to cause linear expansion, what would happen to the distance between the numbers 1 and 10?

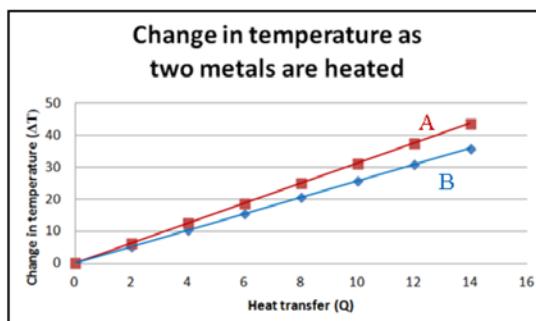


- A. The distance would increase
- B. The distance would stay the same
- C. The distance would decrease
- D. Unsure/ Don't know

**Question 2:**

Using the concept of specific heat capacity, can you explain why a large percentage of electricity usage in Australian houses is taken up by water heating devices such as hot water systems, kettles and hot water washing machines?

Use the below graph for questions 3a + 3b:

**Question 3a:**

The specific heat capacity ( $c$ ) of copper is  $0.39 \text{ kJ/kg.K}$ , and the specific heat capacity of germanium is  $0.32 \text{ kJ/kg.K}$ .

An experiment was done where heat was transferred to two blocks with the same mass of germanium and copper and the temperature change was measured. The results are plotted on the graph above.

Looking at the graph above, explain which line (A or B) represents copper and which line represents germanium. *Ensure that you explain your answer.*

**Question 3b:**

If the experiment was to continue and more heat was to be added to the metals. Would the change in temperature for copper be the same when the heat change is from  $52\text{-}54 \text{ kJ}$  as when the heat change is from  $0\text{-}2 \text{ kJ}$ ? *Briefly explain your answer.*

**CONCEPTS 6**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *“I understand the concepts of linear expansion and specific heat capacity well ”*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Please explain why understanding the concepts of linear expansion and specific heat capacity is important for 1st year physics students?

**Reflection 3:**

To what extent do you agree with the statement: *“This information will be helpful for my study of physics this semester”*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**CONCEPTS 7**

**Online Learning Module - Week 7  
INTRODUCTION TO IDEAL GASES**

**INFORMATION**

**Key terms to know by the end of this session:**

Ideal gas	Universal gas constant (R)
Pressure	Moles

**Why do you need to know these concepts?**

An ideal gas is a theoretical model of a gas which is used extensively in thermodynamics. It is important to know not only the properties or the definition of an ideal gas but what an ideal gas means for our understanding in thermal physics.

**What you need to know:**

Assumptions of an ideal gas:

- Molecules do not exert a force on each other (from being in a close to each other)
- Large number of molecules
- Molecules are point-like
- Molecules are in constant random motion
- Collisions of molecules with walls of a container and other molecules obey Newton's laws and are elastic.

If a gas is deemed ideal then we can use the ideal gas law. This is an equation (below) determined experimentally which describes the relationship between a variety of properties of the gas.

$$pV = nRT$$

Pressure (p):

Pressure is the force exerted by the gas per unit area of the container holding it. Gas pressure is measured typically by allowing a small amount of the gas to be released through a valve and the rate of flow measured but can also be directly measured by the force exerted on a section of the container holding the gas. Should the gas be in a container with a lid that is free to move up and down to change the volume of the gas, the pressure will always be constant at 1 atm = 1.01x10<sup>5</sup> kPa.

Volume (V):

The volume of an ideal gas is the volume of the container that it is held in. The gas will expand to fill a rigid container.

Number of moles (n):

The number of moles is defined as the number of individual molecules divided by Avogadro's constant (N<sub>A</sub> = 6.02x10<sup>23</sup>).

Universal gas constant (R):

The gas constant is the same for all gases. It is a constant that determines the relationship between the properties of an ideal gas. R = 8.314 J.mol<sup>-1</sup>.K<sup>-1</sup>.

Temperature (in Kelvin not Celsius)

The temperature of the gas can be measured with a thermometer. As described in previous lectures, temperature relates to the average translational kinetic energy of the molecules of gas.

**CONCEPTS 7**

**QUESTIONS**

**Question 1:**

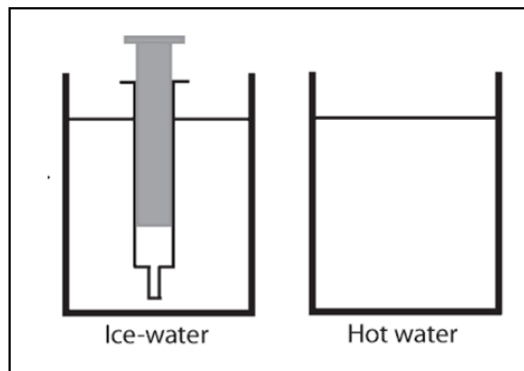
The following statements may be true or false. Circle the ones you think are TRUE. (There may be multiple true statements).

- A. It doesn't matter if you use Celsius or Kelvin as the scale for temperature with the ideal gas equation as they both have the same interval length.
- B. The volume of the gas is the volume of the container the gas is held in.
- C.  $R$ , the universal gas constant, is the same for all gases with the same number of molecules, regardless of their molecular mass.
- D.  $n$ , the number of moles, is the same for all gases with the same number of molecules, regardless of their molecular mass.

**Question 2:**

For questions 2a, 2b and 2c use the following information:

A syringe that contains an ideal gas and has a frictionless piston of mass  $M$  is moved from a beaker of cold water to a beaker of hot water. Answer the following questions and consider that the syringe reaches thermal equilibrium with hot water.

**Question 2a:**

How does the gas temperature change?

- A. Increase
  - B. Decrease
  - C. No Change

**Question 2b:**

How does the gas pressure change?

- A. Increase
  - B. Decrease
  - C. No Change

**Question 2c:**

How does the gas pressure change?

- A. Increase
  - B. Decrease
  - C. No Change

**CONCEPTS 7**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: “*I understand the concept of an ideal gas well*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Please explain why understanding ideal gases is important for 1st year physics students?

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**CONCEPTS 8**

**Online Learning Module - Week 8  
THERMAL PHYSICS PROCESSES**

**INFORMATION**

**Key terms to know by the end of this session:**

- Cyclic process
- Isothermal process
- Isobaric process
- Isochoric process
- Adiabatic process
- Work done by a gas

**Why do you need to know these concepts?**

From the ideal gas equation (below), there are many variables that can change in thermodynamics processes. Therefore, there are assumptions that can be made where particular variables are held constant. This makes understanding and calculating changes due to thermodynamics processes easier.

$$pV = nRT$$

**What you need to know:**

Cyclic Process:

A process that eventually returns to its initial state. This means that the values of pressure ( $p$ ), volume ( $V$ ) and the temperature ( $T$ ) may change but by the end of the process will return to the initial values. This does not mean that nothing has changed, heat or work can be done by the gas or the surroundings.

Isothermal Process:

Isothermal processes occur when there is no change in temperature. If an ideal gas undergoes an isothermal process then assuming the number of molecules doesn't change then the pressure ( $p$ ) times the volume ( $v$ ) is constant.

Isobaric Process:

Isobaric processes occur when there is no change in pressure. If there is no change in pressure then the volume and temperature will change proportionally to each other. That is, if the volume increases, the temperature must also increase.

Isochoric Process:

In an isochoric process, the volume will not change. This leaves the pressure and temperature to change and again they will change proportionally to each other.

Adiabatic Process:

An adiabatic process involves no heat transfer in or out of the system. This does not mean that the temperature doesn't change, rather, if the temperature does change it is often because heat transfer from the system is restricted.

Work done by a gas/system on the surroundings:

Consider an ideal gas which pushes a piston outwards from an initial volume  $V_1$  to volume  $V_2$  with

## CONCEPTS 8

### Work done by a gas/system on the surroundings:

Consider an ideal gas which pushes a piston outwards from an initial volume  $V_1$  to volume  $V_2$  with force  $F$ .

Work done by the gas can be calculated to be:

$$W = \int_{V_1}^{V_2} p \cdot dV$$

If  $V_2 > V_1$  (the gas is expanding) then the work done by the gas/system is positive.

If  $V_2 < V_1$  (the gas is contracting) then the work done by the gas/system is negative.

Work done by a gas ( $W$ ) and heat transfer ( $Q$ ) are not properties of states, rather things that can occur when an ideal gas undergoes a change of  $p$ ,  $V$  or  $T$ . You cannot say "what is the work or heat transfer of a gas" as you can say "what is the pressure or temperature of a gas". Rather you may be asked questions such as "How much work is done by the gas/system on it's surroundings as the gas is heated?".

### QUESTIONS

#### Question 1:

Explain why it is possible to have an ideal gas undergo an isothermal process (no temperature change) even if you apply heat to the container the gas is held in?

#### Question 2:

Match the following questions and answers about thermal physics processes.

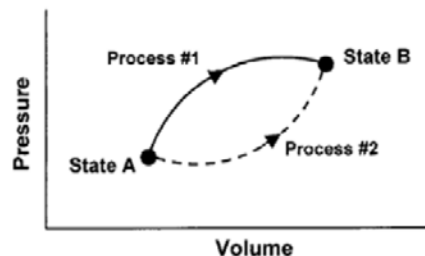
Questions	Answer Options	Match
1. An isochoric process has constant _____	A. Volume	1= A/B/C/D
2. An adiabatic process has no _____ into or our of the system.	B. Heat Transfer	2= A/B/C/D
3. An isothermal process has constant _____.	C. Temperature	3= A/B/C/D
4. An isobaric process has constant _____.	D. Pressure	4= A/B/C/D

#### Question 3a:

Complete the following sentence using the below options:

Work done by the gas in Process #1 is \_\_\_\_\_ than Process #2.

- (a) Greater than
- (b) Less than
- (c) Equal to



#### Question 3b:

Explain how you chose the answer to the previous question in 1-2 sentences:

**CONCEPTS 8**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: “*I understand thermal physics processes well*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Explain why “*Understanding thermal physics processes is important to first year physics students*”?

**Reflection 3:**

To what extent do you agree with the statement: “*This information will be helpful for my study of physics this semester*”?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree



<b>CONCEPTS 9</b>
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<b>Online Learning Module - Week 9</b> <b>THERMAL PHYSICS APPLIED: HEAT ENGINES</b>	
INFORMATION	
<p><b>Key terms to know by the end of this session:</b></p> <ul style="list-style-type: none"> <li>• Heat Engine</li> <li>• Efficiency</li> <li>• Carnot Cycle</li> </ul> <p><b>Why do you need to know these concepts?</b></p> <p>Heat engines are a key application of some of the concepts you have learnt so far in the thermal physics module. There are many examples of heat engines in everyday life (for example internal combustion engines in cars) and they are all bound by a fundamental issue relating to the second law of thermodynamics whereby they can never be 100% efficient. The Carnot Cycle is an example of the ideal thermodynamics process for a heat engine to operate at the maximum efficiency allowable while not violating the second law of thermodynamics.</p> <p><b>What you need to know:</b></p> <p><u>Heat Engines:</u></p> <p>Much of the energy that we use is derived from the burning of fossil fuels. This produces heat, but often we require mechanical energy and therefore, we require devices which convert heat energy into mechanical energy. These devices are known as heat engines. Heat engines absorb heat from a high-temperature source and expel heat to a lower-temperature source.</p> <p>An important feature of a heat engine is how much work it produces (mechanical energy). The first law of thermodynamics implies that for a cyclic process there is no change in internal energy. Therefore, the change in heat energy (<math>Q</math>) is equal to the change in work (<math>W</math>). Therefore the amount of work produced by the engine is equal to the amount of heat energy absorbed from the hot reservoir (<math>Q_H</math>) minus the amount of energy expelled to the cold reservoir (<math>Q_C</math>).</p> <table border="1" style="margin: auto; width: 50%; text-align: center;"> <tr> <td style="padding: 10px;"><math>W = Q_H -  Q_C </math></td> </tr> </table>	$W = Q_H -  Q_C $
$W = Q_H -  Q_C $	

## CONCEPTS 9

### Efficiency:

Efficiency is the amount of work energy output per unit of heat energy supplied.

$$e = \frac{W}{Q_H}$$

If the work is equal to the amount of heat energy absorbed minus the amount of heat energy expelled, then minimising the amount of heat energy expelled would maximise efficiency. Therefore, the heat energy expelled is the waste. Experimentally (and theoretically) it is impossible to construct a heat engine with no waste.

The efficiency of a heat engine can therefore be calculated using:

$$e = 1 - \left| \frac{Q_C}{Q_H} \right|$$

### Carnot Cycle: (pronounced "kar no")

Physicists have known that there will always be waste heat from heat engines and this encouraged the development of the hypothetical Carnot Cycle which is the cycle which operates at the theoretical limit of efficiency.

To understand why such a limit exists, you need to be aware of the second law of thermodynamics and that therefore some processes are reversible and other are not reversible. In the Carnot cycle all processes are reversible.

### QUESTIONS

#### **Question 1:**

Using the terms "Work", "heat energy supplied" and "heat energy expelled" explain how efficiency can be maximised for a heat engine.

#### **Question 2:**

Can you think of why some processes in thermal physics are reversible and others are not? In the space below, give an example of a non-reversible process and explain why it is non-reversible.

CONCEPTS 9

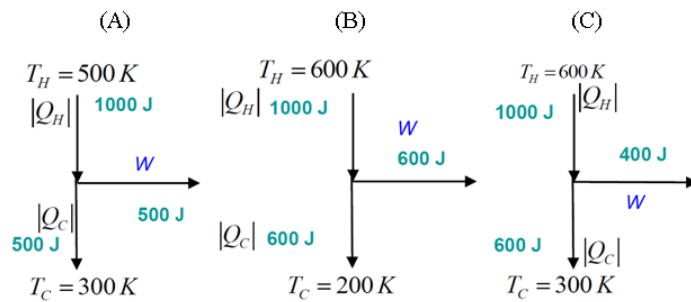
QUESTIONS

**Question 3a:**

A hybrid petrol-electric car has a higher efficiency than a petrol-only car because it recovers some of the energy that would normally be lost as heat to the surrounding environment during breaking. If the efficiency of a typical petrol-only car engine is 20% what efficiency (as a percentage) could be achieved if the amount of heat loss during breaking is halved?

**Question 3b:**

There are three diagrams of heat engines below. Circle the ones you think are feasible as heat engines?



**CONCEPTS 9**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *"I understand heat engines as an application of thermal physics well"*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

**Reflection 2:**

Explain why *"Understanding heat engines as an application of thermal physics is important to first year physics students"*?

**Reflection 3:**

To what extent do you agree with the statement: *"This information will be helpful for my study of physics this semester"*?

Strongly Agree

Agree

Neither A or D

Disagree

Strongly Disagree

## CONCEPTS 10

## Online Learning Module - Week 10

### APPLICATIONS OF SIMPLE HARMONIC MOTION

#### INFORMATION

**Key terms to know by the end of this session:**

- Simple harmonic motion
- Restoring force
- Sinusoidal

**Why do you need to know these concepts?**

Simple harmonic motion is the most common form of oscillation that you will encounter in the first year physics - oscillations and waves module. It is typical for oscillating motions and therefore allows generalising a motion such that its properties can easily be compared with other oscillating bodies.

**What you need to know:**
Definition of Simple Harmonic Motion:

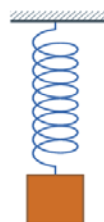
Simple harmonic motion (SHM) is defined by a periodic motion with a restoring force that is directly proportional to displacement.

This means that there will be a force on the oscillating body in the direction to bring it back to an at-rest position. To understand this, it is best to consider an object attached to a spring that is say 5cm in length. When the object causes the spring to stretch ( $>5\text{cm}$ ), the restorative force is pulling the object back to the rest length of the spring. When the object causes the spring to compress ( $<5\text{cm}$ ) the restorative force from the spring is pushing the object outward to bring it back to a 5cm length. The resulting motion of the object is simple harmonic motion because it is a periodic motion with a restoring force that is directly proportional to displacement.

The motion will be sinusoidal when considering the change of position of the object with time. That is, a graph of displacement versus time will be a sine or cosine function for periodic motion.

Examples of Simple Harmonic Motion:

A mass on a spring (both horizontal and vertical/suspended)



A pendulum which only swings at small angles (for example a grandfather clock, a child's swing, a circus trapeze)



## CONCEPTS 10

### Energy in Simple Harmonic Motion:

There is energy in an oscillating system, but how might you work out how much energy?

Energy in the system is equal to kinetic energy (KE) + potential energy (PE) and unless the energy is lost through friction or other means then the form of the energy changes between the two types. Consider an object oscillating on a spring. When the object is stationary (KE=0) then the potential energy is a maximum and you can calculate the potential energy for the amount of compression of the spring. When the spring is at normal length (PE=0) then the kinetic energy is a maximum and if you know the speed you can calculate the kinetic energy.

Either answer will give you the energy of the system as kinetic energy is transformed into potential energy and back to kinetic energy during one half of the cycle.

### QUESTIONS

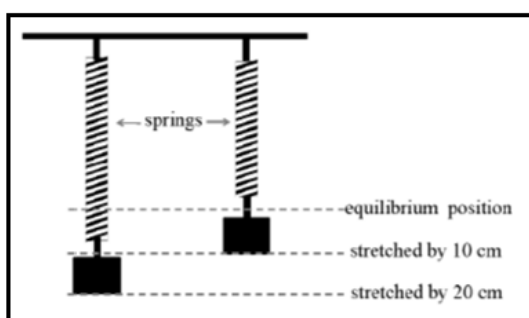
#### Question 1:

Using the definition of simple harmonic motion, which of the following do you think can be approximated as simple harmonic motion? (More than one answer may be correct)

- A. Rolling a marble from side to side in a glass bowl
- B. Bouncing a tennis ball on the ground with a racquet
- C. Hitting a pool ball hard so that it hits the opposite sides of the table multiple times at a fast speed
- D. Holding a ruler half off the end of a table and flicking it so it moves up and down on the free end
- E. A bungee jumper, having jumped off a bridge

#### Question 2:

Two equal masses are attached to separate identical vertical springs next to one another (see diagram below). One mass is pulled so its spring stretches 20 cm and the other pulled so its spring stretches only 10 cm. The masses are released simultaneously.



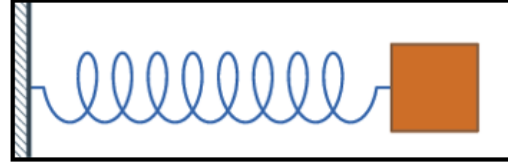
Which mass passes the equilibrium position first? *Explain the steps you took, or things you did, to get to your answer.*

**CONCEPTS 10**

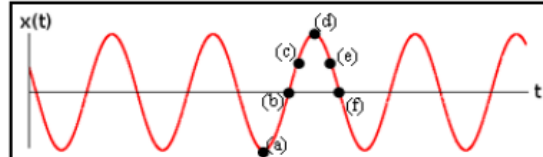
**Question 3:**

For questions 3a and 3b use the following information:

Consider a mass oscillating horizontally on a spring:



A displacement - time graph for the spring is pictured with 6 points on the graph marked (a)-(f):

**Question 3a:**

Circle the letters that correspond to the points position(s) where the horizontal acceleration of the block is zero?

A
B
C
D
E
F

**Question 3b:**

Circle the letters that correspond to the points position(s) where the potential energy of the block is maximum?

A
B
C
D
E
F

**Question 3c:**

Circle the letters that correspond to the points position(s) where the kinetic energy of the block is maximum?

A
B
C
D
E
F

**CONCEPTS 10**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *"I understand applications of simple harmonic motion well"*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

Explain why *"Understanding applications of simple harmonic motion is important for first year physics students"*?

**Reflection 3:**

To what extent do you agree with the statement: *"This information will be helpful for my study of physics this semester"*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree



CONCEPTS 11

Online Learning Module - Week 11  
MECHANICAL WAVE

INFORMATION

**Key terms to know by the end of this session:**

- Mechanical Wave
- Transverse and Longitudinal Waves
- Restoring force
- Wavelength
- Frequency

**Why do you need to know these concepts?**

These are key definitions in the oscillations and waves module that you will encounter this week. Knowing the definitions well will prepare you for the material you are covering in lectures so that you can better understand the connections, methods and implications that are used to understand waves and solve problems. Without understanding these concepts you will be unable to calculate the speed of a wave, distinguish between different types of waves, understand the principle of superposition or standing waves.

**What you need to know:**

Mechanical Waves: A mechanical wave is made up of oscillations of particles which results in a transfer of energy through a medium. The particles oscillate either in the same direction as the energy transfer, or perpendicular to the direction of the energy transfer of the wave, but do not move along with the wave. Consider a pulse in a rope, the pulse moves along the rope, and the individual particles on the rope oscillate up and down, but even though the wave moves through the medium, the particles on the rope do not move all the way along with the wave.

Some properties of any mechanical wave that can be described include:

- Shape or pattern (such as a pulse, or a sinusoidal curve)
- Speed of the wave
- Energy transmitted
- Number of dimensions (some waves such as on a rope transmit energy in one direction and so one dimension, waves from dropping a rock into a pool spread in two dimensions)

Mechanical waves can either be transverse, longitudinal or both.

Transverse waves: Transverse waves involve particles oscillating perpendicular to the direction of the energy transfer of the wave. A pulse on a rope is a simple example. You can take a photo of a transverse wave and see the sinusoidal motion of particles moving up and down.

## CONCEPTS 11

Longitudinal waves: Longitudinal waves are also known as pressure waves. If it was in a gas, there are compressions (where the gas particles move closer together) and rarefactions (where the gas particles move further apart). These can still typically be represented by a sinusoidal wave. As the compressions and rarefactions progress through a gas, the particles oscillate in the same plane as the direction of the wave.

When can mechanical waves be both? Water waves are made up of both transverse and longitudinal components. At the surface you can see evidence of a transverse wave with particles moving up and down in waves, but there is also an element of water particles moving parallel with the waves and this is often under the surface of the water.

Restoring force: Waves are only able to propagate because of the restoring force present in the medium. The restoring force is a force that opposes the displacement of the particles that are oscillating (think back to the definition of Simple Harmonic Motion). Knowing the source of the restoring force is important as it is used to calculate the speed of waves propagating through the medium.

Wavelength: The wavelength of a mechanical wave (given the symbol of the Greek letter lambda,  $\lambda$ ) is the distance between parts of the wave that are in the same phase. This means, the distance between two peaks of a transverse wave, or two compressions in a longitudinal wave. Information about the wavelength is often presented in the form of angular wavenumber,  $k = 2\pi/\lambda$ .

Frequency: The frequency ( $f$ ) of a mechanical wave is related to the frequency of simple harmonic motion. It is the number of oscillations per second of a particle which is oscillated by the wave. Information about the frequency is often presented in the form of angular frequency,  $\omega = 2\pi f$ .

The speed of the wave is therefore equal to the frequency times the wavelength =  $\omega/k$ .

CONCEPTS 11

QUESTIONS

**Question 1:**

A property of mechanical waves is the number of dimensions.

If an example of a 1D wave is a pulse on a string, an example of a 2D wave is the ripples from a rock falling into a pool, can you describe an example of a wave propagating in three dimensions?

**Question 2:**

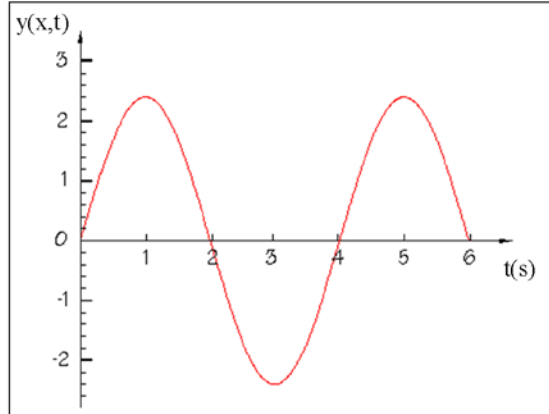
Explain in 2-3 sentences, as if to a fellow first year physics student, what is meant by a

mechanical wave.

You may use any combination of words, numbers or descriptions of graphs or equations.

**Question 3:**

What information can you provide about the graph below:



You may use any combination of words, numbers or descriptions of graphs or equations.

**CONCEPTS 11**

**REFLECTION**

Research indicates that reflecting on your learning can improve your understanding of physics subject matter.

**Reflection 1:**

To what extent do you agree with the statement: *"I understand mechanical waves well"*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 2:**

Explain why *"Understanding mechanical waves is important for first year physics*

*students"*?

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Reflection 3:**

To what extent do you agree with the statement: *"This information will be helpful for my study of physics this semester"*?

COMMON MODULE

Online Learning Module - Week 12  
REFLECTION

The following questions are designed to allow the University to get feedback on the effectiveness of the online learning modules. Please complete the following.

**Question 1:**

To what extent do you agree with the statement:

"The online learning modules were *helpful* for learning physics this semester"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 2:**

Name one thing about the online learning modules that was helpful for learning physics this semester? (If applicable)

**Question 3:**

To what extent do you agree with the statement:

"The online learning modules were *relevant* for learning physics this semester"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 4:**

To what extent do you agree with the statement:

"The online learning modules were *demanding* to complete"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

**Question 5:**

To what extent do you agree with the statement:

"I put a lot of *effort* into the online learning modules each week"

Strongly Agree | Agree | Neither A or D | Disagree | Strongly Disagree

COMMON MODULE

**Question 6:**

What motivated you to continue completing the online learning modules throughout semester?

**Question 7:**

What other resources did you use to complete the online learning modules (if any):

**Question 8:**

Please write 1-2 sentences explaining whether you think it is important for physics students to be fluent with physics communication tools such as graphs, equations and diagrams.

**Question 9:**

What was the first language that you spoke as a child?

**Question 10:**

To further investigate the helpfulness of the online learning modules we would like to interview some students to learn more of their experiences. A movie ticket and other treats will be provided should you be willing to be interviewed and all interviews will be conducted at the University. If you are willing to be interviewed please write a suitable time period in the space below, otherwise leave it blank.

Consider:

- During Week 13 or StuVac
- During the second week of exams (The week starting Monday 24/6/13)
- During Week 1-2 of Semester 2.

Thank you for giving feedback on the online learning modules.

We wish you all the best preparing for your Semester 1 exams and encourage you to make the most of final opportunities to learn such as visiting the physics duty tutoring sessions, attending week 13 workshops and downloading and completing past exam papers.

If you have any final comments about the online learning modules please write them below.

## **Appendix D**

### **Relevant human ethics forms**

All activities involving human participation of this research were conducted under the supervision and approval of the University of Sydney Human Ethics Committee.

In this appendix are included the three relevant participant information statements that were offered to participants before they consented to be involved in the research.

These include:

- (i) The Participation Information Statement for university students completing the Representational Fluency Survey (relevant for Chapters 2 and 3).
- (ii) The Participation Information Statement for year 12 physics students completing concepts or representations based worksheets (relevant for Chapter 4).
- (iii) The Participation Information Statement for university students completing weekly online learning modules in first year physics (relevant for Chapters 5 and 6).

- (i) Participation Information Statement for university students completing the Representational Fluency Survey (relevant for Chapters 2 and 3).



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Facsimile: +61 2 9351 7726  
Email:  
manjula.sharma@sydney.edu.au  
Web: <http://www.usyd.edu.au/>

#### PARTICIPANT INFORMATION STATEMENT

**(1) What is the study about?**

To be an expert in physics, individuals will need to be able to express their knowledge and solve problems using a variety of representations. This study is investigating the relationship between developing skills in using multiple representations and developing as a physics expert.

**(2) Who is carrying out the study?**

The study is being conducted by Mr Matthew Hill and will form the basis for the degree of BSc (Honours) at The University of Sydney under the supervision of Associate Professor Manjula Sharma.

**(3) What does the study involve?**

The study involves completing and returning a written survey on representational literacy. The findings from the survey will be used for comparison with your examination results.

**(4) How much time will the study take?**

The survey will take 20 minutes to complete

**(5) Can I withdraw from the study?**

Being in this study is completely voluntary and you are not under any obligation to consent to complete the survey. Submitting a completed survey is an indication of your consent to participate in the study. You can withdraw any time without affecting your relationship with The University of Sydney.

**(6) Will anyone else know the results?**

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

**(7) Will the study benefit me?**

The study will provide you with the opportunity to attempt a variety of diagnostic questions and reflect on what you found simple or difficult. If you choose to get feedback, reflection on your answers to the survey may benefit you in assisting you to understand how you can improve in your physics ability.

**(8) Can I tell other people about the study?**

An investigation into multiple representation proficiency and physics expertise of university students  
Version 2 – 13 May 2011

Page 1 of 2



Yes, by all means. There is no reason to keep this study a secret.

(9) What if I require further information?

When you have read this information, Mr Matthew Hill will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Mr Matthew Hill, [mhill@physics.usyd.edu.au](mailto:mhill@physics.usyd.edu.au), BSc (Honours) student or Assoc/Prof Manjula Sharma, 9351 2051, Room 226E, Physics Building, [m.sharma@physics.usyd.edu.au](mailto:m.sharma@physics.usyd.edu.au), Head of the SUPER group.

(10) What if I have a complaint or concerns?

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or [ro.humanethics@sydney.edu.au](mailto:ro.humanethics@sydney.edu.au) (Email).

*This information sheet is for you to keep*

- (ii) Participation Information Statement for year 12 physics students completing concepts or representations based worksheets (relevant for Chapter 4).



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#### PARTICIPANT INFORMATION STATEMENT

**(1) What is the study about?**

To be an expert in physics, individuals will need to be able to express their knowledge and solve problems using a variety of representations. This study is investigating the relationship between developing skills in using multiple representations and developing as a physics expert.

**(2) Who is carrying out the study?**

The study is being conducted by Mr Matthew Hill and will form the basis for a PhD (Physics) at The University of Sydney under the supervision of Associate Professor Manjula Sharma.

**(3) What does the study involve?**

The study involves completing the following worksheet that you will be given to help you in your understanding of physics for the HSC.

**(4) How much time will the study take?**

The worksheet will take 40 minutes to complete

**(5) Can I withdraw from the study?**

Being in this study is completely voluntary and you are not under any obligation to consent to complete the survey. Submitting a completed survey is an indication of your consent to participate in the study. You can withdraw any time without affecting your relationship with The University of Sydney or Barker College.

**(6) Will anyone else know the results?**

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

**(7) Will the study benefit me?**

The worksheets have been designed based on the findings of previous physics education research. They have been created to improve particular aspects of your physics ability in preparation for your HSC exams. Completing the worksheet should help you in your year 12 studies.

**(8) Can I tell other people about the study?**

Yes, by all means. There is no reason to keep this study a secret.

**(9) What if I require further information?**

When you have read this information, Mr Matthew Hill will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Mr Matthew Hill, [mhill@physics.usyd.edu.au](mailto:mhill@physics.usyd.edu.au), PhD student or Assoc/Prof Manjula Sharma, 9351 2051, 21 Ross St, Forrest Lodge, [m.sharma@physics.usyd.edu.au](mailto:m.sharma@physics.usyd.edu.au), Head of the SUPER group.

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*This information sheet is for you to keep*

- (iii) Participation Information Statement for university students completing weekly online learning modules in first year physics (relevant for Chapters 5 and 6).



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**(2) Who is carrying out the study?**

The study is being conducted by Mr Matthew Hill and will form the basis for a PhD at The University of Sydney under the supervision of Associate Professor Manjula Sharma.

**(3) What does the study involve?**

The study involves completing the online learning modules that are part of your 1<sup>st</sup> semester physics course.

**(4) How much time will the study take?**

The online learning modules are designed to take 15 minutes each week during semester.

**(5) Can I withdraw from the study?**

Being in this study is completely voluntary and you are not under any obligation to consent. You can withdraw any time without affecting your relationship with The University of Sydney. If you withdraw, your participation in the online modules will only be considered regarding your assessment in the unit of study, and not for research purposes.

**(6) Will anyone else know the results?**

All aspects of the study, including results, will be strictly confidential and only the researchers will have access to information on participants. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

**(7) Will the study benefit me?**

The modules were designed using research-based principles for your benefit. Successful completion of the modules should improve your understanding of physics over the semester.

**(8) Can I tell other people about the study?**

Yes, by all means. There is no reason to keep this study a secret.

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Version 4 – 25 January 2013

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**(9) What if I require further information?**

When you have read this information, Mr Matthew Hill will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Mr Matthew Hill, [mhill@physics.usyd.edu.au](mailto:mhill@physics.usyd.edu.au), PhD student or Assoc/Prof Manjula Sharma, 9351 2051, 21 Ross St Forrest Lodge, [m.sharma@physics.usyd.edu.au](mailto:m.sharma@physics.usyd.edu.au), Head of the SUPER group.

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*This information sheet is for you to keep*