

Student Reflection Response to Multimedia

An Exploration of Student Reflection as Facilitated
by Physics Educational Videos

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Dedication

To all educators, everywhere: thank you.

Statement of Originality

This statement certifies that, to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any other degree or for other purposes. I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources has been acknowledged.

Petr Lebedev

Statement of Contribution

I approached Professor Manjula Sharma in 2017, expressing interest in investigating the “critical thinking” skills of students in the PhD program. After I was accepted and an initial review of the literature, my research focused on student reflection. The central idea explored in this thesis is my own; namely, investigating reflection as facilitated by multimedia using questions and answers.

The first set of videos were sourced from the Science YouTube channel named “Veritasium”, with permission from the channel’s creator, Dr Derek Muller. The second set of videos were written, designed, produced, filmed and edited by me. The survey which gathered insights on reflection was designed and written by me.

I developed the analysis and coding categories and received insights and feedback from my supervisor. Throughout the process my supervisor directed my work, provided oversight, and gave constructive criticism. The literature on reflection and adult-learning was sourced independently. My co-supervisor (Dr Christine Lindstrøm) stepped in half-way through the project, guiding me towards additional literature and providing feedback. My co-supervisor, Prof. Michael Wheatland, was supportive throughout the process, providing occasional feedback on both the research and the writing of the project.

Chapter 5 of this thesis has been published (Lebedev and Sharma, 2019). I designed the study, collected and analysed the data, and was the primary author on the paper.

Chapter 6 of this thesis has also been published (Lebedev, Lindstrøm, and Sharma, 2020). I designed this study, collected and analysed the data, and was the

primary author on the paper.

I acquired feedback from the national and international physics education research community through a series of conference presentations. A full list of publications and presentations appears on page 7 and 8.

In cases where I am not the corresponding author of a published item, permission to include the published material has been granted by the corresponding author.

Petr Lebedev

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Included Papers and Presentations

The following list includes refereed papers and presentations that were written and presented as part of the research for this doctoral program and on which some of the chapters of this document are based.

Refereed Papers

- Petr Lebedev and Manjula Devi Sharma. Riddles on youtube: Investigating the potential to engage viewers in reflective thinking. *Research in Learning Technology*, 27, 2019
- Petr Lebedev, Christine Lindstrøm, and Manjula Devi Sharma. Making linear multimedia interactive: Questions, answers, types of reflection. *European Journal of Physics*, 2020

Conference Presentations

2017

- Changing your mind on the internet — can a YouTube audience think critically — oral presentation. Proceedings of the Australian Conference on Science and Mathematics Education, Monash University, 27-29 September 2017, ISBN Number 978-0-9871834-6-0.
- Critical thinking on YouTube using questions and answers — oral presentation. Australian Association for Research in Education, 26-30 November 2017, Canberra.

2018

- How Does the Question Affect Student Reflection? — oral presentation. American Association of Physics Teachers, Washington, DC.

- Critical Reflection and Physics Education Multimedia — poster presentation. Physics Education Research Central, Washington, DC, 2018.
- Riddles and reflection: the question matters — oral presentation. Proceedings of the Australian Conference on Science and Mathematics Education, Flinders University, 26-28 September 2018.
- Riddles in Veritasium: Making sense of how students reflect — oral presentation (presented by Prof. Manjula Sharma). International Conference on Physics Education, 1-5 October 2018, Johannesburg.
- Physics, Multimedia and Reflection: How does the type of reflection by first year students compare to that of the general audience? — oral presentation. Australian Association for Research in Education, 2-6 December 2018, Sydney.

2019

- Questions as a detective story: good clues, red herrings and student reflections — poster presentation. Proceedings of the Australian Conference on Science and Mathematics Education, the University of Sydney, September 2019.

2020

- Student confidence, riddles and reflection — online poster presentation. Australasian Science Education Research Association. 23-26 June 2020.
- Development and evaluation of the “question-solution-reflection” framework — online oral presentation. Proceedings of The Australian Conference on Science and Mathematics Education, September 2020.

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Links to Multimedia

The links to multimedia that are relevant to the research studies are listed below.

The scripts for these videos are included in the appendix.

Videos for Study 1 and 2

Video 1: Questions

Video 2: Solutions

Videos for Study 3

Good Clues

No Clues

Bad Clues

Solution

Abstract

This dissertation considers reflective learning strategies in physics education, specifically addressing student responses to “linear multimedia” — in our case, educational videos. It is an analysis of the manners in which students responded to these strategies, and the impact of prompts or questions on their responses. Three exploratory studies on reflective thinking in the context of linear multimedia for physics education were conducted and synthesized within the dissertation. Both multimedia learning and reflective thinking constitute important parts of physics education research (PER), yet there is a gap in the literature at their intersection. Similarly, reflection is ever-present in educational literature, but is rarely explicitly addressed or studied.

Of the three studies conducted as part of this thesis, the first occurred in an informal learning context and the latter two occurred in the context of first year university physics study. All three studies were structured similarly; two videos were each followed by a phase of reflection as outlined by John Dewey (1933). The first video presented physics questions to the students, while the second video provided the solutions. Participants were instructed to write down their answers after watching the first video and to note any modifications to their answers after viewing the second video. The students were asked to provide a reason as to why they did or did not modify their answers.

Three main findings emerged from the research. First, using Dewey’s phases to design videos (one with questions and another with solutions) and then asking the students to reflect on their answers, was a simple and effective way of introducing interactivity into a typically non-interactive medium. Second, the vast majority of students modified their answers when their initial answer did not match the solution and did not modify their answers when it did. When prompted, students reported the reasons for opting to modify or not, and these reasons were coded into seven distinct categories. These categories were consistent with those found in

the existing literature. Students gave similar reasons for both modifying and not modifying their answers. Third, the types of questions and the incorporation of “clues” into questions elicited different types of reflection.

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Chapter 1

Introduction

What has roots as nobody sees,
Is taller than trees,
Up, up, up it goes,
And yet, never grows

J.R.R. Tolkein

1.1 Motivations: The Research That Was Not There

As noted by Aalst (2000) Physics Education Research (PER) is a broad and multidisciplinary field. This thesis assumes this multidisciplinary nature and draws inspiration and research insights from a wide variety of disciplines and areas of the literature. One of the goals of PER is to conduct experiments, collect data, and apply this new knowledge into improving the quality of physics education resources in an evidence-based way (?). Like many researchers in PER, my own interest originates in my love for physics and desire to teach physics better. I also wished to combine this with another passion: film-making. When this research began, I wished to make effective educational films and to add to the growing body of literature in this vital, yet still under-researched area of PER. As part of this thesis I have

1. Designed a novel, physics education, multimedia intervention grounded in theoretical foundations.
2. Evaluated the efficacy of the intervention.
3. Discussed the implementation of the intervention.
4. Described further necessary research to further validate and advance the ideas presented in this thesis.

The thesis focuses on two important aspects of contemporary education: reflective thinking and learning with multimedia. A review of the literature is presented in Chapter 2 and a brief write-up follows to explain the motivation for this research.

Multimedia learning forms a substantive part of the educational landscape and has become even more important during and after the COVID-19 pandemic. There is robust research on the use of multimedia assets as teaching tools in physics education, but much of the research focuses on how effective multimedia is at teaching procedural skills or concepts (Mayer and Moreno, 1998; Mayer, 2005; Muller et al., 2007; Muller, 2008; Kirstein and Nordmeier, 2007; Altherr et al., 2003). Much less research has assessed the efficacy of using multimedia to explore, study, and facilitate meta-cognition, critical-thinking, or reflection.

Reflection is acknowledged as a vital part of learning (Boud et al., 2013). While there is important research and writing about reflection within many disciplines (including philosophy, psychology, and education (Dewey, 1933; Mezirow, 1998; Boud et al., 2013; Boyd and Fales, 1983)) the research on reflection in PER primarily focuses on the professional development of teachers. This research often asks “How do teachers reflect on (and hopefully improve) their practice?” (Moon, 2013; Borghi et al., 2001; Wulff et al., 2021; Barak and Shakhman, 2008), rather than “How do students reflect on their thinking and learning?”.

There is a gap in the literature at the intersection of these two topics: the reflective thinking of physics students interacting with educational multimedia. Furthermore, there is a lack of research on techniques and strategies for promoting

reflection through educational multimedia. This thesis fills some of these gaps, presenting three studies in which a framework for encouraging and evaluating reflective thinking in physics students utilizing linear multimedia is developed and evaluated (where linear multimedia is non-interactive, one-directional multimedia, such as video).

1.2 Personal Statement: My Lens

Cinematographers use different lenses for different emotional impacts (Brown, 2016). Focal lengths of the lenses affect the audience's perception of the subjects; a wide lens placed close to the subject can convey the feeling of intimacy, while a telephoto lens can make the subject feel more detached and distant. There are also characteristics of various lenses; how they render colour, the look of the out-of-focus areas, how sharp they are, how much they vignette (how an image shades off into the surrounding colour at its edges). Certain lenses are used to achieve certain looks; if a cinematographer wants a clinical and sharp image, Zeiss or Panavision lenses are used. If a more vintage look is desired, the cinematographer can reach for a set of Leica R series primes, and if a soft and dreamy look is required, one can put on a Helios 44-2 lens. All of this is to say that the lens choice that a cinematographer makes on set may have a drastic impact on the final look and feel of the movie.

Similarly, the lens of a researcher affects the research. However, unlike a cinematographer, researchers cannot voluntarily change the lens they use.

In this section, I will briefly outline my personal history and interest in physics education, and the specific topics that I explore in this thesis. The aim of this personal statement is to provide some context and explain the lens through which this work was perceived and shaped.

I've been interested in science since I was very young. Partially because I, like many children, was curious about how the world worked and also partially because both of my parents were (and still are) physicists. While having physicist parents

presented some unique challenges, the positives far out-weighed the negatives. I was also fortunate to have great teachers; whatever question I had about the world they helped me to find answers with openness and curiosity. Much of my early interest in science can be linked to the profession of my parents and my teachers, but the media I consumed also had a profound impact. I was already interested in science, but David Attenborough's documentaries, Carl Sagan's "Cosmos" series, and episodes of "Bill Nye the Science Guy" and "Mythbusters" solidified this interest. In early high-school I became interested not only in science, but also in the art of science communication and physics education. After enrolling in my undergraduate geophysics degree, this interest evolved further as I watched many science communication/physics education channels on YouTube including Veritasium, SmarterEveryDay, MinutePhysics, PhysicsGirl, and others. Towards the end of my undergraduate degree, it became clear to me that while I wanted to do physics research, I also wanted to communicate and teach physics. As a long-term viewer of this informal physics education, I have noticed trends in its quality. Some content was high quality, entertaining, and educational, while others fell short. I made an effort to watch only the exceptional science communication content and aimed to understand what made it great. I wished to figure out what worked and what didn't.

Being a fan of Derek Muller's Veritasium channel, I knew about his thesis, which focused on designing effective physics education multimedia (Muller, 2008). This was my first introduction to physics education research (PER). Over time, it became clear to me that Derek's research was contributed significantly to the quality of his science communication. The understanding of pedagogy, in a specific medium was incredibly useful for him and essential to the quality of his videos. I sent Professor Manjula Sharma, the supervisor of Derek's thesis an email, and a few months later I moved across the country to initiate this PhD project.

The goal of this project is very practical; to enhance physics education by incorporating multimedia into instructional methods.

1.3 Background

Multimedia tools are commonly utilized in teaching and learning. Over the last three decades, ample research has been conducted on how to effectively implement them (Mayer, 2005; Muller, 2008). The majority of the literature focuses on conceptual gains as a proxy for student knowledge and multimedia tools are typically assessed via pre-tests and post-tests. Practitioners also commonly utilize multimedia tools that are designed to teach procedural skills (such as in Khan Academy videos (Gray et al., 2017; Gray and Lindstrøm, 2019)). Teaching procedural skills is important but there are important meta-skills that also deserve consideration in science education and multimedia.

Outside of the multimedia research, there is much educational research that extends its focus beyond conceptual, procedural, or content knowledge, reaching to more abstract, yet incredibly important skills, including metacognition (Livingston, 2003), self-regulation (Zimmerman and Schunk, 2011), critical thinking (Ellerton, 2015; Paul and Elder, 2019), and reflection (Rodgers, 2002). There is limited research in the intersection of these domains of educational research. In particular, little research has been conducted on the interplay between multimedia and reflective thinking.

The goal of this thesis is to explore how student reflection manifests in multimedia learning, what it looks like, and how to adapt existing pedagogical multimedia learning approaches to deepen student reflection.

Initially, this PhD research considered critical thinking. Critical thinking is a fascinating topic in physics education and in the science communication spheres; it involves questions like student capacity for critical thinking relative to age and stage of education, the ability of students to assess source validity, thinking processes, meta-cognitive skills related critical thinking, the ability to differentiate between the content of an article in a respected journal and one published in a predatory journal. Although critical thinking research poses interesting questions it was not

ultimately the focus of this PhD work.

After delving into the literature, two clear observations emerged: 1) critical thinking is ill-defined, and most of them are vague and all-encompassing, and 2) measuring student critical thinking appeared to be nonviable. For example, a highly cited researcher in the field of critical thinking Ennis (1964, 1989), argues that “critical thinking is the correct assessing of statements”. By contemporary analytical standards, this notion is far too broad, vague, and may not be generalizable (it may not be an appropriate criterion to apply in some contexts). The notion of “correct assessment” is unclear. It may also be possible for a critical thinker to come to an incorrect conclusion; Newton’s theory of gravity is not equally correct to Einstein’s, but Newton was considered comprehensively correct for large stretches of history. Judging critical thinking skills based on “correctness” is imprecise. If astrophysicists researching Weakly Interacting Massive Particles to determine whether this explains dark matter are found to be wrong, and that instead dark matter comprises axions, or an unknown entity, were these researchers not critical thinkers? Peter Ellerton (2015) argued that “...many of those who claim to value critical thinking are hard pressed to explain exactly what they mean by it beyond typically diffuse references to ‘higher-order thinking’ or ‘general reasoning characteristics’. Instead a more precise skill associated with critical thinking emerged as the topic of this research.

The concept of reflection was described within the literature on critical thinking. The study of reflection or reflective thinking (these terms will be used interchangeably for the remainder of the thesis) became the focus of the research. While pinning down a clear definition of reflection is non-trivial, it does have tighter constraints than critical thinking. Reflective thinking is an integral part of education and of human experience. Great thinkers from diverse schools of thought agree on the importance of reflection. Reflection on one’s actions allows one to learn and to become more proficient in domains of knowledge but also to become a better person. It allows one to adjust one’s ideas when faced with new information. The neuroscientist and philosopher Daniel Dennett claims that “consciousness is an intellectual illusion

created by us because we're so darn reflective" (Dennett, 2018). As a thesis in the field of PER, this research approaches reflection from a pedagogical point of view rather than a philosophical one. An in-depth review of the literature on reflective thinking is provided in Chapter 2.

1.4 Outline

This thesis attempts to fill the gap identified earlier in this section and to understand how student reflection manifests in interactions with multimedia tools, how it is characterized, and how to adapt existing pedagogical multimedia learning approaches to deepen student reflection.

This thesis contains eight chapters. **Chapter 1** contains the goals of the project and explains its motivations. **Chapter 2** contains a review of relevant educational literature, focusing on reflection, multimedia learning, and the social media learning context. **Chapter 3**, discusses the methodological framework and the mixed-methods methodology of the data collection and analysis. Three iterations of the study are outlined and the primary methods that were used to conduct these studies are explained. **Chapter 4** discusses the selection and design of the videos for the three research phases. This chapter gives a broad overview of the methodology (detail appears later in the specific study chapters). **Chapter 5** discusses Study 1 in a social media context involving members of the general public. **Chapter 6** discusses Study 2, which built upon the insights of the first study and was conducted with first year physics students at the University of Sydney. **Chapter 7** discusses Study 3 which incorporated the insights of the first two studies and used videos specifically-designed to encourage different types of reflection. Finally, **Chapter 8** presents the findings, implications, discussion, and conclusions drawn from the three studies.

Chapter 2

Literature Review

Thirty white horses
on a red hill,
First they champ,
Then they stamp,
Then they stand still.

J.R.R. Tolkien

This literature review discusses existing work in fields related to the subject matter. Central to the selection of literature was the primacy of the topic of reflection, multimedia, and informal learning and science communication. As noted, physics education research (PER) is an interdisciplinary field, and while many of the studies referenced fall within the core field of PER, many also fall within education research, adult learning, psychology, sociology, science communication, and other fields of scholarship. The concepts referenced are integral PER, but are rarely explicitly addressed in the field. Reflection is a vital concept in PER, but tends to remain implicit within the literature. This concept is discussed more explicitly in the fields of education and psychology. Both the conceptual and evaluation frameworks rely on research from those fields. To the best of my knowledge, this thesis is also the first study to analyse the link between student reflection and multimedia learning, in the context of university-level physics education, and in informal,

social-media based learning. At the core of this thesis, and of PER in general, is interdisciplinary scholarship.

In this literature review, a brief history and overview of PER is provided and relevant literature on multimedia learning, reflection, informal learning, and how students understand mechanics and electricity is addressed. Research which informed the quantitative and qualitative data analysis is also highlighted. The theoretical underpinnings of the research methodology and research methods are discussed in Chapter 3.

2.1 Physics Education Research: An Interdisciplinary Science

What is now considered the discipline of PER originated at a number of colleges in the United States in the 1960s and 1970s. It explores various aspects of teaching and learning physics, such as how students learn physics, how they think about various concepts, and common misconceptions. Crucially, it also focuses on the creating, testing, and improving teaching methods to improve the teaching and learning of physics. The physics departments of several universities began formal and informal PER research groups in this period, including the University of Washington, Kansas State University, the University of Maryland, CU Boulder and others. Since then, the field has expanded rapidly. It is now an international field of research, with PER groups in physics departments at universities all over the world. The goals of PER are broad and the field has broad scope. Inevitably, as the field grew researchers became interested in different parts of PER, focusing on varied interests within the field. Examples of this include the scholarship of the efficacy and role of multimedia learning, the use of lecture demonstrations, student misconceptions and alternative understandings of topics, the role of collaborative learning, active learning, multiple representations, peer instruction, the use of technology, inquiry-

based learning, and other topics. There are also fundamental epistemic questions, that link PER to cognitive science. Some concerns within these fields might be how students conceptualize the world and how they think about the elements of physics being presented to them (McClelland, 1985; Altherr et al., 2003; Mazur, 1999; Wulff et al., 2021; Hermita et al., 2017; Hill et al., 2015).

PER is a practical field of research: a fundamental objective of the field is to study how to improve the quality of physics teaching and learning rigorously. The majority of early physics education researchers and the founders of PER were physicists, using the skills they developed as part of their scientific training and careers to explore how to teach physics most rigorously and effectively (Meltzer and Otero, 2015; Bevilacqua and Giannetto, 1996). Much of the work in PER was done, and continues to be done, within departments of physics, and not departments of education. A typical PER researcher also has a formal educational background in physics, rather than education.

The participants in PER studies can range from young children, to children in primary and high school, to students enrolled in university courses, to adult learners. Studies may take place within formal education contexts such as schools and universities, and also in a number of informal learning spaces including in person and online science communication events. Yet, the majority of participants in PER studies are university students enrolled in physics classes (Kanim and Cid, 2020). This is partially a matter of convenience as this is the easiest group to recruit into experiments. These are the students that PER academics and PhD students teach during the semester and they are the easiest to recruit into studies. However, it's not only a matter of convenience. There are valid reasons why physics students at universities are a group uniquely suited for research in PER. Given that PER students teach these students rigorous study is well spent improving methods of practice. This close tie to the subject matter and to the availability of students are among PER's strengths.

As noted by Beichner (2009), there are several reasons why PER originated, and

to this day mostly remains, in the departments of physics, and not of education, “... physicists are familiar with the complex and often subtle aspects of physics as covered in college-level coursework.”. He also asserts that the researchers who study learning by college students should teach these classes to understand the subtleties and intricacies of the the subject matter and to understand which problems the students find particularly challenging. Yet, just because the typical PER group is based in a department of physics, shouldn’t mean it is or should be contained to the walls of the physics building. Much research has been conducted outside of the university context. For the field and its insights to continue to grow it is vital that PER researchers conduct studies with young children, school-aged children, within adult education classes, and in informal and science communication settings. PER cannot be removed from the broader context of society; science and society are not separate but are deeply interlinked. Most of the learning opportunities that exist in the modern world do not take place in the classroom (Schugurensky, 2000). I will discuss more on informal learning towards the end of this chapter.

Just as PER studies more than university-level physics students, it also draws upon a vast well of literature in fields outside PER. PER is and has been from its inception an inherently interdisciplinary science, building up on ideas from education research, psychology, cognitive science, social studies, sociology, and other fields. At the heart of it, PER is also an applied science. It connects ideas from diverse fields, designing interventions, validating instruments, and conducting rigorous experiments, all with the goal of learning how to teach physics better. The approach is highly scientific and rigorous. A pioneers of PER, Joe Redish, stated that “We must treat the teaching of physics as a scientific problem” (Redish, 1994). This echoes John Dewey’s viewpoint, articulated half a century before Redish that “If you have doubts about how learning happens, engage in sustained inquiry: study, ponder, consider alternative possibilities and arrive at your belief grounded in evidence” (Reese, 2013). Arriving at beliefs grounded in evidence is what PER aims for.

Much of the field's theoretical foundations lie in works that predate the recognition of PER as an academic field. An example is the work of the psychologist Jean Piaget (Piaget, 2003) whose theory of cognitive development and his constructivist philosophy of education had a profound impact on the field (Von Glasersfeld, 1982). Another example is Lev Vygosty, a psychologist whose Zone of Proximal Development influenced the thinking of physics education researchers significantly (Vygotsky et al., 1994). Furthermore, the work of Joseph Schwab (Schwab, 1958, 1969, 1983), an educationalist who not only paved the way for what is now referred to as inquiry based learning but also highlighted the importance of the social context in education also influenced the thinking of physics education researchers significantly. Teaching and learning does not occur in a vacuum and societal influences must be taken into account. More recently PER has been influenced by the works of Kahneman and Tversky (Kahneman and Tversky, 1973, 1982, 1984), an economist and cognitive scientist. They are founders of a field now known as behavioural economics, and their Dual Process Theory has become increasingly influential in PER. Another example, which is highly relevant to this research, is the work of psychologists Allan Paivio and Richard Mayer, whose research on cognition led Paivio to develop dual-coding theory. This then led Mayer to apply and expand the theory within his research on effective educational multimedia (Paivio, 1990; Mayer and Moreno, 1998; Mayer, 2005). Without these and many other researchers outside the field of PER, the field would be impoverished. PER's interdisciplinary nature is a strength.

There are concepts which are integral and implicitly to PER but are not explicitly addressed or deeply researched. One such implicit concept is reflection. Reflection is present within and related to many important theories in physics education research, yet it is rarely explicitly addressed or studied. Reflection is present within the work of Piaget on cognitive conflict. This is an essential part of many curricula (Mischel, 1971). The concept influenced Kahneman and Tversky's dual process theory, in which System 1 is fast, automatic, involuntary, and relies on heuristics and rules of thumb, and System 2 which is slower, methodical, and requires deliberate

concentration. While Kahneman and Tversky do not explicitly discuss reflection, the error-checking element of two system thinking relies on reflective thinking. Reflection is also implicitly present in the study of metacognition in physics education. It explores how students think about their own learning. It is also present in work on sense-making, and on problem solving. Cognitive conflict, dual-process theory, metacognition, sense-making and problem solving are not equivalent to reflection. These theories, which are central in the canon of PER, rely on reflection. Yet, despite its importance, reflection is rarely addressed directly or studied within the field.

An extensive and growing volume of literature exists on the topic of multimedia learning, starting with the foundation work of Paivio (Paivio, 1990). The study of multimedia learning has become a staple in PER in part due to the psychologist Richard Mayer's profound influence and impact on the field. Studying how students learn through multimedia and how to create effective multimedia has grown in importance as technological progress has made educational multimedia content more accessible and ubiquitous. The value of this research has increased further during and after the COVID-19 pandemic and the rapid proliferation of online learning precipitated by social-distancing measures. Yet the vast majority of the literature focuses on using multimedia to augment student learning, conceptual understanding, or procedural skills. There is a gap in the study of the effect of multimedia interventions on the meta-cognitive aspects of learning, such as reflection. The lessons learned from the study of effective educational multimedia have been considered in the selection, curation, and creation of the multimedia treatments for the three studies. However, to select and create videos which could encourage student reflection literature from outside of PER was necessary.

2.1.1 Education Research on Mechanics and Electricity: Staples of the Genre

As noted in the earlier section, one of the advantages of physicists doing PER is their familiarity with the subject matter. Some of the most frequently studied topics in PER are Mechanics and Electricity and Circuits. These are staples of the genre. In both of these physics topics, there is extensive literature on what students find challenging, the alternative concepts that students develop, and how to most effectively teach these topics. These topics were selected for the three studies within the thesis.

Mechanics has been a staple of physics education research since the inception of the field (Leboutet-Barrell, 1976). It is a foundational area of physics and is typically the first topic taught in first year university-level physics. The concepts covered in mechanics are vital to the remainder of a student's physics learning journey. It is so foundational that it is taught in high school and earlier and also permeates the informal learning space (Gustafsson, 2013). It is also an area in which students struggle with concepts and frequently develop alternate conceptions of the subject matter (Van Hise, 1988). The number of students who enter first year university with alternative views that are incongruous with a scientific understanding is high, as measured by tests such as the Force and Motion Conceptual Evaluation (FMCE) and the Force Concept Inventory (FCI) (Thornton et al., 2009; Savinainen and Scott, 2002; Lampara, 2022). Although it may seem intuitive to people with a rich physics background, there are many concepts in mechanics which are strange and counterintuitive to novice learners. Perhaps due to a combination of these reasons, mechanics has received significant focus in PER. Decades worth of literature considers what does and doesn't work when it comes to teaching mechanics (Brown and Clement, 1992; Freudenthal, 1993) as well as robust measurement tools, such as the FCI and FMCE. There is also extensive literature on the alternative understandings of mechanics held by students (Van Hise, 1988; Brown and Clement, 1987; Self et al.,

2008; Van Hise, 1988), and innovative teaching techniques such as Interactive Lecture Demonstrations (ILDs) to address them (Sokoloff and Thornton, 1997; Sharma et al., 2010).

Studies in multimedia learning have frequently utilized mechanics as the testing ground for the reasons mentioned above. In addition the teaching of mechanics is well suited to multimedia treatments (Muller et al., 2007). Mechanics and especially kinematics are among most visual parts of physics; they are easy to illustrate, animate, and film. It is much easier to make a video of a basketball flying through the air, than to show how a hot metal bar cools down and transfers heat to a cooler metal bar. There are also fewer abstractions in mechanics; if a basketball is used in a demonstration, this is an object students have direct experience with. By comparison, electrons or quarks are much harder for students to conceptualize. There is a close correspondence between the animated concept and the physics phenomena being explained. There are dozens of studies which explore mechanics instruction through multimedia treatments (Holzer and Andruet, 2000, 1999; Li and Lee, 1999; Sadaghiani, 2012; Yu et al., 2005; Mayer, 2005). The multimedia treatments include animation (Muller et al., 2007), demonstrations (Sokoloff, 2022), simulations (Wieman et al., 2008; Perkins et al., 2006), and more recently Virtual (VR) and Augmented Reality (AR) experiences (Grivokostopoulou et al., 2017). Multimedia learning and mechanics are so deeply intertwined with PER, that the SUPER group chose a ball tracing out a parabolic arc through the air as its logo.

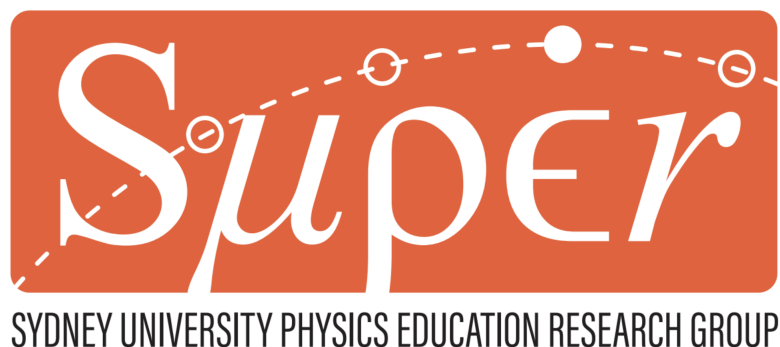


Figure 2.1: Within the SUPER Group logo a ball traces a parabolic arc through the air

Mechanics content is covered in supplemental learning materials available on the internet, such as CrashCourse and Kahn Academy. CrashCourse Physics, which is tied to the American College AP1, an algebra-based introductory physics curriculum, has a 47 part series of videos on physics. The first 13 of these videos cover mechanics, from motion, forces, and vectors to Newton's laws. Once again, the appeal is clear; mechanics fits perfectly into the medium that accommodates moving images.

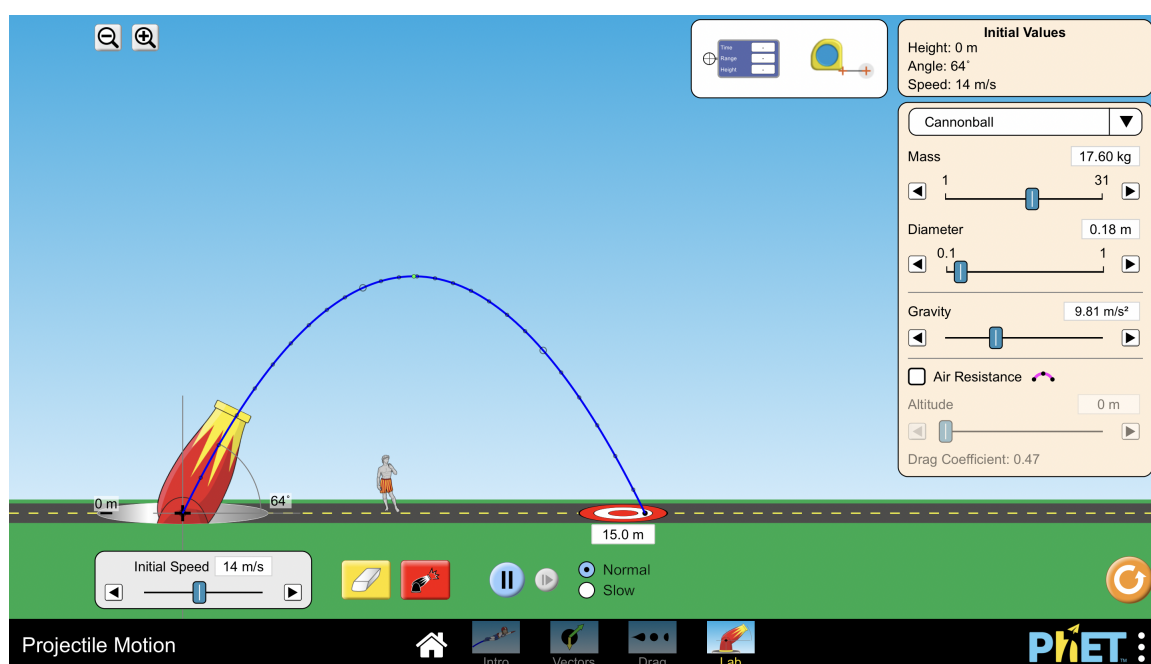


Figure 2.2: A screenshot of a PhET interactive mechanics simulation

Mechanics is also a popular topic of informal learning and science communication videos on YouTube. A few popular videos include SmarterEveryDay's series of video on the mechanics of helicopters, PhysicsGirl's videos about Newton's cannon and the intermediate axis theorem, and Veritasium's videos about misconceptions about falling objects. These kinds of videos and demonstrations are also mainstays of science communication shows, and have appeared on TV programs such as "Bill Nye the Science Guy" in the 1990s, Julius Sumner Miller's "Why Is That So" in the 60s and 70s, and the PBS show "Thank You Mr Wizard" in the 1950s. Mechanics is a mainstay topic in multimedia science communication.

A potential reason for the popularity of mechanics in both formal and informal multimedia teaching is because of how visual it is. As media scholars have noted, the medium through which something is communicated affects the message, or as Marshall McLuhan famously put it in 1964 "The medium is the message" (McLuhan, 1964). Mechanics, and especially kinematics, are well suited for multimedia treatments. The visual medium enables the motion of a ball flying through the air in a parabolic arc to be illustrated. Movies are, after all, moving pictures and some of the earliest and most iconic films from early cinema documented a galloping horse and a speeding train.

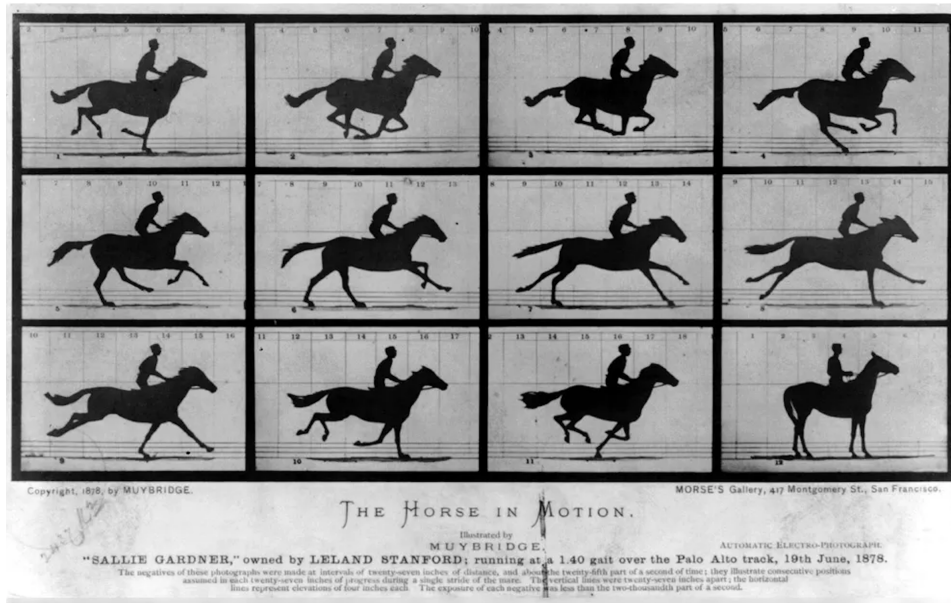


Figure 2.3: One of the earliest motion pictures: The Horse in Motion (Muybridge, 1882)

Electricity and Circuits

The other topic chosen for study was electricity and circuits. Electricity and circuits are also a foundational part of many physics curricula. It is frequently taught in many university level courses in the first year of undergraduate study. At the University of Sydney where the research was conducted, the topic constitutes a large part of the laboratory component of the first year, second semester physics courses. This topic was partially chosen for logistical reasons; the intervention had to be on the same topic as coursework. There were also robust theoretical reasons to create multimedia interventions focusing on electricity and circuits.

Like mechanics, there is much literature on the alternative understandings of students regarding electricity and electrical circuits and measures educators can take to adequately address them (Andre and Ding, 1991; Sencar and Eryilmaz, 2004; Franklin, 1992; Hermita et al., 2017; Saxena, 1992; Raduta, 2005). There is also a substantial body of literature on the use of multimedia interventions to teach electricity, magnetism, and circuits, and concerning which strategies are more effective (Adrian, 1997; Sadaghiani, 2011; Dbowska et al., 2013; Stelzer et al., 2010).

Unlike mechanics, this topic has a higher level of abstraction; students can't see electrons vibrating near the edges of a coil of wire creating excitations in electromagnetic (EM) fields in a way that they can see a ball flying through the air. As a result, visualizations and multimedia treatments must typically use representations of topics at hand. While mechanics seems ideal for the visual medium, one could argue that electricity is not; essential information about this topic cannot be seen directly with human eyes. It is the job of the educator to create effective representations of these concepts; field lines to represent magnetic fields, or yellow balls to represent electrons flowing through a closed circuit, or even measuring devices such as voltmeters. This creates an interesting contrast with mechanics.

Mechanics and electricity are represented very differently in multimedia interactive simulations. The simulations in question were created by the PhET at the University of Colorado Boulder, yet the differences are stark. The mechanics simulation (see Figure 2.2) includes a demo with very little abstraction; a cannon ball flies in a parabolic arc. The tool allows the user to toggle the force vectors on and off and shows the vertical and horizontal velocities of the ball. However, even these slightly more abstract features are close to real life. By contrast the electricity interactive simulation (see Figure 2.4), which focuses on the workings of a capacitor, is far more abstract than the mechanics simulation. The simulation includes wires, a battery, and a capacitor which the students are familiar with. However, the magnitude of current flowing across the dielectric is represented through the density of arrows. Additionally, to represent current and voltage, a simulacrum of a multimeter is shown. When compared to the attributes the students must observe in the mechanics simulation (height, horizontal velocity, and vertical velocity), the attributes the students must observe in the electricity simulation (voltage, current, and current density) are far more abstract. This abstraction is a large part of why the topic of electricity and circuits was chosen as it provides an ideal test case. If an intervention is effective in the context of mechanics, it may not also be effective in the instruction of electricity and circuits. It is unclear whether students would respond differently

to similarly constructed multimedia treatments across these two topics and whether the type of reflection students engaged in would be similar in these distinct topics.

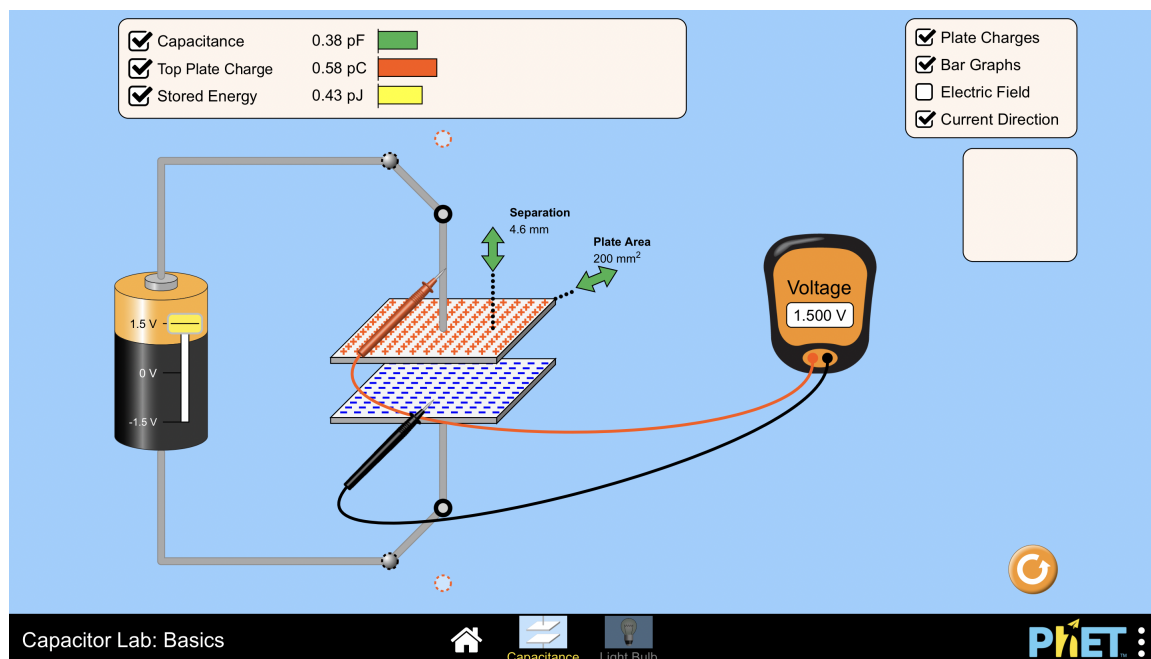


Figure 2.4: A screenshot of a PhET interactive simulation on capacitance. Positive and negative charge build-up is visible across the plates, represented with higher or lower numbers of positive and negative symbols per unit area

During script writing, the *no clues* and *good clues* were straightforward. The *no clues* group simply contained the question, and the *good clues* group contained hints that guided the students towards the correct solution. This drew attention to the metal glove, tin-foil hat, grounding wire, and the salinity of the water in the pool. We hoped that these clues were good and obvious enough to guide people to be thinking about the resistances of the various components of this “circuit”. The script for the *bad clues* was more complicated. It was important to that the bad clues given were believable and related to common misconceptions about circuits. One such misconception is that “it’s the current that kills, not the voltage” (Saxena, 1992; Peşman and Eryılmaz, 2010). While this statement is vaguely “true enough”, it makes the mistake of de-coupling current from voltage. Current, voltage, and resistance are all linked via Ohm’s law ($V=IR$). By providing a clue that misleads

the students by priming them to focus on the fact that Tesla coils produce very high voltage, but relatively low current, we were hoping that this would distract and confuse the students in the *bad clues* group.

It is also worth noting that in reality, the answer to why the man in the swimming pool does not get electrocuted by the Tesla coil is more complicated than simply being much more resistive than the salty water or the metal. The other big contributing factor is the high frequency produced by the Tesla coil, and the skin effect. As is often the case in physics education, the real picture of the world is more nuanced and complicated than something that can be summed up in a short video. This is the reason that in my research I attempted not to use the terms such as “correct”, “incorrect”, “right”, and “wrong”, instead choosing to use words “matched”, and “not matched”. These words do not give a value judgement on the students answer, just simply note if the answers did, or did not match the solution provided.

2.2 Multimedia Learning

Multimedia tools have been used since the dawn of humankind. A loose definition of multimedia is that “multimedia is when two or more content forms are used in conjunction” (Mayer, 2005). According to this definition, theatre is a form of multimedia; it combines the visual spectacle of the actors on stage and the auditory and narrative performances of the actors saying their lines. A concert with a light show is also a form of multimedia; it combines the audio from the music and the visuals of the lights. A book with pictures or diagrams is multimedia, as are films, interactive webpages, video games, and virtual reality. Multimedia is a tool that can be used to achieve a variety of goals. This thesis focuses on the use of multimedia as a tool for education.

A definition from Tay Vaughan’s 1993 book notes that “Multimedia is any combination of text, graphic art, sound, animation, and video that is delivered by com-

puter. When you allow the user – the viewer of the project – to control what and when these elements are delivered, it is interactive multimedia” (Vaughan, 1993). Within this thesis the term *multimedia* is used to refer to video, which is the medium of focus within the thesis. Some lessons can be universally applied to other forms of multimedia, which will be covered later in this chapter. The majority of this literature review will focus on linear educational multimedia, which is educational video. Vaughan’s definition of multimedia, which emphasizes the use of computers to deliver content is disregarded within this thesis, although computers were used to distribute the multimedia. While much of the work on educational multimedia did indeed occur after the revolution of personal computers, multimedia advancements and research predate this, as discussed in the next section.

2.2.1 Multimedia: Educational from the Beginning

Following the onset of photography came the slide projector; with which photographs and drawings were projected through a lens onto a screen. Soon after the onset of photography, inventors realized that by projecting a series of photographs one after the other it was possible to create the illusion of motion. Video clearly had the potential to revolutionize education. The first educational films emerged in the early 1900s; Thomas Edison claimed that motion pictures would replace textbooks in classrooms and revolutionize education (Oppenheimer, 2003). Clearly textbooks remain an important element of classrooms, but educational multimedia has played a growing role in education in the recent decades. The advent of educational multimedia technologies has profoundly affected both the formal, and informal educational landscape (Vaughan, 1993). Yet, there are cases where advances in educational technology do not lead to positive outcomes in student learning; this multimedia must be firmly rooted in effective pedagogy. With new educational technologies, it is important for high quality research to be conducted in representative settings to determine if it is indeed an improvement over old methods of teaching. Over the

last half century an impressive collection of literature has accumulated on a variety of educational multimedia.

In the next section some of the multimedia learning literature that is relevant to this research is described.

2.2.2 Interactive vs Linear Multimedia

A variety of learning technologies are available and used, ranging from interactive simulations, short linear videos and gaming, to virtual reality (Wieman et al., 2008; Perkins et al., 2006; Vaughan, 1993). In science education, multimedia offerings with elaborate forms of interactivity and feedback loops are used in formal settings to prompt reflective thinking with the intention of guiding a learners' understandings such that it is more congruent with current scientific understandings (Coller and Scott, 2009; Crook et al., 2015; Stieff, 2005; Wieman et al., 2008).

Contrary to the expectation that such interactive multimedia would dominate formal learning, linear videos in the form of lecture recordings (Yeung et al., 2016), video slices with classroom-based learning cycles (Mayo et al., 2009), and social media sites sharing short videos are tremendously popular (Rosenthal, 2018; Tan and Pearce, 2011). Some YouTube channels such as “CrashCourse” and “Khan Academy” support formal learning as they cover similar content as curricula (Gray et al., 2017). Although there is some evidence that some teachers are not adept at determining which videos are appropriate for classroom use, it is also common for teachers to using carefully selected videos from other channels such as SmarterEveryDay, MinutePhysics, PhysicsGirl, and Veritasium as added support for the curriculum content (Crook).

Each learning technology has its own advantages and challenges. Whilst technologies with feedback loops and interactivity can place the learner in control, prompting reflective thinking (as substantiated by substantive research (Coller and Scott, 2009; Stieff, 2005; Wieman et al., 2008)), the linearity of videos is aa limi-

tation. Films and documentaries (which are types of educational video) have been used for both formal and informal learning for nearly a century. The forms of linear videos which are becoming most ubiquitous and standard in the adult education arena are lecture recordings and Massive Open Online Courses (Gosper et al., 2013). While there are some disadvantages to lecture recordings in supporting learning, they provide easy access and connectivity to students that may not otherwise be able to access the lectures. They also allow students to review the content, coming back to rewatch earlier lectures (Yeung et al., 2016). In discussing mobile mixed technologies, Sinfield (2018) argues that “learning is a lifelong experience ... pedagogy is applied to communities and not just institutions; thus, ... part of this pedagogy becomes greater than the education system within tertiary institutions”. Linear video in its various forms are part of the pedagogy of learning in the lifelong learning endeavour beyond formal institutions (Knox and Bayne, 2013). Tan and Pearce (2011) investigate free educational resources for use within their own course, including carefully selected YouTube videos. They found YouTube videos practical and reported that most learners found them worthwhile and interesting. The connectivity between students and the wider world is captured through “real world examples”. For example, Marçal et al. (2018) use short animated videos, whilst Mayo et al. (2009) use video slices. Such examples capture Dewey’s pragmatic conception of learning as a social activity Dewey (1923). While YouTube videos bring “real world examples” into formal learning contexts, the pedagogy of formal learning can permeate informal learning, connecting and structuring formal and informal learning. In the spirit of lifelong learning, pedagogy becomes greater than the education system (Knox and Bayne, 2013; Sinfield, 2018). Within science education, examples of YouTube creators include SmarterEveryDay, PhysicsGirl, MinutePhysics, and Veritasium.

Most educational videos on YouTube feature direct instruction (Jones and Cuthrell, 2011), with little incorporation of feedback loops which could registering audience responses or interactivity. This is partially due to the nature of the medium; while

it is possible to skip back and rewind a video, YouTube does not include inbuilt interactive capabilities such as multiple-choice quizzes (Guo et al., 2014b). Yet when refutation, dialogue, and Socratic dialogue are included as a guiding pedagogical framework, there is an uptick in the conceptual learning gains of students (Muller et al., 2007). Therefore, it's possible to include a form of “interactivity” even in linear multimedia. Some creators have taken this one step further by asking a question and encouraging viewers to write down their answers in one video, and then providing the solutions in another. This interactivity provides time for reflective thinking. As noted by Dewey, reflective thinking is also facilitated by a community which functions as a group of like-minded others. This can be achieved in the comments section of a social media website like YouTube (Lee, 2023).

2.2.3 Multimedia and Informal Learning

Documentary films primarily made for public audiences are examples of multimedia in the informal educational context, including from documentaries produced by the BBC's Natural History Unit in the late 1950s, to Carl Sagan's *Cosmos* in the 1980s, to “Bill Nye the Science Guy” in the '90s. As video-encoding technology moved from tape, to DVD, to digital file formats, videos became more accessible. Importantly, it was not just the distribution of video that became more accessible, but also its production. The cost of personal video cameras has gone down and the image quality has drastically increased. Due to the ubiquity of smartphones, everyone can create high-quality looking and sounding multimedia.

Rosenthal (2018) summarizes the behaviour of viewers who engage informally with science-based learning technologies as planned. According to Rosenthal, viewers engage with YouTube videos for several reasons: they perceive their engagement as worthwhile as it satisfies a need; their engagement is enjoyable and they do so out of self-interest; or they engage to gather knowledge. These reasons motivate individuals to engage in the behaviour of seeking out or following the YouTuber,

potentially leading to reflection and responding to messages. Such behaviour is found in adult informal education on topics ranging from immunization, to patient information and parent driven campaigns, to sustainable agriculture (Bentley et al., 2019; Carter et al., 2018; Covolo et al., 2017; Pithadia et al., 2019). Given that YouTube videos used in informal learning can lead to reflection and action, it is important to understand viewer responses.

Many education researchers argue that learning is a social activity (Schwab, 1958; Hausfather, 1996; Dewey, 1923). Furthermore, learning management sites have resources for some degree of student-lecturer or student-student interactivity. Being a social media platform, YouTube offers connectivity among like-minded individuals enabling learning as a social activity. There is also interaction between creators and followers, often but not always cultivating a form of community (Rotman and Preece, 2010). Educational channels on YouTube are exceedingly popular, which supports Rosenthal's assertions; the viewers gain something valuable from watching and subscribing to these channels. The largest educational channels attract tens of millions of subscribers and some videos have garnered hundreds of millions of views. There are many reasons why people watch YouTube videos. Rosenthal notes that some individuals seek YouTube videos in line with their motivators, and by following and subscribing they converge on and reinforce their motivators. The behaviour of seeking or following whilst aware of like-minded others who are socially connected via the channel can lead to reflection and responding to messages. Although the use of pedagogically sound, short, linear videos on YouTube as a form of learning has increased in popularity over the last 10 years, research into their efficacy as educational tools is limited and under-researched. Given the importance of reflection and the impact of linear multimedia content in classroom and informal settings (Dabbagh and Kitsantas, 2012), it is worth researching how to encourage reflective thinking among the viewers of linear multimedia content.

2.2.4 Multimedia: Principles and Craft

One of the giants in the multimedia learning sphere is Richard Mayer. Over the course of his career he has outlined multimedia learning principles; these are guidelines which have demonstrated efficacy. 24 of these multimedia principles are covered in the highly influential Cambridge Handbook of Multimedia Learning (Mayer, 2005). Not all these principles are relevant to the research project at hand, and they will not all be listed, but these principles are a solid foundation on which to base the design of educational multimedia. If an educational video breaks these guidelines, this should be done mindfully and there should be a valid pedagogical reason for doing so. Some of the principles that are most relevant to the design of the videos in this research project include:

- The Coherence Principle: Humans learn best when extraneous, distraction material is not included.
- The Signalling Principle: Humans learn best when they are shown where they should place their attention on the screen, for example, by highlighting, emphasizing, or drawing a bright red circle around what the student should focus on.
- The Redundancy Principle: Humans learn best with graphics and narration, rather than graphics, narration, and text. This following from cognitive load theory and dual-processing theory.
- The Temporal Contiguity Principle: Humans learn best when the audio and visuals are presented simultaneously, rather than with a time-delay.
- The Spatial Contiguity Principle: Humans learn best when the text and visuals are presented closely together.

These multimedia principles are mainly based in cognitive load theory (Sweller, 2010) and dual-process theory (Wixted, 2007). They have been extensively studied as good guiding principles for crafting effective educational multimedia.

Yet there is evidence that shows that contradicting some of these principles can still lead to effective educational multimedia. Much of what Mayer has distilled can be thought of as principles for “crafting educational multimedia”. One must also select and carefully implement pedagogy. Breaking the multimedia principles is not necessarily a bad thing; there must only be a valid reason for doing so. An example of this appears in the work of Muller and Sharma (Muller et al., 2008). In their study, carefully adding “redundant” information related to common student misconceptions actually improved student conceptual understanding. During a number of experiments, students were given pre-tests to check their prior knowledge and were then they were split into groups for viewing multimedia interventions which used various pedagogical techniques. Later, they were given a post-test to assess learning gains. The pedagogical techniques compared exposition (in which the presenter explains the relevant concepts), Socratic dialogue (in which two students discuss the concept and raise various misconceptions), and refutation (in which common misconceptions were explicitly addressed and then refuted). The two treatments containing misconceptions (refutation and dialogue) lead to higher mean gains. Contrary to Mayer’s principles, the extraneous material lead to increased gains in student understanding.

Another vital consideration is the craft of film making. Humans are visual creatures and are sensitive to subtle cues from their environments (Tetlan and Marschalek, 2016; Barcelo et al., 2000). Due to the ubiquity of multimedia, the audiences of both formal and informal educational content are more sensitive than ever to craft (Montero Sánchez, 2021). Students in particular have become incidental connoisseurs of multimedia having grown up in a world where both the consumption and the creation of multimedia (primarily short-form video content) is ubiquitous (Montero Sánchez, 2021). This has necessitated the need for high-quality videos to be selected and created for these studies. The videos must be in focus, well composed, well lit, and well edited. There are important considerations to the creation of high quality multimedia like proper framing, leaving appropriate

headroom, utilizing the rule of thirds, and understanding how various lighting set-ups, and colour-grading are interpreted by the audience (Brown, 2016; Deren, 1960; Wheeler, 2012). While there is extensive literature on these topics, the technical considerations are best discussed in specific detail; hence a more in-depth discussion of this is presented in Chapter 4.

2.3 Reflection

2.3.1 From Critical Thinking to Reflection

Initially, this research was intended to explore critical thinking. Critical thinking may appear essential to physics education and to science communication. Related research may consider the critical thinking abilities of students at an undergraduate level, the changes in these abilities over a tertiary education, measuring competency in determining the validity of sources, or discerning between the content of an article published in a respectable journal or a predatory journal.

As noted by Stassen et al. (2011) “While there is general agreement that critical thinking is important, there is less consensus, and often lack of clarity, about what exactly constitutes critical thinking. For example, in a California study, only 19 percent of faculty could give a clear explanation of critical thinking even though the vast majority (89 %) indicated that they emphasize it” (Paul et al., 1997). The study is more than two decades old yet this problem persists. Countless studies in recent years attempt to define critical thinking and yet there is no universally accepted and rigorous definition. For example, a highly cited figure in the field of critical thinking, Ennis (1989, 1964), argues that “critical thinking is the correct assessing of statements”. It is unclear what “correctly assessing” means. There are many ways to be a critical thinker, and not be able to correctly assess a solution to a problem. All available definitions are either too broad or too vague to be useful in constructing rigorous experiments. This ambiguity may stem from the fact that

critical thinking is not one isolated skill or one method of thinking, and that it must apply to many situations and is inherently multifaceted Barnaby (2016); Williams et al. (2001); McBride (1991)

A more narrowly defined concept which is closely associated with critical thinking is reflection. The study of reflection or reflective thinking (both terms will be used interchangeably for the remainder of this thesis) provided a more suitable and narrow scope. While it is still non-trivial to pin down the definition of reflection, it is less nebulously defined in the literature. Despite it being more manageable to work with, it is no less compelling than the notion of critical thinking. Reflective thinking is an integral part of education and of being human. Great thinkers from many diverse secular, religious, philosophical and pedagogical schools of thought, agree on the importance of reflection. Reflection on one's actions allows one to learn and become more proficient in domains of knowledge. It also allows one to become a better person. It allows one to adjust previously held ideas when faced with new information. The neuroscientist and philosopher Daniel Dennett even notes that "consciousness is an intellectual illusion created by us because we're so reflective" (Dennett, 2018). This thesis concerns reflection as applied to pedagogy. Even without the meta-cognitive benefits of developing reflective thinking in students, deliberate practice to increase reflective thinking the academic context has demonstrated importance. In 2011, Lew and Schmidt conducted a study of 690 first-year applied science students, in which there was a link between self-reflection and improvements in academic performance (Lew and Schmidt, 2011).

2.3.2 Defining Reflection

This section discusses some of the common definitions of and concepts surrounding reflection. After noting some of the similarities and differences in the way that reflection is commonly defined in the literature, a working definition will be identified by the end of the section. Different scholars have conceptualized this topic in varying

ways some of which are applicable to this research project, namely, that apply to reflection in response to multimedia physics education.

Boud et al. (2013) describes reflection as “...a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to a new understanding and appreciation” while Boyd and Fales (1983) describe it as a “process of internally examining and exploring an issue of concern, triggered by an experience, which creates and clarifies meaning in terms of self and which results in a changed conceptual perspective”.

While there are varying definitions of reflection, they converge on a few important ideas. Reflection requires an experience of something that is potentially startling or confusing. Reflection requires the interpretation of an experience. Reflection is an active process, requiring the active participation of the person reflecting; there is no way to be passively reflecting. Some researchers also note that reflection can, but does not need to, occur in a community, for example discussing ideas with peers, colleagues, and mentors can help to facilitate reflection Rogers (2001).

Many researchers note that reflection is non linear; it is an organic, evolving,, and self-referential process. Rogers (2001) notes that “the process of reflection does not always have a defined beginning and end. Thus, it should be viewed as continuous, much like an ever-expanding spiral in which challenging situations lead to reflection and ultimately to new interpretations or understanding. These new understandings may then lead to new challenges and additional reflection.”

The organic and self-referential process of reflection and the lack of a precise, universally agreed upon definition, makes the study of reflection challenging. Yet the framework of John Dewey, one of the first scholars of reflection in the educational context, provides some clarity.

2.3.3 John Dewey and Reflection

There are several reasons why Dewey's framing of reflection was chosen for this study. He was one of the earliest educationalists (rather than philosophers) to focus on reflection. Another is that his attitude towards reflection emerged from scientific study rather than philosophical or metaphysical thought or reasoning, and his framework is highly practical. Dewey's framework for reflective thinking would be instructive in other contexts, however it is in context of science education that it serves best. As noted by Mann et al. (2009), Dewey's definition of reflection shares similarities with critical thinking.

In his foundational 1933 book "How we Think" (Dewey, 1933), Dewey explores several modes of thought, including imagination, belief, stream of consciousness, and reflection. Dewey notes four important features of reflective thinking.

1. Reflection is a meaning-making process that moves a learner from one experience into the next with deeper understanding of their relationships with and connections to other experiences and ideas. It is the thread that makes continuity of learning possible and ensures the progress of the individual and ultimately society. It is a means to moral ends.
2. Reflection is a systematic, rigorous, and disciplined way of thinking with its roots in scientific inquiry.
3. Reflection can occur in a community, in interaction with others.
4. Reflection requires attitudes that value the intellectual growth of the self.

While Dewey was used as a primary source, this research also relies on insights from Carol Rodgers (2002). Rodgers refined and clarified many of Dewey's concepts. In much of Dewey's work, his ideas about education, society, and democracy intersect and interact. Even in discussing reflection, these ideas are related to concepts of morality and societal progress. While many prefer to believe that physics teaching and learning is conducted for "essentially moral ends" and for the "progress of society", this is outside of the scope of this thesis. Rogers' interpretation of Dewey

clarifies reflection within the educational context. As such, this thesis discusses parts of Dewey which are relevant to teaching and learning physics effectively.

There are several salient ideas within the writing. Among these is the idea that reflection is a process beginning with an experience or an event that triggers the process of reflection.

Dewey's framing of reflection resembles the scientific method; a learner is faced with a perplexing experience and methodically attempts to understand, ramify, and explain that experience. Dewey notes various "sub-processes" which are involved in reflection. As noted by Rogers, these sub-processes are present in the writing but are not listed all together. Out of Dewey's writing, Rogers identified 6 phases of reflection:

1. An experience
2. A spontaneous interpretation of the experience
3. Naming of the problem or question that arises from that experience
4. Generating possible explanations for the problem or questions posed
5. Ramifying the questions into a hypothesis
6. Experimenting or testing the hypothesis

This collection of phases is useful in researching reflection. It also allows one to find and to create educational multimedia that guides students through these phases.

Dewey outlines reflective thinking as a meaning-making process that moves a learner from one experience into the next with a deeper understanding of relationships; providing a thread that makes continuity of learning possible. It is a disciplined way of thinking, requiring attitudes that value the personal and intellectual growth of oneself and of others. It is interesting to note that the notion of thinking is retained. It is framed as an intentional process that can be learned and consciously practised. Given that reflection can be learned, it can be taught (in the

sense that learning contexts can be created for reflection to be learned (Hubbs and Brand, 2005)). Such learning contexts would, according to Rodgers (2002), have different phases of reflective thinking.

Most researchers concede that reflection is a complex, self-referential and organic process Rogers (2001). To study reflection, these phases of reflective thinking can be used (Rodgers, 2002; Dewey, 1933). The complexity of reflective thinking emerges in the taxonomy proposed by Mezirow (1998). Mezirow's research which shows that adult learners (such as university students) exhibit different types of reflection. Pertinent to this study are Mezirow's overarching types of outward-focusing and inward-focusing reflection. In outward-focusing reflection, learners are intent on reconciling their answers with discipline content and tools, while in inward focusing, they are intent on reconciling their answers with their own learning and actions (Lebedev and Sharma, 2019). The process allows learners to re-calibrate their learning (Sharma and Bewes, 2011).

2.3.4 Types of Reflection

Scholars of reflection also note that there are different types of reflection (Boud et al., 2013; Chang, 2019; Korthagen, 1993; Zahavi, 2011; Hubbs and Brand, 2005; Mezirow et al., 1990). Jack Mezirow proposed a useful framework for understanding the types of student reflection (Mezirow et al., 1990; Mezirow, 1998, 1997b). Mezirow's research focuses on adult learning and articulates different kinds of reflection (Mezirow, 1990, 1991, 1997a, 2000; Taylor, 2007). There are similarities between the work of John Dewey and Mezirow and Mezirow expanded upon the work of Dewey. Both approach education with pragmatism and both focus on the importance of experiential learning. Mezirow highlights reflection as a vital skill for learning beyond the classroom, arguing that reflection triggers transformative learning, that can alter the course of lives by those who undergo it (Mezirow, 1990).

The details of Mezirow's taxonomy of reflection is further elaborated in Chapters

3, 5, 6, and 7, where the methodology for the data analysis is presented in detail. Mezirow's taxonomy of reflection is broad; it includes reflection on individual level and on the systemic or organizational level. Reflection is also categorized according to the impact it has on a learner (for reasons that will become clear as the methodology of this research is presented). This element of the taxonomy is not useful for the purposes of this study. Yet, Mezirow's classification of individual reflection, focusing on the kind of reflection an adult learner could be experiencing, was vital. Briefly, Mezirow discusses the reflection on the content, the process, premise, and the context.

- **Content Reflection:** This involves reflecting on the content of one's learning experience, including the facts, information, and concepts encountered. Content reflection focuses on what was learned and its significance.
- **Process Reflection:** Process reflection involves examining the process of learning itself. This includes considering how one learns, the strategies used, and the effectiveness of those strategies. Process reflection encourages individuals to evaluate their learning methods and adapt them as necessary.
- **Premise Reflection:** Premise reflection entails critically examining the underlying assumptions and beliefs that shape one's perspectives and actions. It involves questioning the validity and origins of these assumptions, as well as considering alternative viewpoints.
- **Context Reflection:** Context reflection involves considering the broader contextual factors that influence one's learning experiences and perspectives. This includes examining social, cultural, historical, and situational factors that shape how individuals perceive and interpret information.

This taxonomy is mirrored in the work of Hubbs and Brand, in their publication "The Paper Mirror: Understanding Reflective Journaling". They focus on the use of journaling to facilitate student reflection. One of the ways they propose to assess student reflection is through a 2x2 grid (see Figure 2.5). Reflection is assessed

according to two dimensions: whether it is shallow or deep, and whether it is content or process focused. This echoes Mezirow's ideas which breaks down reflection into critical and uncritical (corresponding to deep and shallow), and process or the content (corresponding to inward-focused and outward-focused reflection).

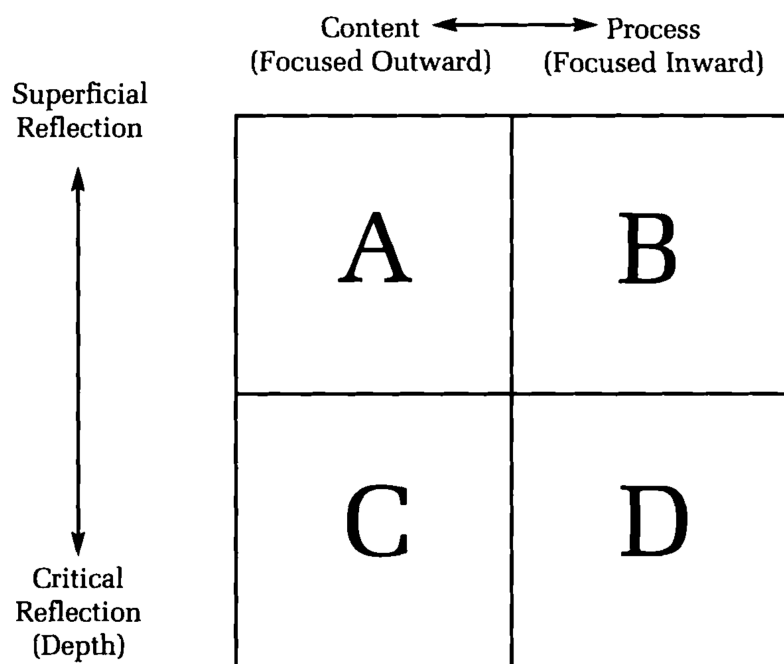


Figure 2.5: A 2×2 grid of the types of reflection, as presented by Hubbs and Brand (2005)

These taxonomies and ways of looking at reflection emerged organically as the studies were conducted. They are described in more detail in the chapters concerning the three studies.

2.4 Informal Learning

This final section of this chapter, includes a brief note on informal learning. According to Livingstone (2001), informal learning is learning that occurs outside of a formal educational institution or setting. It is frequently self-directed, learner-initiated, and often driven by an individual's interest or immediate needs (Living-

stone, 2001). Under this definition, informal learning can occur through everyday experience, travel, participating in sports, visiting museums and science centres, joining community clubs, and playing video games are considered informal learning (Falk and Dierking, 2010; Ito et al., 2013; Stebbins, 2007; Eraut, 2004; Gee, 2003). Informal learning can and does happen in a large variety of contexts. Of relevance, is that informal learning is facilitated by the internet, social media networks, and multimedia platforms such as YouTube.

As new communication technologies have developed so has their use in supporting informal learning. The definition of informal learning is very broad and elements relevant to the thesis will be highlighted. The rapid evolution of digital multimedia technologies has transformed the landscape of informal learning, presenting a vast array of opportunities for learners of all ages. Platforms like YouTube have become a hub for educational content, with countless channels dedicated to topics ranging from physics to economics, enabling users to access knowledge at their own pace (Burgess and Green, 2018). Similarly, Massive Open Online Courses (MOOCs) have allowed access to college-level courses from renowned institutions such as MIT, offering flexible learning experiences outside the traditional classroom to everyone with interest in the topics (Pappano, 2012). Furthermore, documentary films (distributed platforms like Netflix and BBC) have elevated public understanding of complex issues, blending compelling storytelling with factual information to foster a deeper appreciation and awareness of various subjects (Aufderheide, 2007). Collectively, these multimedia platforms have expanded the horizons of informal learning, making education more accessible and diverse than ever before.

Social media platforms have become powerful arenas for collaborative, informal learning, fostering rich dialogue and knowledge exchanges among users worldwide. These platforms (including Twitter, Facebook, and LinkedIn) enable professionals, enthusiasts, and curious minds to converge, share insights, and pose questions on diverse topics, from academic research to everyday challenges (Greenhow et al., 2016). The immediacy and interactivity of these platforms allow for real-time feedback and

iterative learning, amplifying understanding through communal information sharing and thinking (Veletsianos and Kimmons, 2016). Moreover, the participatory nature of social media encourages users to co-create content, collaboratively refine ideas, and construct knowledge in a fluid, dynamic manner (Jenkins et al., 2006). The decentralized, user-driven nature of social media thus imbues informal learning with a unique collaborative essence, reshaping how knowledge is disseminated and acquired in the digital age.

YouTube has become a pivotal platform for physics education. There are dozens of YouTube channels focused on physics education, capitalizing on its vast user base and disseminating a wide range of content. Common themes include fundamental principles, complex theories, and experimental demonstrations, often catering to both novices and seasoned learners (Cakir and Delialioglu, 2018). However, the platform also is beset by issues, such as misinformation, varying video quality, and a lack of standardized pedagogical approaches (Guo et al., 2014a). While popular physics channels might cover a number of physics topics ranging from Newtonian mechanics, to thermodynamics, to quantum mechanics, and to relativity, educators have raised concerns about the depth, accuracy, and didactic efficacy of some content (Scherer et al., 2019). While there are challenges with informal physics education on YouTube, studies have indicated the potential of YouTube to serve as a supplementary educational tool, to foster engagement and aid conceptual understanding (Breslow et al., 2013). It is also an important part of the existing educational landscape, playing an important part in the education milieu that students exist in. The literature on this topic is growing but there is a need for more rigorous exploration of best practices and content evaluation in the YouTube physics education space. The first two studies as part of this thesis aim to fill this gap.

Chapter 3

Methodology

Voiceless it cries,
Wingless flutters,
Toothless bites,
Mouthless mutters.

J.R.R. Tolkein

This chapter discusses the research methodology. The research framework (Design Based Research (DBR)) as well as detailed descriptions of the three research studies are also included. The mixed-method methodology is described and the quantitative and qualitative data analysis is outline. The evaluation framework drawn from literature is also introduced. This builds upon the work of Mezirow, Hubs, and Brand (Mezirow, 1998; Hubbs and Brand, 2005) to analyse student reflective thinking.

3.1 Overview of Research Methodology

In this section the methodological approach of the overall dissertation and the three research studies are outlined. An explanation of how the three studies are linked together is also provided.

3.1.1 The Research Framework

In his influential book *Foundations of Social Research*, Crotty (1998) outlines different types of social research. Sometimes research is highly structured, well planned, and well executed. Such ‘experimental or quasi-experimental research’ generally has research questions associated with statistical methods, such as the efficacy of placebos and clinical treatment, or evaluations before and after testing. These are categorized as positivist approaches. Other research may be unstructured and can be conducted under a particular lens adopted by the researcher. Hence, interactions as well as the perspective of the researcher must be considered. These range from ‘subjectivist’ to ‘interpretivist’ lenses. Between these two approaches is the ‘constructivist’ approach, which is the outlook of this thesis.

Despite the particular interest of this thesis in assessing the role of reflection in changing individuals minds when viewing videos, there was insufficient literature in this area to frame a more ‘postivist’ research approach. As such, the ‘constructivist’ approach was adopted, in which methods were developed in iterative cycles of studies and persistent exploration of literature.

The research was not pre-planned and then conducted. While one could pretend that before the literature search was initiated and the first pilot study was conducted, that it was clear how the research would turn out, what the research questions would be, what answers would emerge, and what methodology would follow to arrive at the answers, this would not only be untrue, but would be a disservice to the work. This project, like many other scientific projects, was iterative. It only became clear what the methodology was in process. The research questions were moulded by the data as it was collected and the literature as it was read. Every research study revealed insights, areas for improvement, and new questions.

3.1.2 Design-Based Research

The iterative approach, is well described by the framework of Design-Based Research (DBR) (Collins, 1992; Brown, 1992). In their 2003 paper the design-based research collective outline five central goals of DBR (Collective, 2003).

1. The central goals of designing learning environments and developing theories or “prototheories” of learning are intertwined.
2. Development and research take place through continuous cycles of design, enactment, analysis, and redesigns.
3. Research on designs must lead to shareable theories that help communicate relevant implications to practitioners and other educational designers.
4. Research must account for how designs function in authentic settings. It must not only document success or failure but also focus on interactions that refine an understanding of the learning issues involved.
5. The development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest.

In this research, the DBR framework was utilized in the following five ways:

1. The goal of the research was to create an analytical approach to analyse educational videos as to how they elicit and support reflection.
2. The research took place in inter-connected research phases, each drawing from the knowledge gained from the previous phase.
3. The research aims to share relevant pedagogical practices to encourage reflective thinking in this context.
4. The research exists in authentic formal and informal educational settings.
5. This research is practical and the goal is to reach a deeper understanding of pedagogy to teach more effectively.

First, the design of learning environments and interventions and educational theories were closely linked and one informed the other. Second, iteration was essential throughout the research and the phases of design, deployment, testing, analysis, and redesign were repeated. New insights were gathered from each phase of the research which were used to inform the subsequent stages of the research. Third, the “shareable theories” that were gathered from this research have been shared in two peer-reviewed papers and several international conferences. Fourth, the research was performed in authentic settings. This is the educational equivalent of *in vivo* testing, rather than *in vitro* testing. Fifth, the processes were documented extensively from their inception to their outcomes.

The goals and ideas of DBR closely align with the research methodology used in this thesis, consisting of three distinct studies, each building on one another. The research was also conducted in authentic learning environments which were well-suited for the demographic whose learning and reflection were being examined.

After performing a literature search on the role of reflection and reflective thinking in changing individuals minds when viewing videos, Study 1 was planned and executed. This provided valuable insights and ideas for the coming iterations. Even as the data analysis for Study 1 was beginning (including immersion in the data and the emergence of interpretations) new literature and influences were still being explored. The research of Jack Mezirow, an educationalist whose work concerned adult learning (Mezirow et al., 1990; Mezirow, 1998), was discovered and influenced the analysis of Study 1. The methodology for Study 2 was synthesized following reflection on Study 1 and feedback received in response to several questions: “What were the participants answers to the questions on the videos?”; and, “Do I know if participants were changing their minds if their answers were incorrect, partially correct, or correct?” Study 2 expanded upon the scope of the first by asking participants to write down their answers. Furthermore, the research was conducted in the formal teaching and learning environment of a first year physics class. The works of Hubs and Brand, psychologists whose research concerns ‘reflective journals’ were

essential to this analysis (Hubbs and Brand, 2005). Study 3 was built upon the insights of the first two studies.

The three research studies are not separate from each other but constitute parts of a whole. Study 3 could not be conducted without having conducted the second, which could not have been conducted without the first. This was a highly iterative way of doing research, full of trial and error. It was a scaffolded learning process and aptly described as ‘constructivist’ research as articulated by (Crotty, 1998). Yet when the three studies are taken together, they form a cohesive whole and serve the same goal of investigating the role of reflection and reflective thinking in changing individuals minds when viewing videos.

3.2 Overview of the Three Studies

The three research studies were conducted in 2017, 2018, and 2019. The details and specifics of the methods, data analysis, results, and implications for each of these studies are described in Chapters 5, 6, and 7. However, to understand the methodology used in the thesis, and how the studies fit together systematically into a larger, cohesive, academic body-of-work, it is important to examine how the studies are interlinked using the five central goals of DBR. Hence, a summary of each study, the context, and the data collected is provided in the following few sub-sections. Table 3.1 shows the interventions, samples, and survey questions for each one of the three studies. In-depth explanations of the content of the videos and how reflection was embodied in them is presented in Chapter 4.

	Intervention	Sample	Survey
Study 1 (chapter 4)	Two “Veritasium” videos, one posing four questions, the second providing the solutions	General public/followers of the Veritasium science channel, n=2200	2 survey questions per physics question, after video two (did you change your answer, and why did you not change your answer.)
Study 2 (chapter 5)	Two “Veritasium” videos, one posing four questions, the second providing the solutions	First year physics students at the University of Sydney, n=508	2 survey questions per physics question after video one (what is your answer, what is your confidence in your answer?), 2 survey question per physics question after video two (did you change your answer? Why/why not?)
Study 3 (chapter 6)	Three videos asking the same physics question, with varying “clues”. One answer video.	First year physics students at the University of Sydney, n= 380	2 survey questions after video one (what is your answer, what is your confidence in your answer?), 2 survey question after video two (did you change your answer? Why/why not?)

Table 3.1: Overview of the three research studies, including the interventions, samples, and the survey questions asked.

Study 1: Reflection in Informal Learning and Social Media

On the 11th of April, 2017 Dr Derek Muller (a previous graduate of the Sydney University Physics Education Research Group) posted two videos on his physics education and science communication channel YouTube Veritasium.

- In the Questions Video, he presented his audience with four physics questions, encouraging them to write down their answers in the comment section of the video.
- In the Solutions Video, which was published a week after the first one, he provided the solutions.

The scripts for both of these videos are presented in the appendix and the videos can be accessed on the Veritasium YouTube channel (<https://www.youtube.com/watch?v=HgCXdNhV>
Veritasium[https : //www.youtube.com/watch?v = 72DCj3BztG4t](https://www.youtube.com/watch?v=72DCj3BztG4t) = 1sabchannel =

Veritasium). These videos constituted the Study 1 intervention.

In YouTube's description section under the Solutions Video, a link to a survey was included, which was hosted on survey platform SurveyMonkey. The survey consisted of 8 items, which amounted to 2 per physics video question (see Figure 3.1).

1. After watching the solutions video, did your answer to question 1 (mystery cylinder) change?

☐ Yes

☐ No

☐ My answer was correct.

If you answered No - why did your answer not change?

Figure 3.1: The two items for the first question relating to the Questions Video. The item was adapted and repeated for each of the four physics questions

The survey was open for 7 days during which time both videos were viewed more than 1 million times. A total of 2220 people answered all 8 items in the survey. Following first round of data collection for exploratory Study 1 the following questions emerged: "Will these questions help glean evidence on reflection and individuals changing their minds?", "Can the data collected be meaningfully interpreted?", and "Is this worth pursuing with a more rigorous sampling method?" Study 1 was successful and reaped robust data to analyse and to assess whether the method of data analysis and interpretation were adequate. It also provided an understanding of how the study could be refined and areas for improvement.

An assessment of the five central goals of the DBR framework, what Study 1 had achieved, and how this led to Study 2, is as follows:

1. Study 1 demonstrated that the goal of creating a framework to study the topic, to elicit reflection in students via linear educational multimedia, was viable and paved the way for Study 2.

2. Study 1 was well suited to be iterated upon in another inter-connected research study (Study 2) drawing from the knowledge gained.
3. Study 1 was undertaken to share relevant pedagogical practices to encourage reflective thinking in this context and as a result a paper was published and numerous presentations were made.
4. Study 1 was conducted in an authentic educational setting, it was informal, and well suited as a precursor to Study 2.
5. Study 1 was practical and the goal was to develop a deeper understanding of pedagogy to teach more effectively through reflection.

Some interesting questions were left unaddressed in Study 1. When results from Study 1 were presented at a number of conferences, these questions were reiterated by members of the PER community.

Study 2: Reflection in the Formal Learning Context of a First Year Physics Class

Study 2 explored very similar questions, with similar methods, and improved upon Study 1 in its focus on goals 4 and 5 of the DBR framework. The intervention used the same two Veritasium videos. The differences were two-fold; first, this study was conducted with the first year physics student cohort at The University of Sydney, and second, more questions were asked of the students (students were asked to provide their answers after watching the Questions Video). Furthermore, as explained below, completion contributed one mark towards their lab component, strengthening Study 2 in terms of the goals of DBR.

As the second iteration of DBR, Study 2 incorporated feedback and insights from Study 1. It was refined in its ability to investigate the role of reflection and reflective thinking in changing individuals minds when viewing videos as discussed below:

- The study took place within a teaching and learning environment. Therefore, pedagogy and practice were central to the study.

- While the sample size was smaller than in Study 1, the results were likely less biased. Upon completing the survey, the students were given 1 mark on their pre-lab score for that week, which was not significant, especially given that students regularly miss completing pre-labs. Nevertheless, almost all of the students who watched the videos responded to the survey. Therefore, the data captured diversity through sampling. This is distinct from Study 1 where millions of people watched the videos on YouTube, while only 2220 people responded to the survey. This could have heavily skewed the data.
- In the survey for Study 2, students were asked to write down their answers after watching the Questions Video and before watching the Solutions Video. This was controlled as students were unable to progress to the next page. The students were also asked if they had already watched the videos to filter out these students.
- In Study 1, only those participants who said that they did not change their answer were asked why they did not do so. In Study 2, all students who said that they did change their answer were asked why they did so.

In Study 2 the survey was deployed through REDCap, the university's data handling and storage platform for student data. On the first page of the REDCap survey, the students watched the Questions Video and were prompted to write down their answers to the questions, as well as their confidence in their answer.

Video One



Write down your answer to question one (Mystery Cylinder)
* must provide value

Please indicate how confident you are about your answer to question one
* must provide value

Uncertain Certain

Change the slider above to set a response

Write down your answer to question two (Bike)
* must provide value

Please indicate how confident you are about your answer to question two
* must provide value

Uncertain Certain

Change the slider above to set a response

Write down your answer to question three (Running track)
* must provide value

Please indicate how confident you are about your answer to question three
* must provide value

Uncertain Certain

Change the slider above to set a response

Write down your answer to question four (Train)
* must provide value

Please indicate how confident you are about your answer to question four
* must provide value

Uncertain Certain

Change the slider above to set a response

Figure 3.2: Page one of the survey, where the students are prompted to write their answers to the physics questions as well as their level of confidence in their answer

After the students had responded to these eight items (two for each of the four physics questions), they were taken to the next page where the video containing the solutions was provided. After watching the Solutions Video, the

students were presented with part two of the survey, which consisted of eight items total, two for each question. The first survey question for each physics question was “After watching the solutions video, did your answer to question one (description of the question) change?” with two buttons for “Yes, I did change my answer” and “No, I did not change my answer”. The next prompt for each question asked the student to provide a reason for modifying or not modifying their answers. The webpage was coded in such a way that when the students selected one of the radio buttons, the question reflected their choice. If the student selected “I did change my answer” the question read “I did change my answer because”. If the student selected “I did not change my answer” the question read “I did not change my answer because”. More detail is presented in Chapter 6.

Please watch the solutions video.



4 Revolutionary Riddles Resolved!

Share

After watching the solutions video, did your answer to question one (mystery cylinder) change?

* must provide value

☐ I did change my answer

☐ I did not change my answer

reset

[a1] because

* must provide value

Expand

After watching the solutions video, did your answer to question two (bicycle) change?

* must provide value

☐ I did change my answer

☐ I did not change my answer

reset

[a2] because

* must provide value

Expand

After watching the solutions video, did your answer to question three (running track) change?

* must provide value

☐ I did change my answer

☐ I did not change my answer

reset

[a3] because

* must provide value

Expand

After watching the solutions video, did your answer to question four (train) change?

* must provide value

☐ I did change my answer

☐ I did not change my answer

reset

[a4] because

* must provide value

Expand

Figure 3.3: Page two of the survey wherein the students were prompted to respond if they did or did not modify their answers, as well as their reasons for doing or not doing so.

Given the five central goals of DBR framework, Study 2 was assessed as follows:

1. Study 2 consolidated the exploration of reflection and moved the overall study closer towards the creation of a framework to elicit reflection in

students via linear educational multimedia. Insights from Study 2 laid the groundwork for further exploration in Study 3.

2. Study 2 used the insights gained from Study 1 to raise the additional query regarding why students changed their answers as well as their confidence in their answers. Aspects of this progress were improved upon in Study 3
3. Both Study 1 and 2 led to publications in high quality physics education and pedagogical journals, sharing the relevant pedagogical practices which encourage reflective thinking.
4. Given that Study 2 was conducted in an authentic, formal educational setting, the conclusions and insights gained can be expanded upon in Study 3.
5. Study 2 was practical and it provided a deeper understanding of pedagogy to teach more effectively through student reflection. This pedagogy was further expanded upon in Study 3.

The results and analysis from Study 2 also facilitated the development of a more in-depth framework of student reflection. Given that the codes developed for Study 1 were applicable in Study 2, the framework was demonstrably valid and it had an appropriate pedagogical foundation. There were subtle differences in the coding, which are discussed in detail in Chapter 7, but the two studies had striking amounts in common. That the same codes were able to be used in analyzing student reflection in such vastly different contexts reinforced the validity of the work and the theoretical framework for data analysis. While confidence data were collected, it was not analysed, or included in the paper published from this study.

Another element in common was the conceptualization of reflection developed by Hubbs and Brand, and how that compared to the view of reflection by Jack Mezirow. Although these conceptualizations came from vastly different contexts (Hubbs and Brand in psychology and Mezirow in adult education),

they both asserted notions of “inward facing” and “outward facing” reflection (Hubbs and Brand, 2005; Mezirow et al., 1990). These similarities and differences are explored further in Chapter 6. This reaffirmed the validity of the theoretical framework. Study 2 affirmed that the questions, methods, and analysis were sound and further research, in the form of another iteration, could be performed.

Study 3: Guiding Reflection Through Modified Questions

In the first two studies, the intervention was created by Veritasium. For Study 3, I carefully designed the intervention in collaboration and discussion with my supervisors and the research group. The interventions were specifically designed with Dewey’s phases of reflection and all prior insights and experiences in mind. This study was designed to probe two questions;

1. Did the videos created (based on Dewey’s phases of reflection) work for electricity content (a much less visually striking and more abstract field of physics than kinematics)?
2. Could different types of reflections be triggered by changing the clues included in the question video?

Having gained numerous insights from the first two studies, Study 3 was based on videos which were created in house. I carefully scripted, produced, filmed, and edited the videos. In total, four videos were created; three asked the same physics questions with varying clues and one solution video. The three videos asked the same question, but one provided *good clues*, another provided *no clues*, and the third included *red herrings*, in parallel with the question. The students were randomly assigned to watch one of these videos, as part of their pre-lab work. After watching the video, they were asked to write down their answer and their confidence in their answer. The confidence was measured on a sliding scale from 0 to 100. Thereafter, all three groups of students watched the

same answer video, and were prompted to report if they modified, or did not modify their answer along with their reasons for doing so or not. More detailed information on the data analysis is presented in the chapters pertaining to the separate studies.

Although this was the last study included in the thesis, there were many ideas and insights which could inform subsequent tests. DBR is not merely a research methodology for singular researchers and it included the entire community of educational researchers. One of the goals of DBR is the development of shareable theories, which can be used by the next set of researchers to iterate, build upon, and further advance the area of study. There were several avenues of further research identified, some of which are discussed in more detail in Chapter 8.

3.3 Research Methods

In this section the study's research design is described. Sevilla (1992), Williams et al. (2007), and other researchers categorize educational research into three types: qualitative, quantitative, and mixed methods. Within these three broad types, there are methodological sub-types. Each has their own distinct advantages and disadvantages. Importantly, each type of research method allows the researcher to conduct a different kind of inquiry and pursue different questions (Creswell and Clark, 2017), adapting to particular approaches and philosophical slants (such as positivist, constructivist, subjectivist, and interpretive approaches (Crotty, 1998)). These are different tools which are used for different jobs. Vitally, as noted by Walliman (2010), there are also differences in handling and analysing the data such that interpretations align with research goals and questions, and allow the researcher to draw sound conclusions. These subtleties of the research methods are discussed in the next subsections.

3.3.1 Mixed-Methods

To explore the role of reflection and reflective thinking, and how individual minds changed after viewing the videos, mixed-methods research was utilized, drawing on both quantitative and qualitative data. According to Leech and Onwuegbuzie (2009) “Mixed methods research represents research that involves collecting, analyzing, and interpreting quantitative and qualitative data in a single study or in a series of studies that investigate the same underlying phenomenon.” The premise of mixed methods research is that a combination of quantitative and qualitative approaches provide a better understanding of the subject of study than either approach separately (Clark et al., 2008).

The mixed methods research paradigm is in common use in educational research (Greene, 2007; Creswell, 2014), and was the optimal choice for the research at hand. Within the literature search it became clear how exploratory the topic was, and as a result how exploratory the research would need to be. Using both qualitative and quantitative methods was the only way to adequately answer the research questions. Solely quantitative research would have been ill-suited as quantitative methods are adept at answering well defined numerical questions, and they would not be suitable for open ended research which requires conceptual scoping. Using solely qualitative methods would also have been ill-suited as the study incorporated a great deal of numerical data (the number of students who changed or did not change their answer, the number of students whose answers matched the solution, and the student confidence levels). This exploration into student reflection required both quantitative and the qualitative methods. Due to the exploratory and iterative nature of the research, and the presence of research questions that quantitative or qualitative data alone could not answer, both were utilized. Importantly, the mixed methods approach facilitated a nuanced and deep understanding through the interpretation of qualitative and quantitative information in parallel, triangulating and

querying emerging subsets and groupings. The links between qualitative and quantitative data added additional depth and nuance to the findings, resulting in high quality conclusions.

Quantitative Methods

Quantitative research entails the collection and analysis of numerical data to draw conclusions (Cramer, 2003). However, to reach meaningful conclusions from the numerical data, it is vital to pose the appropriate questions, and to parse the data carefully and critically (Albers, 2017). In educational research there is also more than one type of quantitative data and each has its own utility. In this section expands upon the methods of gathering and analysing the quantitative data that were collected as part of the three studies.

Some data is inherently numerical, for example the most logical way to express an amount of money in dollars is quantitatively. Other examples include the velocity of a ball in meters per second, the mass of an object in kilograms, or the age of a student in years. These data can be ‘discrete’ or ‘continuous’ in nature. Other data are inherently non-numerical and are called ‘nominal’, such as colour of eyes or subjects studied. Yet other data are ‘phrases’ which could be converted into numerical values such as the confidence that each student had in their answer or how nervous they were about an exam, or how trustworthy they find their teacher (Connolly, 2007). These data are ‘ordinal’ and can be converted onto a scale (Stevens, 1946). A commonly used example of this is the Likert scale, which was first introduced in 1932 (Likert, 1932; Joshi et al., 2015). The original Likert scale uses a series of questions with five possible responses, including *strongly approve*, *approve*, *undecided*, *disapprove*, and *strongly disapprove*, where *strongly approve* is assigned the numerical value 1, and *strongly disapprove* is assigned the numerical value 5. Variations of the Likert scale have been used extensively in psychology and education research, allowing re-

searchers to convert essentially qualitative data into something which can be approached quantitatively. However, in order for this method to be valid certain conditions must be satisfied. It is important to note that ordinal data have a set of assumptions underpinning its collection.

In this research the following were utilized:

Discrete data:

- The number of students who clicked on various boxes (modified, or not-modified)
- The number of student answers that matched the answer
- The number of students who fell into several categories

These data were processed in Microsoft Excel, which was suitable as the analysis was quite simple; it simply counted the number of students who selected various options from a drop-down menu, or counted the frequency of codes assigned to student responses.

Continuous data:

The study also used ordinal data that were converted into numerical data through a Likert-like “visual analog scale” (VAS) (Messaris, 1998). These included:

- The confidence of the students in their given answer.

This data was only collected in the third research phase (see Chapter 7 for further detail). It was important that data was obtained on the differences in student confidence for various groups. In order for the data to be comparable, the mean confidence of the students and the standard deviation were required. It was also necessary to determine whether the differences were statistically significant. While this could have been done in Excel, a more powerful statistical program was used as this made the computation simpler. These data were analysed with SPSS and will be discussed in Chapter 7.

There are study specific subtleties and details in the quantitative data analysis. These are discussed in detail in each of the chapters associated with the research studies.

Qualitative Methods

As with quantitative data, there are different types of qualitative data, and different philosophical underpinnings and assumptions which govern the use of each type. There are always sub-types and differing approaches to collecting these data. A central component of DBR is the use of appropriate tools and methodologies to answer the research questions. One shouldn't use a ruler to measure temperature, nor should one use an atomic clock to measure the oscillations of a pendulum in a first-year physics practical; here a simple stopwatch would do. The instrument must both capture the quantity being measured and reflect the appropriate level of precision necessary. Similarly, there are trade-offs between the different approaches to retrieving qualitative data; what matters is that the correct tool is used such that the data answers the research questions. With this in mind, a few commonly used tools in qualitative research will be described along with the reasons one might have for using them.

Due to the diversity of educational research, it is hard to pin down all off the ways qualitative research can be performed. The educational anthropologist Wolcott (1992) identified 25 methods. Others typically find fewer and frequently disagree on the types. This research refers to those identified by Creswell et al. (2007), which were adapted from the work of Morse and Field (1995). Creswell's categorization is frequently used in other qualitative Physics Education Research projects, and it is congruous with the ideas presented within the DBR community. The goals of this research place it firmly within the domain of grounded theory, which according to Lewis-Beck et al. (2003) "refers to a set of systematic inductive methods for conducting qualitative re-

search aimed toward theory development.” This is suitable in that this thesis aims to develop a theory and a framework to understand how students engage in reflective thinking as they experience linear multimedia interventions on physics, which are designed to engage them in reflective thinking. Lewis-Beck et al. (2003) also note that “These analyses provide focused, abstract, conceptual theories that explain the studied empirical phenomena”, which is appropriate for this research.

<i>Type of Research Question</i>	<i>Qualitative Design</i>	<i>Illustration of Questions Within TI Context</i>
Chronological/story-oriented questions: Questions about the life experiences of an individual and how they unfold over time	Narrative research	What stories does a client tell us about the T1 process?
In-depth, descriptive questions: Questions about developing an in-depth understanding about how different cases provide insight into an issue or a unique case	Case study	How do four counselors share problem-focused or potentially “hard-to-hear” test results with clients?
Process questions: Questions about experiences over time or changes that have stages and phases	Grounded theory	What theory best explains the therapeutic effects of TI?
Essence questions: Questions about what is at the essence that all persons experience about a phenomenon	Phenomenology	What does <i>timing</i> mean to counselors who regularly share test results with clients?
Community action questions: Questions about how changes occur in a community	Participatory action research	How do community mental health centers better optimize their use of psychological tests in day-to-day practice?

Table 3.2: Table adapted from Creswell (2007)

The data collection method, the qualitative research focus on mainly on short-answer responses, the absence of a validated survey, and the online data collection were selected as these were the appropriate instruments with the ap-

appropriate level of precision to answer the research questions. The next few paragraphs outline common means of collecting and analysing qualitative data and will then explain the reasoning specific methods were chosen.

Qualitative data are typically subdivided into three types: interviews, direct observations, and written documents Libarkin and Kurdziel (2002). Each has its own advantages and disadvantages.

Interviews are conversations with the subjects of the study in which participants are asked questions which are designed to help the researchers answer their broader research questions. Interviews can be structured, semi-structured, or open. Interviews can be further broken down into one-on-one interviews (where each student is interviewed individually), or focus groups (where a number of students answer questions in a group setting). Focus groups are typically shorter to execute and allow more students to participate, give voice to their ideas, bounce ideas off of each other, developing arguments, or provide explanations. An interview on the other hand, typically takes more time, but could lead to a deeper discussion with the individual. Interviews are normally audio recorded and offer subtle and nuanced insights from the data. Challenges include sampling, obtaining adequate representation, and respondents reporting what they think the interviewer wants to hear rather than what they really believe (Alsaawi, 2014).

Direct Observations occur when the researcher observes the subjects. Ideally, researchers are passive observers who are detached from the situation under observation and who have no influence on the participants. The observer should be a fly-on-the-wall. Direct observation in classrooms can be carried out using video recordings but observation can also be carried out in person. In both cases, students and teachers can be aware of the observation and behaviours may be different when students know they are observed from when they do not know they are observed. The information must be recorded

and must be carefully crafted so as not to distract from the research question Taylor-Powell and Steele (1996).

Written Documents can come in a variety of formats. Some research relies on analysis of long form student writing (like journals) or the analysis of student essays. Some studies use Likert scale responses using validated survey instruments or multiple choice answers on concept inventories written to test student knowledge. Some are online and some are delivered in person Hubbs and Brand (2005).

An online, short answer survey was chosen as the primary method of data collection because these were appropriate for the task. Within Study 1, it was not possible to administer a paper-based survey to Veritasium audience. Within Study 2 and 3, students were already engaging with online “pre-lab” work, into which the study fitted naturally. This was the correct tool for the context as a minimally invasive data collection method which could easily be distributed to all of the students studying first year physics. One of the logistically feasible ways of creating an intervention in the class was to:

- 1) create an educational intervention which was relevant to what the students were studying at the time, so the coordinator of first year physics laboratories could assign it as a “pre-lab” activity
- 2) have the intervention take similar amount of time as a normal “pre-lab” assignment. This necessitated relatively short videos and also short-form answers that could be completed in the usual 10-15 minute time allotted. Interviews were seriously considered as an option, but after consulting with my supervisors it was decided that due to the exploratory nature of the research, it made more sense to collect a larger number of responses, which would not have been possible with interviews which are time-intensive to conduct and analyse.

The use of validated survey instruments was also considered and then ruled out. The reason for not using a validated survey instrument like the California

Critical Thinking Test (Facione, 1991), was that they were not finely tuned to the kind of data required nor to the research question. These tests and inventories focus on the critical thinking and reflective thinking abilities of the student as a whole and a more means of data collection was required.

Once the data were collected, the qualitative analysis began. Once again, the analysis was guided by the goals of this research which was investigating the role of reflection and reflective thinking in changing individuals minds when viewing videos, or more specifically, an exploration of student reflection as mediated by multimedia learning based on Dewey's phases of reflection. The coding had to be inductive and no preconceived theories or expectations were introduced to the coding. The responses were read and observed at length. Within Study 1, a week was spent reading the responses, looking at ideas presented, and searching for a way to make sense of the students codes. Once some ideas emerged, these were discussed with my supervisor. This cycle repeated a few times, until robust categories emerged. A definition for each code was written to encapsulate the core, fundamental, similarity between seemingly disparate responses. The responses were coded aside from 150 responses which were given to a research student in the physics education research group to code following guidelines provided to them. A few example codes were performed together and then he coded the 150 responses independently. My coding was compared to his coding and the intercoder reliability was determined to be sufficiently high (above 80 %) to consider the codes robust (O'Connor and Joffe, 2020).

Pure inductive coding was only possible within Study 1. During Studies 2 and 3, responses that resembled the questions were expected, as the questions were very similar, and the codes used in Study 1 were presumed to be applicable to the later studies. Nevertheless, this assumption was reviewed and the data were explored with an open mind. The change of context from informal learning to a university classroom section may have required bespoke codes and a small

variation to the codes was uncovered, which is described in more detail in the chapters pertaining to Study 2 and Study 3. However the coding remained robust for all three studies. The intercoder reliability test was performed for all three studies and was over 80% for all.

As noted above this is a broad overview of the methodology and the details of both the quantitative and qualitative methodologies are provided in the chapters associated with each study. The interpretation of the results were also deeply shaped by the theoretical framework which shaped this research. It is outlined in detail in the literature review and is elaborated on in the chapters associated with the three studies.

3.4 Summary

In summary, in this chapter the methodology used within the three research studies was outlined. The research was conducted using the Design-Based Research framework, which utilizes an iterative approach. Each study was carefully designed to best achieve the research goals. As new data and insights emerged from previous studies, the plans for the next study were modified. Each study informed the next. Due to the highly exploratory nature of the work, the data collected was both qualitative and quantitative.

The next chapter will outline the educational intervention in detail, namely, the videos. Their selection and creation, as well as the theoretical underpinnings which guided this process will be elaborated upon.

Chapter 4

Intervention

A box without hinges,
key or lid,
Yet golden treasure inside is hid.

J.R.R. Tolkien

4.1 Design of the Videos

To explore the role of reflection and reflective thinking in changing individuals minds when viewing videos adequately, it was vital to select and design appropriate, evidence-based, and well crafted videos to underpin the intervention. Hence, the videos deserve a chapter of their own. There are three primary pillars of the videos which will be discussed: the **craft of multimedia creation**, the **subtleties of physics content**, and the **use of Dewey's phases of reflection**. The first section of this chapter provides background on each of these pillars, drawing on extant literature. Next, each of the videos are examined with respect to these pillars.

4.1.1 The Craft of Multimedia Creation

Humans have strongly developed visual senses and are sensitive to subtle cues from our environments (Tetlan and Marschalek, 2016; Barcelo et al., 2000). Additionally, due to the rapid rise in visual content from the early days of cinema to the near-ubiquity of visual media (Messaris, 1998) both the public and students are sensitive to the craft of the media that they are presented with. Contemporary students have been immersed in multimedia from very early in their lives, from cinema and television, to content on the internet. The rise of social media websites and apps like YouTube, TikTok, Reddit, Instagram, Twitter, and others have made multimedia ubiquitous. Many websites and apps that did not start out as video-focused websites, like Twitter and Instagram, have incorporated video as a pivotal part of their platform. Most students, who have grown up in such a multimedia-rich world, are used to both the consumption of media and the creation of it. It is now a normal part of life for younger generations to create multimedia by recording a video with their phone and sharing it on social media platforms. They are not uncritical consumers of video and are instead active participants in a culture that is comfortable and familiar with video (Montero Sánchez, 2021).

In recent decades, the technology of both visual media creation and distribution has increased rapidly. Video recording technology has evolved from 16mm and 35mm film cameras, to super-8 home movies, to the rise of the digital compact camera and now the ubiquity of the smartphone; almost anyone now has the ability to create high quality visual media (Montgomery, 2018). The biggest leap has occurred in the last 15 years following the rise of smartphones with the ability to record in HD and 4k definitions. It is now possible to shoot and edit high quality multimedia content entirely on smartphones. Hence, students can distinguish between high and low quality videos, as they are likely to take multiple videos and optimise by selecting those which are fit-for-purpose. In

fact, unwittingly, many have become connoisseurs of social media. Therefore, it was vital that the videos selected and created for this research, were of high quality or suitable for the purpose. The craft of filming, including technical elements like focus, framing, lighting, and editing needed to be considered. What those technical points mean for the story, the mood, the emotions of the audience, were also important to help select and create high quality multimedia interventions. In some cases compromises were made, but sometimes these compromises made a video feel more authentic and grounded.

All of these technical considerations concerned effective storytelling (Leu), in which focus is directed on what is important to the story and distractions are left out. While creating visual multimedia is an art form, there are well established and accepted guidelines for the art, such as effective composition, lighting, and editing (Brown, 2016; Deren, 1960; Wheeler, 2012). For example, some typical framing techniques include placing the subject at the centre of the frame with appropriate head room (leaving some space left at the top of the frame) or the rule of thirds (where the frame is split evenly into thirds horizontally and vertically, and the subject is placed in one of those intersecting lines) (Amirshahi et al., 2014). These are long-standing techniques of framing, which have been consistently utilized by artists, photographers, and cinematographers to create pleasing and aesthetic compositions. In a recent study, (Koliska and Oh, 2021) note that

“The rule of thirds appears to enhance participants’ ease of information processing by raising attention to the predominant visual content of an image, making it more salient to the observer”.

These ideas are not dissimilar to Sweller’s cognitive load theory, and Mayer’s signalling principle, which are discussed in the next few paragraphs (Sweller, 2010; Mayer and Moreno, 1998). In short, the videos needed to be made well enough that their quality was not distracting to the viewer and so that the

viewer could focus on the salient content presented in the video.

In the process of selecting and then later creating these videos, the topics selected were also paramount. It was vital that the physics contained in the videos was linked to common student alternative conceptions, that the videos closely matched Dewey's phases of reflection (Dewey, 1933; Rodgers, 2002), and that the video followed Richard Mayer's principles for effective educational multimedia (Mayer, 2005; Mayer and Moreno, 1998; Creswell and Clark, 2017). The physics and the reflection is covered in the next sections of this chapter. While Mayer's principles, their applications, and their limitations are covered extensively in the literature review, they were front of mind while seeking out and creating videos for this research.

It was important to me that the viewers could focus on the content being presented and not be distracted by extraneous matters. That the viewer's attention was focused on and their cognitive load used up on the complex physics, rather than distracting video-making technique (Sweller, 2010). The videos in question needed to follow the **coherence principle**, meaning that extraneous words, pictures, and sounds were excluded from the video and every frame included important information related to riddles featured in the videos. The video maker also needed to signal to the audience what elements of the video were important for the riddle, and what was not. This is known as the **signalling principle**. This can be achieved with words, or body language, or camera techniques like zooming in, or pulling focus. In this case the lens was literally focused on what was important, or in post production an arrow or circle was added to dictate where the viewer's eye should go. Studies which have used eye-tracking have shown that the eye is drawn to the part of the frame that is brightest, has a human face in it, has the highest change in contrast, orr uses bright and saturated colours (Brown, 2016). This was all considered within the video selection and creation. The **redundancy principle** also had to be

demonstrated. According to this principle, there should be no unnecessary onscreen text in the video, and all the information should be provided via the audio and visuals. This serves the goal of focusing the viewer's attention on the riddles. The **spatial and temporal contiguity** principles also had to be respected. Accordingly, corresponding words and pictures are presented simultaneously and close together on the screen so as to manage cognitive load. All these considerations were kept in mind when sourcing and creating the videos for this research.

4.1.2 The Subtleties of Physics Content

The second vital consideration was the subtleties of physics content. The criteria for selecting the videos were straightforward. They had to contain three primary elements.

- The physics presented in the videos had to be correct or intentionally appropriate for the research
- The physics had to be content and age appropriate and the content had to be related to what the audience could engage with and/or students were studying in their courses.
- The physics had to relate to common student alternative conceptions

The reasoning for the first is self-explanatory. The physics needs to be congruent with current scientific understandings. These are educational videos, and it is vital that current understandings and interpretations of the world, as viewed by physicists, are shared with those who engage, be they the public or students. However, sometimes, within research, disparate ideas are inserted to investigate which videos are productive for teaching.

Second, the physics content clearly needed to be relevant and age appropriate. This pertains to the subject matter chosen, the questions asked, and the level of prior knowledge required in the answers. To engage first year students, the

content had to be a part of curriculum and the teaching program such that students would meaningfully engage with it. For the public, general mechanics was also appropriate, as the subjects discussed are common to every day life. Questions about rolling cylinders, running tracks, and bikes were deemed to be engaging to the general public as they are relevant and relatable to everyday experiences.

To meet these content criteria, the videos and scripts were reviewed by the SUPER group and by other physics academics at The University of Sydney. Concerning their age appropriateness, the first year students focus on mechanics and kinematics as their primary topics in semester one, and electromagnetism and circuits in semester two. Therefore, the first batch of videos was intended to relate to mechanics and kinematics, and the second batch to electricity and circuits. In terms of public audience, focusing on mechanics was deemed appropriate due to it's relevance and repeatability, especially focusing on the behaviour of everyday objects like bikes (Norman, 1988). In terms of alternative conceptions, there is extensive literature on student alternative conceptions regarding mechanics and electricity and electrical circuits, and how to appropriately address them. The specifics are discussed in greater detail in the following section along with references relating to the relevant literature (for the concepts covered in the electricity videos) (Andre and Ding, 1991; Sencar and Eryilmaz, 2004; Franklin, 1992; Hermita et al., 2017; Saxena, 1992; Raduta, 2005).

4.1.3 Reflection

The third pillar is reflection. The motivation for creating and curating these videos was to base them around Dewey's phases of reflection, as outlined in 1923 and as clarified by Rogers in 2002 (Rodgers, 2002; Dewey, 1923). This framework was chosen for reasons discussed in Chapter 2 as are the finer details

of Dewey's points. To briefly summarise, Dewey lists 6 phases of reflection, which are:

1. A perplexing experience
2. A spontaneous interpretation of the experience
3. Naming of the problem or a question that arises from that experience
4. Generating possible explanations for the problem or for questions posed
5. Ramifying the questions into a hypothesis
6. Experimenting or testing the hypothesis

The goal of the videos was to guide the students through these stages, to encourage them think along these lines, and to scaffold their reflective process. The videos selected and created for these research phases had to include several elements. The first video had to include a perplexing experience, the time for students to interpret the experience, and the posing of a question. In the second video the answer had to be presented.

The details relating to how Dewey's phases were followed for the various videos are presented in the upcoming section.

4.2 Mechanics Videos

This section outlines why these particular videos were selected, how they match the metrics for craft, reflection, and appropriate physics. The selection criteria for the videos will be outlined followed by the physics content. As discuss the physics content is discussed, the craft involved in creating the multimedia will be discussed, as it is impossible to separate the details of physics from how the physics is presented in the video. Thereafter, the section will explain how the videos match Dewey's phases of reflection, focusing on Question 1 as an example.

4.2.1 Mechanics: The Craft of Multimedia Creation and the Subtleties of the Physics Content

When searching for videos to use in the intervention, it was important that the videos were high quality, well-filmed, and engaging. It was vital that the craft pillar was met. The videos chosen for the first two studies were created by Dr Derek Muller, the creator of the highly popular educational YouTube channel “Veritasium”. At the time of selection, the channel had more than 6 million subscribers, with most videos receiving just over 1 million views within the first few weeks. This level of cultural success and engagement on YouTube is not possible without highly quality craft. All of the standard technical specifications were met by the videos, which were in focus, featuring well composed shots, following standard framing techniques common in videography, featuring good audio quality, and were filmed in 4k (3840 by 2160 pixels) resolution.

Importantly, the video was engaging. Before Derek posed the question, he motivated the video by including a surprising and counter-intuitive visual at the beginning of the video. The footage featured liquid nitrogen being poured into a water container, which created a fine fog, and as the container was placed on a carousel, it created a swirling cloud reminiscent of a hurricane. At this point Derek noted that “when you study physics in rotating frames of reference, or even just rotating bodies, you find some pretty mysterious and counter-intuitive phenomena”.

This introduction serves two purposes: first, it entertains, second, its pedagogically sound. It keeps viewers engaged by showing a strange and counter-intuitive behaviour within the first 15 seconds of the video. It also primes the viewers to expect that the question(s) which follow will have counter-intuitive answers.

Veritasium is well respected in the field for the scientific accuracy of his videos. Dr. Derek Muller, the creator and presenter of these videos, also has a PhD



Figure 4.1: The motivation for this video: A surprising and counter-intuitive phenomenon of liquid nitrogen fog spreading out on a rotating platform

in physics education research from the University of Sydney and has a great track record of presenting robust physics. Even so, when these videos were considered for the studies, they were discussed within the SUPER group and a number of professors at the School of Physics were consulted, to ensure that the answers presented were robust and valid.

Not only was the correctness of the physics important, the questions that were asked and the answers which were presented needed to be content, age, and curriculum appropriate. These interventions were conducted with members of the general public and also with first year university students and it was vital that physics questions which were appropriate for both of these contexts were chosen. For this reason, questions that did not need significant prior knowledge from the students were sought out, to ensure that they were able to solve them. While the work of Anzai and Yokoyama (1984); Alvermann and Hynd (1989) and DiSessa (1982) argues that even “students who have been formally schooled in physics principles may be unable to apply their knowledge to new problems”, it was important that these questions were accessible to both the general public (in a social media science communication based context) and first year undergraduate physics students. For this reason, complex questions

related to quantum mechanics, general relativity, or even thermodynamics were not an option, but mechanics was well suited. Deciding on simple to pose yet counter-intuitive questions was another important task. These necessarily dealt with common alternative conceptions in physics. As noted by Kintsch (1980) “It is change, incongruity, surprise that leads to new learning”. Building upon the rich literature surrounding student reasoning about mechanics, questions that would surprise the students were sought out and something familiar behaving in a way that was incongruous with the previous experiences of a typical student.

This section outlines the questions and solutions presented in the two videos.

Question 1: Mystery Cylinder Students can find the physics of rolling objects to be tricky and can easily develop alternative conceptions (Rohrer, 2002; Duman et al., 2015; Rafika and Syuhendri, 2021). This question presented a cylinder that behaves in a counter-intuitive way. Derek sits down next to a ramp and puts a roll of cello-tape onto it. This is intended to “show [the audience] that [he’s] not doing anything funny with it”. It rolls as expected, accelerating down the ramp. Then Derek introduces the ‘mystery cylinder, a cylinder with black tape around it to cover the internal mechanism. He places it on the ramp and notes that “it rolls, then it stops. and then it rooooooolls, and then it stops”. The camera crops in to a tighter angle framing the stop-start behaviour of this cylinder in closer detail. He then poses a question: “what is inside the mystery cylinder?”.



Figure 4.2: Screenshot from Question 1 showing the ramp down which the mystery cylinder will roll

This particular question is not focused on recall and requires almost no content knowledge. Both a 5 year old child and a physics professor would be able to guess what might be inside the mystery cylinder. One of the responses to this question, posted in the comment section of the YouTube video was “a hamster”. It is an open question which can have many answers and engaging comment thread discussions were posted by the viewers of this video because it is so open ended.

Question 2: Bike In the second question, there is once again a demonstration. A bike is propped up with a string tied to the back pedal. Derek proceeds to tell the audience that he will “pull backwards, horizontally on this string”, and asks the audience to “predict which way the bike will go. Will it go backwards, forwards, or will it just stay there, and not move?” He then asks a few people to give their solutions. Derek counts down to demonstrate and the video cuts to the next question.



Figure 4.3: Screenshot for Question 2 displaying the experimental setup of the bike and the string connected to the bottom pedal

By contrast to the previous question, this is functionally a multiple choice question asking whether the bike will move forward, back, stay still, or whether something else will happen. As with all of these questions, there is an implication that that there is something surprising to this answer.

Question 3: Running Track Derek is standing in a stadium next to a running track. He says “I want you to think about running two laps of this track”... Now the first lap, you can go as slowly as you’d like - let’s call that speed v_1 (underscore letter)”. The camera cuts to a person walking on the running track. Derek then notes “but on the second track, I want you to run faster, such that your total average speed for both laps is equal to twice v_1 .” The video shows a person running fast on this track and an equation is shown to make the question clearer

$$V_{avg} = 2 \times V_1 \quad (4.1)$$



Figure 4.4: Screenshot from Question 3 with the running track in the background and the question being re-stated as an equation

Question 4: Train Derek narrates as videos of trains are shown. He says “Anytime a train is moving, either slowly, or very fast, there is actually a part of the train that is moving backwards with respect to the ground.” Derek clarifies, that “that is not backwards with the respect to the train... at any speed, any normal train will have a part of it which is moving backwards with respect to the ground”. He then poses the question “which part is it?”



Figure 4.5: Screenshot from Question 4 showing the B-Roll of a steam powered train

Solution 1: Mystery Cylinder In the solutions video, Derek sits by the

same ramp and in the same location as the first video. He demonstrates the rolling behaviour of some common answers given to question 1 “over 15% of you said a cylinder containing sand”. He demonstrates the behaviours of sand, gravel, water, and honey. He demonstrates its characteristics and shows experimentally that the rolling qualities of sand, gravel, and water do not match the behaviour of the rolling cylinder. For the honey case he notes that “the cylinder rolls, and then stops, and then rolls some more - this is a pretty good guess.” He then notes that “while the behaviour is not exactly the same as the mystery cylinder, it is similar”. He then unwraps the mystery cylinder showing that “(it) actually contains honey and two ping-pong balls”. He then describes the concepts involved, noting that the shifting of the centre of gravity makes the cylinder stop, and then “as the viscosity of the honey allows the ping-pong balls to move up, the centre of gravity shifts forwards again, allowing the cylinder to roll”. He then notes that “that’s the trick of the mystery cylinder — pretty easy if you want to try it out at home”.

Solution 2: Bike Derek notes that “45% of you noted that the bike would move backwards, about a quarter said that it would forwards, and another quarter said that it would not move at all.” Another 5% noted that “it depends”.

First he demonstrates the experiment, pulling back on the bike pedal, and showing that indeed the bike goes backwards. He notes that for “virtually all bikes, this is what you will find”. He explains that the concept of “net force is backwards, therefore the bike moves back” does not quite work in this case because it is more complicated than a simple spool of string. He then shows a video of a bike moving forwards, even though the pedal is being pulled back.” The correct answer is that the direction the bike will move depends on the gear ratio, the size of the wheel, and the size of the pedal. This is once again explained and a animation of the relevant concepts is shown.

Solution 3: Running Track Standing near the same running track, Derek notes that he was initially confused by this question, and it took him a long time to get to the answer. He then provides the solution “it is impossible”. He walks through the calculation, with animated solutions aiding in his explanations.

Solution 4: Train

Derek notes that many of the answers dealt with the wheels, which is close to the solution. He also discusses a few other common answers and explains his reasoning for why they are not the solution. He states that “some people have said that it maybe the steam, or the air in the train, and that’s... a clever point, but... I would not consider the air to be part of the train ... The part of the train that is moving backwards is the flange part of the wheel - which is below the rail”. To explain this fact, he narrates over an animation, pointing out that the point of a wheel which is in contact with the ground, would have a velocity of zero and any point below that would have a velocity going in the other direction to the motion of the train.

4.2.2 Mechanics: Reflection

To show that the videos follow Dewey’s phases of reflection one of the four riddles will be highlighted. The viewers see an experience, for example the mystery cylinder rolling, and stopping, then rolling again. The reason this question was posed in the first place is that this behaviour is perplexing; it is uncommon to see in every day life. There is a pause to take in the experience and time is taken within the video and the camera cropping to enable the viewers to see exactly what is happening and to process the experience. Derek then poses the question “what is inside the mystery cylinder”. There is once again time for viewers to generate possible explanations for the problem.

In the solution video, instead of presenting the solution outright, the audience is walked-through the experiment in a step-by-step manner, showing the

behaviours of various proposed solutions. This is the experimentation and testing phase. Only after this is the solution presented.

The first question illustrating Dewey's first three phases.	
	The experience and interpretation: The question begins with Derek Muller, showing the behaviour of a 'mystery cylinder'. Derek places the cylinder on the ramp and narrates "... and we will see that, it rolls and then it stops. And then it rolls, and then it stops".
	Naming of the problem: Then the video zooms in to the cylinder rolling, and then stopping. This is the "experience" and "interpretation" phase of reflection. Then Derek poses the question "what's inside the mystery cylinder?"
	Encouraging the generation of explanation, and ramifying into a hypothesis: "you can simply leave your answers in the comments below"

Figure 4.6: The first question illustrating Dewey's phases; the experience, naming the problem and generating explanations.

The first question on the solutions video illustrating Dewey's last phase.	
 	Testing the selected hypothesis: Before Derek presents his solution, he demonstrates that the common responses (sand, water) don't exhibit the behaviour of the rolling cylinder. Derek shows "This contains some powder... Let's see how it rolls... It doesn't seem to roll very far before it stops, and then it won't roll again" "Nearly 25% of you said a cylinder half full of water, so let's try that. This rolls very well, so it's (the mystery cylinder) not water" Then Derek provides the solution, and explains the physics.

Figure 4.7: The first question illustrating Dewey's last phase; testing the hypothesis.

This pattern is also present in the three other questions and solutions where the video questions follow Dewey's phases of reflection.

4.3 Electricity Videos

The specifics of the three pillars (craft of multimedia creation, subtleties of physics content, and the use of Dewey’s phases of reflection) applied to the selection of videos and the third and final research phases focuses. These concerned electricity and circuits and are described in this section.

Prior to running the experiment, I worked as a science consultant on a Discovery Channel TV documentary series, which showcased “bizarre” science. The show used hundreds of minute-length online video clips hooks and the science behind them was later discussed. These clips covered aa variety of content from physics, biology, and chemistry, and were of varying quality; some where fantastic and some mediocre. One clip that stood out was of a strangely dressed man floating in a swimming pool at night, while being struck by “bolts of lightning” from a nearby Tesla coil. Upon closer inspection, one can see that he is wearing a tinfoil hat, a metal gauntlet, and that there is also a grounding wire hanging off the edge of the pool. This clip was fantastically engaging and could have had much pedagogical value, due to its startling and surprising nature. I emailed Dr. Peter Terren, the creator and swimmer in the video, to clarify some specifics about the video. I also asked for his permission to use it as part of the research, to which he agreed.

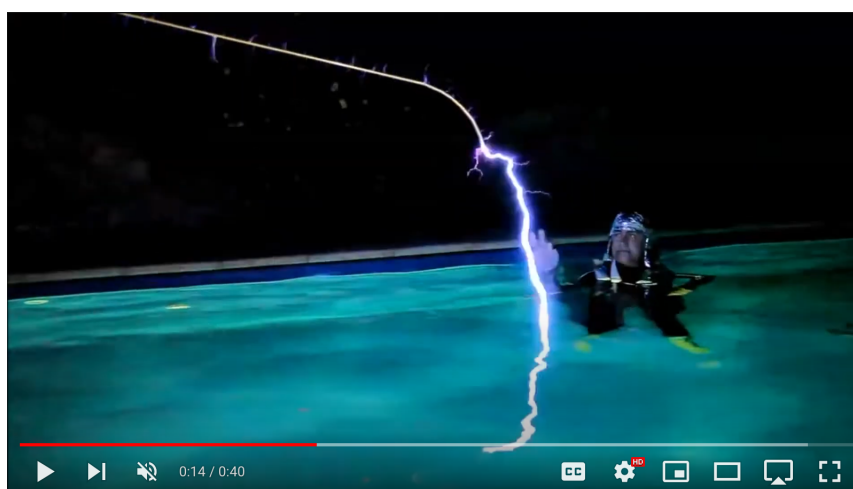


Figure 4.8: The Electricity Video

4.3.1 Electricity Video: Creating the Video for Study 3

One of the striking differences between this video and the the mechanics videos is the setting. The mechanics riddles were filmed outdoors, were well lit, and there was a degree of professional polish to them. This video is in many ways the opposite; it is filmed in a swimming pool, at night, with the primary source of illumination being the light inside the pool and the sparks of the Tesla coil. The viewer might perceive this video as backyard science and is almost amateurish. Yet, there is a highly surprising experience presented on screen and the amateurish look of the video may result in it seeming more believable to the viewer. is results in a more authentic feel. If students doubt the video's veracity, the amateurish look of this video helps to sell the realism of the experience. Despite the surface-level differences between this video and the videos shot by Derek Muller, this video was a good fit for the third study. The physics was appropriate for the audience and a question could be posed in such a way as to match Dewey's phases of reflection.

As the experience was the core of the video, a question was necessary, along with the relevant clues; this would be the relevant scaffolding to turn the experience into a riddle video worth reflecting on. I briefly considered being the presenter myself, but decided that the data analysis would be more impartial if I weren't also in front of the camera. Jules Rankin, an honours student at the SUPER group, agreed to present the videos. I carefully scripted the three Question videos, and one answer video, discussed the scripts with the members of the SUPER group and a professors at the School of Physics. The videos were then filmed, with Joules in front of a green screen, enabling the background to be replaced with the video of the swimming pool and the Tesla coil. The videos were edited in Final Cut Pro X.

To address the research question, it was important to show the students different questions, with different clues. As such, three question videos were made.

The solution to all three riddles was the same as they were the same riddle but featured different clues. Therefore, only one solution video was produced. The intro and question section of all three videos were identical, and they were also identical in length (at 42 seconds long) and in the shots selected. It was important that the videos were consistent and only varied the audio track which provided, or did not provide, clues to the students. The only visual difference between the three videos was featured in the video with *good clues*, which included three red circles highlighting the salient information. This is discussed in the following paragraph.

	No Clues	Good Clues	Bad Clues
Intro	The same intro for all three videos — welcoming the students, priming them for the counterintuitive nature of the question.		
Clues	No clues provided — just silence over the footage.	“Good clues” provided — pointing out the salient information — including highlighting the visuals with a red circle. “you might notice he’s wearing a metal glove which is touching the salt water and also an aluminium hat and there’s also a wire connected to the Tesla coil which is hanging inside the pool”	“Bad clues” provided — mentioning a fact which is true, but unimportant to the solution of this video. This fact also plays into a common misconception about electrical circuits. “A Tesla coil produces very high voltage, but relatively low current — could this be the secret to his survival?”
Question	The same question for all three videos — providing the solution to the question.		
Solution (separate video)	All the students watch the same solution video, no matter what question video they watched.		

Table 4.1: A guide to to differences and similarities between the videos produced

All three question videos began with Jules located in the centre of the frame against a dark background. The video was filmed on a green-screen and the background was a shot from the pool video. This maintained a coherent look and feel within the video and made the transition between “the question” and “the experience” coherent. Jules greets the students and begins to ask the question. As with the previous video, there are a few sentences to prime the audience to expect a counter-intuitive riddle, rather than a straight-forward and typical electricity riddle. He then asks the question.



Figure 4.9: The introduction to the electricity riddle video

“Hi everyone. I hope you’re all doing well. So, we all know that electricity is incredibly dangerous, and we’ve been told since we were kids that electricity and water don’t mix... So how can this man swimming in a pool survive from being struck by two hundred thousand volts from a Tesla coil? ”

After this the three videos split in their content and as such they will be covered one by one.

No Clues During the *No clues* video, there is no extra voice over during the video. This section contains only videos of the man swimming in the pool. The shot selection is identical, as is the run-time of the video (42 seconds).

Good Clues During the *good clues* video there are both visual and audio clues, and hence changes to the video compared to the *no clues* version. While the timings and framing of each shot are identical, a motion-tracked bright red circle is added to point out the important features, as they are mentioned by Jules. For example, when Jules says “you may notice that he is wearing a metal

glove”, a bright red circle appears around the metal glove. The red circle was selected to look hand-drawn, in keeping with the backyard science aesthetic.

This was intended to accentuate that these clues were important and worth paying attention to. To do this, two of Mayer’s principles were followed: the signalling principle and the temporal congruence principle. The signalling principle states that as a large amount of information is presented in the visual medium it is important to signal to the viewer what is important. This was achieved by inserting the brightest, most saturated red circle possible around the important clue. This was particularly important for the grounding wire which hung in the pool. Eye tracking research shows that the human eye gravitates towards the brightest parts of an image, as well as the parts of the image that have the most saturated and vivid colours, areas of high contrast, and areas close to human faces (Beach and McConnel, 2019; Peißl et al., 2018; Majaranta and Bulling, 2014; Oyekoya and Stentiford, 2004; Eckstein, 2017). As so much of the vital information to convey was next to the human face, and in areas of high contrast (the spark contrasting against the black background), it was likely that the the students’ eyes would be drawn to these areas of the screen anyway. However, the saturated red circle explicitly signals to the viewer and helps to draw the eye even more. A vital clue, the grounding wire, is barely visible without explicitly signalling that this is an important clue; otherwise, it is likely that the students would have missed it. This accentuation is achieved visually, with the red circle, and also in the narration.

As all of these clues are shown on screen while Jules reads out the following script “you might notice he’s wearing a metal glove which is touching the salt water. And also an aluminium hat. And there’s also a wire connected to the Tesla coil which is hanging inside the pool”. After each one of these statements there is a pause which gives the students time to absorb this information and perhaps begin to generate spontaneous interpretations of what they are seeing.



Figure 4.10: Red circle signalling the glove

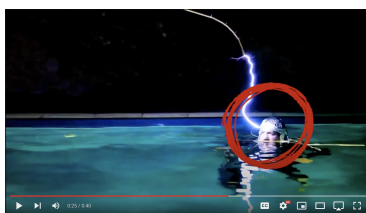


Figure 4.11: Red circle signalling the hat

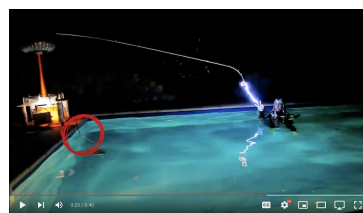


Figure 4.12: Red circle signalling the wire

The shooting and editing process were planned so that the script matched the visuals on screen. The script was read and edited so that the glove is seen when the glove is mentioned, the hat is seen when the hat is mentioned, and so on. This was intended to follow (Mayer and Moreno, 1998)’s temporal contiguity principle, once again managing the students’ cognitive load and focusing their attention on the clues.

Bad Clues The *bad clues* video was identical to the *no clues* video, with the only change featuring in the voice over. Instead of silence over the the footage, Jules provides information about Tesla coils which is true and believable, but does not lead the students to the right solution. The bad clue was written to be believable and was based on a common student misconception about electrical circuits (Saxena, 1992). Jules reads “A Tesla coil produces very high voltage, but relatively low current — could this be the secret to his survival?”.

This is a bad clue and a red herring; the clue is designed to push the students’ thought process away from the solution. It was important that this red herring was effective and that students could find it a plausible explanation to the perplexing experience they just witnessed on their screens. To make it believable, the clue was based on a common misconception about electricity, namely, that current is what is dangerous to humans and the voltage is not an important contributor (Raduta, 2005). This is discussed in more detail in the next section.

As with the mechanics videos, it was vital that the right physics question was

chosen. For this study only first year physics undergraduate students at the University of Sydney would watch the video and not the general public. As this work was conducted during the second semester, it was important that the topic relate to what was being taught at the time which was electrical circuits. As discussed in the literature review chapter, there were many reasons to select the topic of electrical circuits. There is a wealth of literature on students' alternative understandings related to electrical circuits (Andre and Ding, 1991; Sencar and Eryilmaz, 2004; Franklin, 1992; Hermita et al., 2017; Saxena, 1992; Raduta, 2005) and there are also studies about multimedia treatments to address them (Adrian, 1997; Sadaghiani, 2011). This video was well suited to explore the research questions. To answer the question, the students need only basic prior knowledge about circuits, prior knowledge that all first year physics students should have, as they would have learned about electricity in high school and would have revised it recently in the first lectures of the semester. However the video was tricky and counter intuitive, requiring some connecting of dots, a synthesis of ideas, and the application of simple physics to a new, perplexing environment. In this way, it was similar to the questions posed in the mechanics video, it was a perplexing question dealing with uncomplicated physics. It takes some abstraction to think of the Tesla coil, the spark, the person, and the water as a circuit. This is a deviation from the normal ways electricity is taught, where circuits are made of batteries, wires, and resistors. A simplified model of the circuit is presented in Figure 4.13. By abstracting this perplexing experience, looking deeper, simplifying the scenario, and drawing a circuit, the answer becomes obvious. The person has a higher resistance value than the metal suit, glove, hat, and salt water. It is possible to model this as a simple circuit featuring a power supply and two resistors connected in parallel. The person is a resistor with a higher value, the suit-glove-hat combination comprise a resistor with a lower value. As the suit-glove-hat is substantially

more conductive, most of the current will flow through the suit-glove-hat and not through the person.

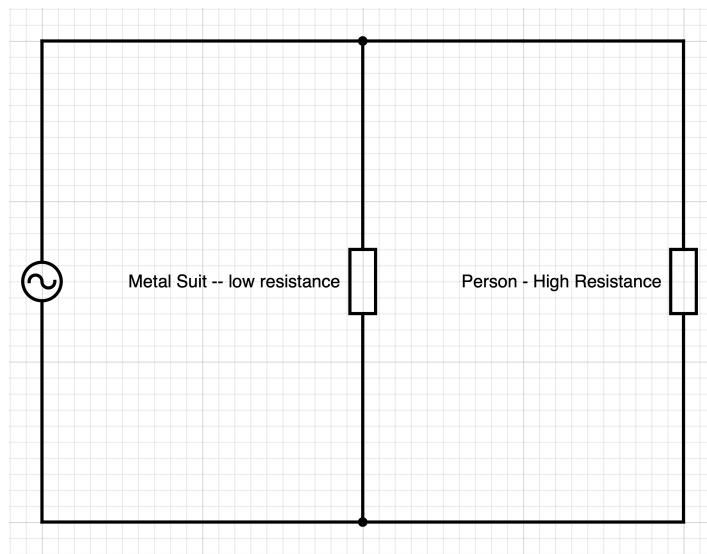


Figure 4.13: Simplified model of the circuit. The AC source is a Tesla coil; the metal suit, hat, and glove are a resistor with a low resistance; and the person is a resistor with a high resistance

The bad clues script was written in such a way as to play on the common electrical safety misconception, that current is the most dangerous electrical characteristic, and that voltage is not important. This is strongly tied to another common misconception that voltage, current, and resistant are thought of independently, instead of as inexorably connected together by Ohm's law (Andre and Ding, 1991).

$$I = \frac{V}{R} \quad (4.2)$$

A number of alternative bad clues were considered but were dismissed. One idea was to include the information about the high frequency AC supplied by the Tesla coil. At higher frequencies more and more of the current density becomes distributed near the surface of a conductor (Lamb, 1883). This is known as the skin effect and it's described by the formula.

$$J = J_S e^{-(1+j)d/\delta} \quad (4.3)$$

where J is current density, J_S is the value at the surface, d is depth from the surface, and δ is the skin depth. Due to the high frequency of the Tesla coil, this effect is indeed helpful to our swimmer, but it is not the primary factor accounting for the swimmer's survival. This bad clue was considered seriously for the red-herring, but was not selected as it featured an unfamiliar concept to all first-year physics students. The red herring would need to work for all the students, not just the ones who are familiar with this more advanced concept in electromagnetism. The goal with these videos was to create a perplexing experience for all that watched it, and for the bad clue to be equally believable to all. This would have complicated the data analysis significantly. Disentangling whether a student didn't write down the answer implicit in the bad clue because they didn't believe in it, or because they didn't understand the red herring, would have been complex. Hence, a more common electricity misconception was chosen.

4.3.2 Electricity: Reflection

The third pillar for designing these videos was reflection. The videos needed to follow the theoretical framework: Dewey's phases of reflection. They needed to follow the same structure as the mechanics videos and had to keep the underlying pedagogy consistent. The video needed to begin with a perplexing experience. Time needed to be left for the students to spontaneously interpret this experience. The question then had to be asked and the students had to then be prompted to generate possible explanations to the question. This had to be worked into a hypothesis which would then be checked to see how well it worked given previous knowledge, or through testing it in the real world. Solutions then had to be written down.

Designing a visually perplexing experience is relatively straightforward for mechanics as this area of physics is very visual. There are plenty of objects that behave in perplexing ways. For example, a spinning top that flips as it spins or can only spin one way, or a tennis racket that is unstable as it spins on its intermediate axis, or a cylinder that intermittently rolls and stops. It was important to find an equally striking, visually dramatic demonstration for electricity and circuits. As discussed in the previous sections, the video of the person swimming in a pool whilst being struck with bolts of electricity from a tesla coil was ideal. It was highly visual and shocking for the viewers (and likely the swimmer). When it was first encountered, it was genuinely perplexing to members of the SUPER group. If John Dewey saw this video, he certainly would agree that the video elicits a “perplexing experience”. Despite the differences between the videos (in the content covered and the presentation style) the pedagogy was the same in both of these videos and they both closely matched Dewey’s framework for reflection. Both allowed students to view and experience something perplexing, which then generated a question. Both provided time for the students to think, generate their ideas, and then provided the solution.

Given Dewey’s emphasis on the importance of doubt in reflection, an important research question concerned the clues given to students and student reflection changed when the questions are altered. Furthermore, it concerned what types of reflection students would engage in when different questions were provided. To explore these questions, all three question videos asked the same question, but provide different clues. The analysis of the data is presented in chapter 7.

4.4 Summary of the The Design Philosophy

The videos were designed with three pillars in mind: the craft of multimedia creation, the subtleties of the physics content, and the use of Dewey’s phases of reflection as a design principle. The details of each of these have been outlined

along with their application in the videos within this chapter. In the next three chapters, the specific details of the studies are discussed and the results for each study are presented.

Chapter 5

Study One: Reflection in the Context of Social Media

Alive without breath,
As cold as death;
Never thirsty, ever drinking,
All in mail never clinking

J.R.R. Tolkein

5.1 Introduction

The broad aim of this study is to investigate how effective videos (designed in keeping with Dewey's phases of reflective thinking) are at stimulating critical reflection as defined by Mezirow (Mezirow et al., 1990; Mezirow, 1998; Rogers, 2001; Dewey, 1933). The research questions of this study are specific to the individual riddles, from a set of four, presented on the YouTube channel Veritasium:

The two broad research questions for this study were:

1. What percentages of respondents who indicated that their answers were correct, changed their answers or did not change their answers?

2. What reasons were given by respondents for not changing their answers and how would students elucidate their own reflective thinking?

The subsequent sections present the pertinent background on the use of videos on YouTube as a learning technology aimed at improving reflective thinking, drawing on the theoretical perspectives of Dewey's phases and Mezirow's taxonomy. This is followed by a detailed description of the methodology, including the specific riddles used from the Veritasium channel, and the methods for data collection and analysis. Results and discussion sections then evaluate the effectiveness of these educational strategies.

5.2 Background

5.2.1 Linear Videos: YouTube as a Learning Technology

The emergence of YouTube as a pivotal tool in informal learning marks a significant shift in how individuals acquire knowledge and skills outside traditional educational settings. Greenhow et al. (2016) emphasize the platform's ability to facilitate self-directed learning, where learners independently navigate a vast array of content based on their unique interests and learning paces. This autonomous approach to learning is further complemented by the diverse range of content available on YouTube, spanning step-by-step tutorials to in-depth discussions. Kousar and Qasim (2018) highlight the platform's effectiveness in delivering practical demonstrations and visual learning aids, which are particularly advantageous for subjects requiring visual understanding, such as the arts, sciences, and technical skills.

Although some participatory learning occurs (as observed by Burgess and Green) the vast majority of learning on YouTube is linear in nature. They also note that while YouTube allows for user comments and community engagement, these features do not equate to real-time interaction between the

educator and the learner (Burgess and Green, 2018). Unlike interactive educational technologies, YouTube primarily offers a sequential form of content consumption. As noted by Kousar and Qasim, learners on YouTube typically follow a fixed progression of content, with videos structured in a start-to-finish format that closely mirrors traditional classroom lectures (Kousar and Qasim, 2018). This linearity can be particularly evident in tutorial or lecture-style videos, where information is presented in a structured, step-by-step manner, leaving little room for learner-driven exploration or adaptation. The implications of this learning style might limit the development of critical thinking and adaptive learning skills, which are often better fostered through interactive educational experiences.

A gap in the literature concerning what reflective thinking could look like in the context of YouTube and whether videos could be designed specifically to encourage reflective thinking in students. This gap in the literature is a crucial area for future research given society's increasing reliance on digital platforms for learning. Understanding how YouTube can be leveraged to enhance reflective thinking could have significant implications for educational theory and practice, particularly in designing digital content that supports deeper learning and personal development.

5.2.2 Reflective Thinking and Dewey's Phases

In comparing visual reflection in a mirror with internal thoughtful reflection, Wade (1997) eloquently articulates that "As a mirror reflects a physical image, so does reflection as a thought process reveal to us aspects of our experience that might have remained hidden had we not taken the time to consider them." Taking time to discern what may not be obvious can lead to a change in behaviour, can bring an idea closer to application, and can commit one to action (Boud et al., 2013).

Given that reflection emerges in several different fields, as noted by Rogers (2001), there are somewhat differing views on how it is defined. However, most scholars converge on and accept a few common features. These include the following: that reflection requires an experience that can leave the learner puzzled or perplexed; and that reflection is a process that requires active engagement with (involving an investment of time) and allows for what may be hidden to become visible. These features imply that reflection is not linear, but is instead an organic, evolving, and self-referential process. Rogers (2001) notes that:

“The process of reflection does not always have a defined beginning and end. Thus, it should be viewed as continuous, much like an ever-expanding spiral in which challenging situations lead to reflection and ultimately to new interpretations or understanding. These new understandings may then lead to new challenges and additional reflection.”

To study reflection as an evolving, complex, and organic process through all these scenarios poses a challenge. Dewey (1933) creates a clear conceptual framework for the study of reflection, splitting reflection into phases which further elaborate its common features.

1. Experiencing something perplexing.
2. Making spontaneous interpretation of the experience.
3. Naming the problem or question that arises from the experience.
4. Generating possible explanations for the problem or questions posed.
5. Ramifying the questions into a hypothesis.
6. Experimenting or testing the hypothesis.

Dewey’s elaborations, which attempt to providing a mechanism for the construction of reflective learning environments, are not dissimilar from those of other researchers (Liu and Elms, 2019; Mayo et al., 2009; Muller et al., 2008). These processes are non-linear and self-referential and can take on different forms, indicating that there are different types of reflection. Another reason

why reflection is important is because it underpins critical thinking and it is one of the pillars that supports critical thinking.

5.2.3 Taxonomy of Reflection

When one writes a response after engaging in a formal or informal learning activity, the writer is likely responding to and reflecting upon clues built into the prompt. This study draws on reflective thinking in the field of adult education, in particular Mezirow (1998), who distinguishes reflection, as articulated above, from critical reflection.

Reflection does not necessarily imply the making of an assessment of the subject. This distinction differentiates it from critical reflection. Critical reflection may be implicit (like when one automatically chooses between notions of good and evil due to assimilated values) or explicit (like when one mindfully and intentionally examines the rationale behind a choice) (Mezirow, 1998). In making the assessment, Mezirow asserts that the viewers involve their own assumptions which underpin the reflection. This feature is particularly evident in adult learners. The term Critical Reflection on Assumptions (CRA) is used when the objects involved in the experience are assessed based on the viewer's assumptions regarding the presenter, the source, content, and context; this reflects an outward focus. Critical Self-Reflection on Assumptions (CSRA), on the other hand, involves assessing one's own concepts, beliefs, feelings or actions in view of the experience. This could mean assessing one's own knowledge, emotions, or responses; this reflects an inward focus. Both of these types of critical reflection involve analysing warranted or unwarranted assumptions pertaining to an experience. CRA focuses on outward assumptions and CSRA focuses on inward assumptions. This taxonomy provides a mechanism for ascertaining the nature of reflective thinking which can be applied in the social media based informal learning context.

5.3 Method

This research came together serendipitously. Derek Muller completed his PhD at the SUPER group in 2008. Since then he's made a name for himself as a science communicator and physics educator through his YouTube Channel 'Veritasium'. Research questions relating to his work included educational videos and the concept of critical thinking (the focus of this research would later become reflection). On the 8th of April, Derek posted a video containing four riddles, and reached out to see if I could read through and categorize comments on the video, to see some of the common answers that the students were giving to the riddles. Given there were already thousands of comments on the video, only a fraction of them were read until a set of typical answers for each question were identified. Derek presented these rudimentary statistics as part of the solutions video, to give a sense of how his viewers did on these riddles.

While reading the YouTube comments their answers were considered through the notion of critical thinking. An interesting opportunity for a pilot study presented itself in seeing whether the viewers did or did not change their answers after being presented with the solutions. These riddles were tricky and many of commenter answers were wrong (or at least, not quite right). This research might consider 1) how many viewers changed their answers, and 2) how the viewers who did not change their answers, justified not doing so. A simple survey was drafted for inclusion in a link under the video (with Derek's permission). Only a few hours later the data was accumulating.

5.3.1 The Questions

The videos used in this study were from the YouTube channel 'Veritasium'. Video 1 contained four questions and video two contained the solutions to the questions. While the videos were not specifically designed to follow Dewey's

1. After watching the solutions video, did your answer to question 1 (mystery cylinder) change?

☐ Yes

☐ No

☐ My answer was correct.

If you answered No - why did your answer not change?

Figure 5.1: Screenshot from the survey focusing on question one of the four riddles

phases of reflection, they did align well. Video 1 captures Dewey’s phases through an experience, posing a question, and the generation of possible explanations. These questions are explained in detail in figures 4.6 and 4.8 in the previous chapter.

5.3.2 The Survey Instrument and Data Collection

Video 1 was published on YouTube followed a week later by video 2. The description box under video two contained a link to the survey hosted on SurveyMonkey®. The survey consisted of one question, containing two parts, duplicated for each of the riddles. For riddle one, the survey asked ‘After watching the solutions video, did your answer to question (riddle) 1 change?’ Respondents could only select one of the following options, ‘Yes’, ‘No’, and ‘My answer was correct’. This part of the survey allowed us to answer the first research question quantitatively. To answer the second research question, we asked another question: ‘If you answered No — why did your answer not change?’ The survey included a text box where the respondents were asked to write their answers. Figure 1 shows how the questions appeared to the viewer.

5.4 Data Analysis

The data from SurveyMonkey® were exported to an Excel spreadsheet and examined to determine if responses were ‘legitimate’. In particular, with the

written responses, if a respondent gave an obvious or silly answer they would be removed. There were no such cases and no data were removed.

Data were analysed with a mixed methods approach (Creswell, 2014). They were analysed quantitatively, by counting the numbers of responses, converting this data into percentages, and generating graphs. This addressed the first research question. Qualitative coding was used to answer the second research question. The subsequent quantitative analysis was quite simple. Three mutually exclusive buttons were available to the participants “My answer was correct”, “I did change my answer”, and “I did not change my answer”. The analysis essentially consisted of exporting the data from SurveyMonkey, importing it into excel, and using the excel function “countif(‘ ’)” to count the numbers for each one of the four questions.

The qualitative data analysis was more complicated. The survey participants were encouraged to write why they did not change their answers within a “free-form” answer. Therefore, the first step of the analysis was to read the data thoroughly while identifying patterns and grouping responses in terms of similarities and differences. Many ways of grouping the data were tested; some codes were quite obvious to identify (such as “My answer was correct”) and others were more complex. After a few iterations and discussions seven codes were identified which are presented in this chapter. These codes emerged organically. After a good set of codes was identified, a random set of 50 responses for each riddle were coded using them. The coding was debated and discussions centred around edge cases and responses that could fit into more than one category. The codes were refined and finalized by two researchers following these discussions. All the responses for each riddle were then independently coded by the same two researchers. The two researchers compared the sorting of responses and made minor changes. Thus, the written responses were inductively coded through an iterative process of coding, comparing, consolidating,

and refining by the two researchers (Burla et al., 2008). As a further check, a third researcher was provided with 50 responses from each riddle to code. The inter-coder reliability was (82.5%) indicating that the categories were robust and categorization of responses to the categories was reliable.

5.5 Sample

The videos attracted more than one million views each. Among the viewers 2220 completed the survey within a week following the release of video two. The sample of 2220 survey participants included viewers who engage with the popular science YouTube channel ‘Veritasium’ for informal learning. At the time of the study, the channel had approximately five million subscribers and 500 million views. The respondents would likely be adults who were lifelong learners of science or, at the very least, were interested enough in science to watch two YouTube videos, answer the riddles, and fill out the survey. The study thus used convenience sampling. The sample was not representative of the general public. Respondents were interested in science and seek out and follow at least one science communication channel. Their behaviour was reasoned and planned providing an interesting perspective on a range of questions, ranging from what fraction reported that they were correct, to why some followers did not change their answers.

5.6 Results and Discussion

The first research question probed the percentages of respondents who indicated that their answers were correct and those who did change their answers or did not. Table 5.1 shows these percentages together with the numbers of respondents. It is worth noting that most respondents persisted in completing the survey for all four riddles. There was variation among the results for

	Number and percentage of respondents for each riddle			
	One	Two	Three	Four
My answer is correct	361 (16%)	695 (31%)	843 (38%)	962 (43%)
I did change my answer	1614 (73%)	1369 (62%)	1143 (52%)	1080 (49%)
I did not change my answer	245 (11%)	154 (7%)	229 (10%)	176 (8%)
Total	2220 (100%)	2218 (100%)	2215 (100%)	2218 (100%)

Table 5.1: The numbers and percentages of responses in each group for each riddle

the respective riddles. 73% of respondents to riddle one said that they did change their answer, whilst less than half did so for riddle four. Only 16% of respondents said that their answer was correct for riddle one, whilst twice as many said that their answers were correct for the other riddles. Whilst there are substantive shifts between the percentages of those who did change their answer and said that their answer was correct, the percentage of those who did not change their answer was within a narrow band of 7%–11%.

The percentages of respondents who indicated that their answer was correct ranged from 16%–43%. It is noteworthy that a larger percentage, 49%–73%, did indicate that they changed their answer; this group responded and took action. There could be a combination of reasons for this distribution. For example, the riddles could have been pedagogically sound, aligning with the phases of reflection outlined by Dewey (1933), and prompting respondents to change their answers. Furthermore, the behaviour could align with the seek and follow behaviour associated with YouTube channels. If those who changed their answers are combined with those who were correct, a more consistent value of around 89%–93% across all riddles is obtained. This supports the assertion of Rosenthal (2018), that engagement is perceived as worthwhile as it satisfies a need, is enjoyable, and arises from self-interest or serves as a knowledge gathering exercise. In short, those who did not change their answer were in the a minority (7%–11%).

Another prominent finding is that there is considerable variation from riddle to

riddle. This variation exists even though all the riddles align with the phases of reflection outlined by Dewey (1933), despite the expected seek and follow behaviour of viewers. It appears that the specificity of the riddle matters; this includes the topic, the way it is posed, and even the actual props used. Viewers who chose to complete the survey connect with a community through shared experiences and respond in specific ways. They are sensitive to the experience offered by the riddle and its peculiarities, and their answers are, therefore, nuanced. This is further substantiated by the responses of those who chose not to change their answer.

Research question two focused on the respondents who had indicated that their answer was not correct, and yet, did not change their answer. Whilst this is was a small percentage of the respondents, understanding their reasons could yield clues as to why people seek out and follow, and yet, did not change their answers. Inductive coding of the written responses generated eight categories. The percentages of responses in each of the eight categories for each riddle are shown in Table 2; those attracting more than 20% responses are shaded. Two points are worth noting. First, the riddles attracted different percentages of respondents in each category. Second, the respondents did not respond in the same manner across the riddles and their responses fell into different categories between riddles. The descriptions and examples of typical responses are shown below.

In the first two categories, the respondents did not need to change their answers because they had no answer in the first instance or their initial answer was correct.

I had no answer was typified by the simple response, ‘I had no answer’.

My answer was correct contained responses such as, ‘I had it right’, and ‘I have done this problem before and knew the physics behind it’.

The responses were generally brief but respondents completed the survey dili-

Category	% of responses for each riddle			
	One	Two	Three	Four
I had no answer	7.3	9.7	11.7	26.8
My answer was correct	1.2	15.3	18.8	21.4
I have an alternative solution	22.0	0.0	10.2	12.5
My answer was almost correct	24.5	5.6	1.5	4.5
My answer was almost correct, with explanation	28.2	20.2	4.5	5.4
I am discontented	12.2	24.2	26.9	8.0
I don't fully understand	1.6	16.1	20.8	17.0
Miscellaneous	3.0	8.9	5.6	4.4
Total	100	100	100	100

Table 5.2: Percentage of responses for each riddle, which were categorized into various codes

gently. These two categories attracted the smallest percentage of responses for riddle one (8.5%) and the largest for riddle four (48.2%).

The next three categories were premised on the assumption that the respondents had adequately analysed the science in the videos. They had an alternative solution or the science in the solution video was close enough to the science in their answer and the respondents did not need to change their answers.

I have an alternative solution contained creative alternatives, such as, ‘I still believe my answer (a cylinder with a fluid and a baffle with a few small holes) could exhibit the same behaviour’. In other words, there is more than one solution to this problem. Sometimes a simple statement was provided, such as, ‘Because I have a different explanation to the same problem’.

My answer was almost correct contained simple and direct statements, for example, ‘I was somewhat correct’.

My answer was almost correct, with explanation contained explanations which often demonstrated a level of prior knowledge or that the respondent was drawing on some first-hand experience. Two example answers read: “I answered a viscous liquid. I don’t think the ping pong balls played a fundamental role, since the jar of honey behaved in a similar way.”, and “I did not predict

the ping pong balls but was mostly correct. The ping pong balls seem to affect the cylinder mostly by keeping the air in two spheres which changes the weight distribution but it is still a viscous liquid with an air pocket.”

These three categories included those who indicated that they had alternative solutions or their answers were close enough. These answers often included an explanation. Generating possible explanations is a common feature of reflective thinking, as is examining and testing explanations (Dewey 1933; Rogers 2001). The focus in these reflections was on the content of the experience, appropriateness of the science used to interpret the experience, and rationale for the solution provided. These responses were premised on the assumption that the viewer had adequately assessed the science in the videos, placing them in CRA category as described by Mezirow (1998). The respondents were critically reflecting on the experience, its credibility, plausibility, and authenticity. The respondents were doing this by comparing their answers to the solution provided, reflecting on the validity of the solution, and critically reflecting on the presenter, source, content, and context. There was a comparison between their answers and the answer provided; the answers could be affirming, close enough, explanations generated, or alternatives provided. These reflections were outward focused and the object is external (the riddle). Collectively these three categories attracted the smallest number of responses (16.2%) for riddle three and the largest (74.7%) for riddle one.

In the next two categories, the respondent was more involved, emotions were sometimes involved, questions were raised, and beliefs were in play. These were all potentially positive or negative. These answers allowed for disagreement or incomplete comprehension of aspects of the riddle (or relevant details). Respondents expressed what they had learned from the video or intended to learn. Often they could identify flaws in their own reasoning or gaps in prior knowledge or in the solutions.

I am discontented was often noted in response to specific features of the video which respondents felt were incorrect or they disagreed with such as, ‘I disagree that the solution uses a reasonable interpretation of the question’. Another example was ‘One component of a bike was forgotten, the ratchet on the back wheel. If your bike doesn’t have one, and you pull with less force than the traction ... but the back wheel won’t spin backwards’.

I don’t fully understand was noted by respondents who elaborated, for example, that, ‘I still don’t fully understand the mechanics of bicycles. Need to re-watch the video again’. Another example was, ‘I predicted the bike behaviour correctly, but my explanation was partially wrong ... the net force points backwards, therefore the bike will move always backwards.’

The category **I am discontented** was interesting as the reflections regarded the technicalities of the experience and its interpretation, but a discrepancy was articulated. There was a sense that something was missing or unfair; the respondents sometimes expressed feeling tricked or articulated that they had not expected the explanation from this particular channel. There was discord or discontent and emotions were expressed. The category ‘I don’t fully understand’ contains responses which were not only reflections on the technicalities of the experience but also contained the respondent’s own train of thought. Most respondents expressed an interest and intent to learn more about the topic, aligning themselves with lifelong learning aspirations. Both of these categories align with reflective thinking in that they are examining and testing explanations (Dewey, 1933; Rogers, 2001). In addition, the reflections pertain to the validity of one’s own concepts, beliefs, feelings, or actions. There is an inward focus, falling into Mezirow’s CSRA. Collectively these two categories attracted the smallest percentage of responses for riddle one (13.8%) and the largest for riddle three (47.7%).

Finally, 3.0%–8.9% of the responses were coded as miscellaneous; these re-

sponses could not be meaningfully coded.

Miscellaneous contained responses that were ambiguous or unclear and were not coded.

Typical responses for each code are presented in table 5.3.

Code	“Typical” example
I had no answer	“I had no answer”
My answer was correct	“I had it right”, “I got it correct”
I had an alternative solution	“I had a different explanation to the same problem”
My answer was almost correct	“I was almost correct”, “My answer was somewhat correct”
My answer was almost correct, with explanation	“I answered a viscous liquid. I don’t think the ping pong balls played a fundamental role, since the jar of honey behaved in a similar way.”
I am discontented	“I disagree that the solution uses a reasonable interpretation of the question”
I don’t fully understand	“I still don’t fully understand the mechanics of bicycles. Need to re-watch the video again”

Table 5.3: Typical responses for each code that the respondents provided for not changing their answers

5.7 Implications for Theory and Practice

In this study, the structure of the videos aligned with Dewey’s phases of reflection and affirmed Dewey’s framework in the informal social media learning context. Another important consideration for the creation of videos that encourage reflection is that the riddle matters; there were variations in the types of reflection between the four riddles. Within riddle one, the second set of categories (encompassing the outward focusing CRA) dominates, whilst for riddle three the inward focusing CSRA dominated. This introduces interesting questions for further research, including; “How does the nature of the riddle affect the type of reflection?”. None of the respondents could be consistently placed in the same category for all four riddles; participants changed their responses based on the riddle.

Given the increasing popularity of YouTube videos and other such resources to complement, supplement, and enrich the lifelong learning experiences of those who engage informally, it is important to understand reflective thinking as responses can lead to action. Being opportunistic in nature, this study should to be repeated in different contexts with different riddles. The sample was specific to those who engage with the particular YouTube channel and the subset who chose to complete the survey. Nevertheless, the sample was sufficient to indicate that some reflection occurs, and the responses align with Mezirow's taxonomy. Furthermore, behaviours of respondents align with what is expected for those engaging with YouTube (Rosenthal, 2018). Further research needs to be conducted on different samples, with different riddles, and different subject areas.

5.8 Summary

The reach of social media, such as popular YouTube channels, is conveyed by the sheer numbers of individuals who engage with them. More than one million engaged during the fortnight for which the study ran. The numbers who engaged diligently often did so in the spirit of lifelong learning. In this study, 2220 viewers completed the survey for all four riddles, providing unique answers for each riddle. The vast majority self-reported that their answers were correct or they had changed their answers, affirming their answers or prompting them to change. The responses provided by those who did not change their answers fell into categories corresponding to the critical reflection categories of (Mezirow, 1998) for adult learners. In short, viewers who follow this particular social media YouTube channel, as part of reasoned and planned behaviour, appeared to be critically reflecting as a result of engaging with the riddles. Investigating YouTube as a learning technology for formal and informal learning is justified by the scope and reach as well as its potential impact.

A unique feature of this research is that it investigates known pedagogical perspectives on reflective thinking, and applies them in the domain of informal, social-media-facilitated learning. The initial results from this study are promising; Dewey's phases of reflection and Mezirow's taxonomy of critical reflection are useful tools for encouraging and analysing reflection occurring in the informal learning context. With Dewey's phases of reflection, an appropriate conceptual framework was found. With Mezirow's taxonomy of reflection, an appropriate evaluation framework was found.

As noted, there were several limitations within this pilot study. This study came together in the early stages of a PhD, while a research direction was still being sought out. This research direction is interesting and worthwhile, and the methodology requires refinement, particularly more rigorous sampling and a more robust survey. Another iteration of this research (with the above mentioned improvements) in a more formal academic context promised to yield more interesting results.

Even before the data were collected, it was hoped that there could be a way to connect the viewer's initial answers to what they said on the survey. For example, a way to check if the respondents who reported that they were correct were indeed correct. It's very easy to fool oneself into thinking one had the right answer all along (Mazur, 1999; Crouch and Mazur, 2001). Sadly, this was not technically possible as this experiment required a more controlled setup. In the question time after conference presentations, during poster sessions, and in informal discussions it was frequently brought up that it would be interesting to see how the students answered initially, and to see whether the students noticed that their answer was different to the solution provided, in some cases. These improvements were incorporated into Study 2. The same videos were used and the respondents were first-year physics students at the University of Sydney. Study 2 is described in the next chapter.

Chapter 6

Study Two: Reflection on Physics Riddle Videos by First Year University Students

No-legs lay on one-leg, two legs
sat near on three legs, four legs
got some.

J.R.R. Tolkein

6.1 Introduction

After the success of the pilot study, in the informal context of YouTube science communication, this study was conducted in the context of a first-year physics class at The University of Sydney.

As flipped, blended, and online learning increases in popularity, so does the ubiquity of multimedia as a learning tool, especially linear videos (Davis, 2013; Hill et al., 2015; Yeung et al., 2016). Asking students questions is also very common, occurring face-to-face, in exams, and online (Tune et al., 2013; Brualdi Timmins, 1998; Hargie, 1978). Combining the question, solution, and

reflection framework with online educational video typically requires a linear, non-interactive medium to be retrofitted with interactivity. Students could be asked to provide their answers while the video pauses (this scaffolds student learning) or to provide their answers at the end and to compare it with the solutions provided (Mayo et al., 2009). While comparing, students reflect on their answers (Dewey, 1933; Rodgers, 2002). Important questions concern whether students notice that their answers are the same as the solution or not, and how students reconcile their thinking and decide whether to modify their answers or not. This process of reflective thinking takes different forms and is regarded as an effective mechanism to aid learning (Mezirow, 1998; Hubbs and Brand, 2005; Lebedev and Sharma, 2019). However, the process of reflective thinking is under researched in the context of online physics education videos.

This study attempts to probe reflective thinking with first year university physics students using question, solution, reflection style online educational videos. The first research question is quantitative, seeking to obtain a sense of the decisions students made.

The two broad research questions for Study 2 were:

1. How many students modified or did not modify their answers, with respect to whether their answers to questions shown in a video matched/did not match the solution provided in another video?
2. What reasons did students give for modifying their answers or not modifying their answers?

6.2 Background

6.2.1 Multimedia

Multimedia as a learning tool can be incredibly effective, but, like any tool, it must be appropriately designed and deployed (Stelzer et al., 2009; Mayer

and Moreno, 1998; Muller and Sharma, 2005). There are many flavours of educational multimedia, ranging from video and interactive demonstrations to augmented and virtual reality (Perkins et al., 2006; Wieman et al., 2010; Stieff, 2005; Marçal et al., 2018; Psotka, 1995; Bower et al., 2014; Lee and Sharma, 2008). Several well-known pedagogical ideas can help create effective multimedia, such as Socratic dialogue, interactivity, addressing misconceptions, and asking questions (Rose, 1999; Perkins et al., 2006; Muller et al., 2008). Asking questions, in particular, is one of the hallmarks of reflective thinking (Dewey, 1933).

6.3 Methodology

6.3.1 Context

The study was conducted in the first semester of a first-year physics course covering mechanics, thermodynamics, and waves at The University of Sydney. This course consists of lectures and tutorials and laboratory classes with an online ‘pre-lab’ activity completed outside of class time. The ‘pre-lab’, administered through the learning management site Canvas, is accessible for a week. The study ran as a ‘pre-lab’ activity in concert with the lectures on mechanics. The activity was not graded but participation contributed 0.125 percent towards student final marks.

6.3.2 Procedure and Intervention

Students were asked to log into Canvas where a link took them to a secure university platform (RedCAP) in accordance with university human ethics research protocols. Figure 6.1 shows the four components to this activity: (a) a video one containing four questions, (b) part one of the survey, followed by a page break (which meant that students could not go back and alter inputs), (c)

aa second video containing solutions, and (d) part two of the survey. While the activity was open for a week and students could take a long time to complete the activity, they were allowed only one attempt.

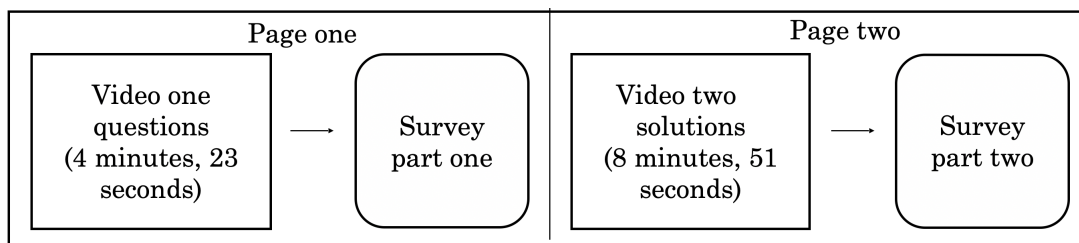


Figure 6.1: The structure of the intervention: Page one contains the question video and the first part of the survey, followed by a page break; page two contains the solutions video and the second part of the survey. The two pages are separated by a page break that prevents students from going back.

Page One: Question Video

The questions video was from the YouTube channel ‘Veritasium ’by Dr Derek Muller. It was an embedded YouTube link which could be paused and re-played. The video presented a sequence of four different situations, primarily on mechanics, posing a question for each (see table 6.1). While the situations and the questions varied in style and content, they were all perplexing. This invited explanations in line with Dewey’s phases of reflection. Figure 6.2 illustrates how different parts of the video follow the first three of Dewey’s phases of reflection in question one; an experience was shown, there was a pause for the viewers to process the experience, the question was posed, and viewers were asked to generate possible explanations.

Question number and its focus	What was asked?
Question One Focus on concepts such as: rotation, inclined plane, centre of gravity, buoyancy	A cylinder is shown to roll down an inclined plane. It rolls, then stops, then rolls again. What is inside the mystery cylinder?
Question Two Focus on concepts such as: rotation, net force, gear ratios	A bicycle has a string attached to the back wheel. The bike is gently supported so it does not tip over. If you pull backwards on the string, which way will the bike move?
Question Three Focus on the calculation of: time, distance, and average speed	When running around a lap of a track, you run at speed . At what speed do you need to run the second lap, so that the average speed of the two laps is equal to 2 times ?
Question Four Focus on knowledge of: wheels, train tracks	A normal train is moving along train tracks. As the train is moving forwards, what part of the train is moving backwards relative to the ground?

Table 6.1: The four questions, their focus, and the specifics of what was being asked, which aligned with the content being covered in the course.

The first question illustrating Dewey's first three phases.	
	The experience and interpretation: The question begins with Derek Muller, showing the behaviour of a 'mystery cylinder'. Derek places the cylinder on the ramp and narrates "... and we will see that, it rolls and then it stops. And then it rolls, and then it stops".
	Naming of the problem: Then the video zooms in to the cylinder rolling, and then stopping. This is the "experience" and "interpretation" phase of reflection. Then Derek poses the question "what's inside the mystery cylinder?"
	Encouraging the generation of explanation, and ramifying into a hypothesis: "you can simply leave your answers in the comments below"

Figure 6.2: The first question illustrating Dewey's phases; the experience, naming the problem, and generation an explanation.

Page One: Survey 1

The students were asked: “Have you seen this video before?”, with the options being yes or no. In part one of the survey, students were prompted to write down their answers to each question in a free-response text box (e.g., “what is your answer to question x (description of question)”). This was followed by a “next page” button. If any text box was left vacant, the students could not progress. After students moved to page two, they could not go back to page one, and so they could not retroactively change their answers.

Page Two: Solutions Video

The solutions video presented the solutions, completing Dewey’s phases by testing the selected hypothesis (see figure 6.3).

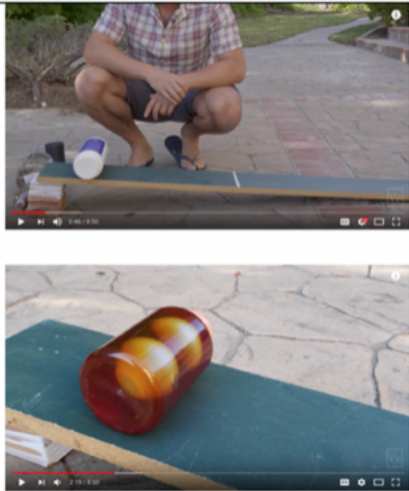
The first question on the solutions video illustrating Dewey’s last phase.	
	Testing the selected hypothesis: Before Derek presents his solution, he demonstrates that the common responses (sand, water) don’t exhibit the behaviour of the rolling cylinder. Derek shows “This contains some powder... Let’s see how it rolls... It doesn’t seem to roll very far before it stops, and then it won’t roll again” “Nearly 25% of you said a cylinder half full of water, so let’s try that. This rolls very well, so it’s (the mystery cylinder) not water” Then Derek provides the solution, and explains the physics.

Figure 6.3: The first question illustrating Dewey’s last phase; testing the hypothesis.

Page Two: Survey Two

Part two of the survey asked: “After watching the solutions video, did your answer to question one (description of the question) change?” There were two

response options: “Yes I did change my answer” and “no I did not change my answer”. If the student selected “I did change my answer” the next statement read “I did change my answer because”. If the student selected “I did not change my answer” the next statement read “I did not change my answer because”. This was repeated for the four questions.

6.4 Data Analysis

After removing incomplete responses and those who did not consent, 508 student responses remained. The data were analysed using a mixed-method approach (Wisdom and Creswell, 2013). Analysis of the data from the first part of the survey involved identifying if student answers matched the solution using a matching protocol as outlined in table 6.2. The matching protocol didn’t focus on the correctness of student answers but rather on whether those answers matched the solution provided. The matching protocol was developed to identify the common ways of re-phrasing the correct solution used by students in their answers. A cornerstone of reflection is the act of comparing and distinguishing one’s answer from the given solution, which is why the matching protocol focused on the match between the solution and student answer, rather than “correctness”. The protocol was discussed with and refined in consultations with my research supervisor.

The analysis from the second part of the survey required coding. The data was thoroughly read and reviewed, and a coding scheme was iteratively developed. The first group to be coded was the cluster of answers in which responses did not match and were not modified (“did not match – unmodified”). The student responses were inductively coded and they aligned with Study 1 (Lebedev and Sharma 2019). The coding used in Lebedev and Sharma (2019) had not been pursued from the beginning because the sample was different; it emerged from public engagement with informal education participants whose motivations are

Question/solution number	What was matched and not matched?
Solution to Question One	Ping-pong ball(s) in honey/viscous fluid is matched. Sand, pendulums, gyroscopes, non-Newtonian fluids, centre of mass, are not matched.
Solution to Question Two	It will usually move backwards, but it depends on the gear ratio is a match. Friction, net-force, torque without gear ratio are not matched.
Solution to Question Three	It is impossible, or you must run at an infinite speed are matches. Calculations with other results are not matched.
Solution to Question Four	‘Flange’ or a qualitative description such as, the part of the wheel that sticks out below the track moves backwards are matched. Smoke, brakes or other answers are not matched.

Table 6.2: Matching protocol developed from the solutions video.

different from the sample of first year university physics students. The second group, which was ”did match – unmodified”, was coded deductively, using coding developed in Study 1. The third group, which was ”did not match – modified”, were inductively coded, as no prior codes have been established for modified responses. The codes for the third group were used for the fourth group, did match – modified.

After all data were coded, a sample of 60 student responses were independently coded by a co-supervisor. The inter-coder reliability of 85% affirmed the validity and robustness of the codes.

6.5 Results and Discussion

Table 6.3 displays the data corresponding to the first research question. The number of students whose answers did or did not match are shown, followed by the number who modified or did not modify their answers.

The numbers of students with matched answers was small for questions one and two. This was approximately doubled for question four and more than doubled for question three. A substantial percentage of students provided answers that did not match. When looking at questions one, two, and four for not matched answers, most students did modify their answers. However, for

Matched					Not matched			
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Modified	2 (0)	6 (1)	15 (3)	12 (2)	358 (70)	319 (63)	256 (50)	251 (49)
Unmodified	28 (6)	32 (6)	171 (34)	74 (15)	120 (24)	151 (30)	66 (13)	171 (34)
Total	30 (6)	38 (7)	186 (37)	86 (17)	478 (94)	470 (93)	322 (63)	422 (83)

Table 6.3: The numbers of students whose answers did or did not match for the four questions, and whether they modified or did not modify their answers after watching the solutions video (including percentages in brackets with respect to the total 508 responses)

not matched answers, the numbers of the students who did not modify their answers despite seeing the solutions video was nontrivial, at 24 to 34%. The reasons the students did not modify their answers, is the subject of research question two.

A pattern is visible in table 6.3 which involves the question types and the matching protocol. Students decided to modify or not modify without being aware of the matching protocol or whether their answers were deemed matched or not matched. The matching protocol (see table 6.2) was equally discriminating for all questions, in that only particular variants on the solution were accepted and these rules were applied consistently. Questions one and two expected students to integrate concepts and were experiential in nature. Question one was mysterious, inviting a level of informed guessing. Question two was cheeky; the students were asked which way the bike would move with the solution being that it would usually move backwards, but it depends on certain factors. For both these questions, students responded and came up with possible explanations. Most students picked up on the clues, had answers that did not match the solution, and modified their answers. On the other hand, a nontrivial percentage did not modify their answers even though their answers did not match. These reflections were probed further by coding the responses.

Question three played with the students' intuition and it was mathematical in nature, with a clear solution. Students whose answers matched, did not modify; those whose answers did not match, mostly modified. Question four was playful; requiring technical knowledge of trains and tracks as well as knowledge of Newton's third law and it had a somewhat obscure solution. This question had the largest percentage of students who had answers which were not matched and which were not modified. Despite the fact that the questions were posed as closed questions, all questions were perplexing and one could offer possible explanations as outlined in Dewey's phases.

The second research question explored the types of reflections. Table 6.4 contains student quotes illustrating the categories of reflection. Note that this coding began as inductive and switched to deductive when data saturation had occurred, therefore, the categories and the similarities are a-posteriori. Thus, during while comparing and distinguishing their answer from the solution (a cornerstone of reflection) students could and did provide similar reasons for both modifying and not modifying their answers. Individual students were tracked through the four questions; no tendency was found in which students consistently provided the same type of reflection for several questions. Table 6.5 presents the number of students in each category for students who both modified and did not modify answers when answers did not match as these were the prevalent categories (see table 3). Next, the categories are discussed drawing on tables 6.4 and 6.5

The "correct", "wrong", and "repeating the solution" categories include answers in which students noticed the clues in the solutions and acknowledged that there was agreement or not. Similarity or mirroring was found between correct and incorrect answers; here students noted that "I did not change my answer because my answer was correct" which was similar to (and mirrored) another answer which read "I did change my answer because my answer was in-

Types of reflection for modified		Types of reflection for Unmodified	
My answer was wrong	“My answer was wrong”, “my logic was wrong” “stationary was incorrect, the force provided could move the bike forward or backward depending on the gear ratio and other factors”	My answer was correct	“my answer was correct”
I am repeating the solution	A comment that repeats the solution to the question given in the video		
My answer was almost correct	“I was close but not exactly right”	My answer was almost correct	“Although I was not fully correct, I was still correct.” “I was not completely correct”
My answer was almost correct with explanation	“I got it partly right with the heavy liquid however did not include the ping pong balls.”	My answer was almost correct with explanation	“Although I said thick, sticky, heavy substance the ping pong balls added to the mixture change the centre of gravity”
I had an alternative answer	“My answer would have worked too”	I had an alternative answer	“My idea of a stretchable object inside the cylinder might still exhibit similar behaviour to that shown by the mystery cylinder...”
I don't fully understand	“I changed my answer from liquids to the ping pong balls in the liquid because I was presented with a valid argument as to why this explanation was superior to my own. This answer was also supported with evidence that I was able to see for myself.”	I don't fully understand	“I don't as of yet understand the explanation but I changed my answer as it was incorrect” “I had no knowledge of bikes and now I do”
I am discontented	“...There really wasn't enough information for us to be able to find the answer, the question was asked in a way that made the audience believe there was a set of fixed assumptions that we had to make.”	I am discontented	“As I suspected, the answers change for various scenarios. There really wasn't enough information for us to be able to find the answer, the question was asked in a way that made the audience believe there was a set of fixed assumptions that we had to make.”
Miscellaneous	A student response that could not be coded	Miscellaneous , Watched beforehand	“I watched the video before” A student response that could not be coded

Table 6.4: The reasons students give for modifying or not modifying their answers (category names are in bold)

correct”. When a student repeated the solution, students took action and wrote the solutions from the video down. While this can be seen as a low threshold action in terms of reflective thinking, the act of writing is a meaning-making

	Modified				Unmodified			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Wrong/correct	82(16)	83(16)	49(10)	47(9)	34(7)	64(13)	20(4)	73(14)
Repeating Solution	81(16)	78(15)	80(16)	67(13)				
Wrong & Repeating	163(32)	161(32)	129(25)	114(22)				
Almost	38(7)	2	0	9(2)	43(8)	36(7)	8(2)	55(11)
Almost (ex)	29(6)	8(2)	0	28(6)	16(3)	14(3)	1	15(3)
Alternative	15(3)	0	1	0	16(3)	0	0	5(1)
Almost, Almost (ex) & Alt	82(16)	10(2)	1	37(7)	75(15)	50(10)	9(2)	75(15)
Don't fully understand	99(20)	107(21)	87(16)	74(15)	4(1)	9(2)	13(3)	9(2)
Discontented	2	17(3)	11(2)	1	1	6(1)	17	2
Don't fully understand & Discontented	101(20)	124(24)	98(19)	75(15)	5(1)	15(3)	30	11(2)
Misc	16(3)	24(5)	28(6)	25(5)	6(1)	22(4)	7(1)	12(2)
Total	358(70)	319(63)	256(50)	251(49)	120(24)	151(30)	66(13)	171(34)

Table 6.5: The numbers of students in each category as well as some combined categories for not matched answers (including percentages in brackets with respect to the 508 total responses)

process that moves a learner from one experience of the disciplinary content into the next. When "wrong" and "repeating the solution" categories were combined, 22% to 32% of students reconciled their thinking and acknowledged that their answers required modification.

Categories "almost correct" and "almost correct with an explanation or an alternative answer" appeared in both the modified and unmodified groups. For example, a typical response was "I did not change my answer because my answer was almost the same" as compared to "I did change my answer though my answer was almost the same", both of these responses are coded as "Almost". Another example was that "I did not change my answer because my solution would have worked". This was very similar to "I did change my answer; but my answer would also have worked". Both of these responses were coded as "Alternative". The answer "I did change my answers because I was not completely correct and there were two ping pong balls inside too", was categorized

as "almost correct with explanation". The answer "I did not change my answer because although I said thick, sticky, heavy substance, the ping pong balls added to the mixture changed the centre of gravity". These reflections are mirrors of each other, the students distinguished their answers from the solution in the video, demonstrating an understanding of the relationships and providing a thread that makes the continuity of learning disciplinary content possible. Table 6.5 shows that around 15% of the justifications for both modifying and not modifying answers fell into these categories for question one. For questions two and four, these justifications were more common among unmodified answers. The justifications were very infrequent or short in question three. The categories discussed thus far fall into the overarching type of reflection captured by Mezirow as outward-focusing (where learners focus on the disciplined study of content and tools). They reconciled their answers with what was being covered or taught (Mezirow, 1998).

The single most popular category of reflection which occurred when answers were modified when they did not match was "I don't fully understand", which categorized 15% to 21% of the students. This was reassuring as these students were able to distinguish that their answer was incongruent with the solution. Sometimes students articulated that they didn't know, which was interpreted as an acknowledgement of gaps in their own knowledge. In other instances this was taken as acknowledgement that that they needed to learn more or different things, and still other times that they had learned new things. In terms of reflection, they students demonstrated a disciplined way of thinking which required attitudes that value personal and intellectual growth. The category "discontented" which emerged among both modified and not modified students, was not large was still significant. These responses expressed discontent with the question, solution, content, or presenter. The questions ranged from being cheeky and to inviting a level of informed guessing. Given this, the low number

of students expressing discontent and falling in this category attests to their rising to the challenge. Again, as students reconciled their thinking, the results for reflections for modified and not modified were mirrors of each other. These categories fell into the overarching type of reflection captured by Mezirow's taxonomy, namely, they were inward-focusing, where learners are focused on their own learning and actions and take responsibility for their learning or become emotionally engaged.

Finally, there were responses which could not be coded for various reasons and those who had watched the video before.

Question 3 was once again distinctively differently received due to its straightforward mathematical nature. This made it the most closed question, that is, a question with one direct answer without other possible explanations. Question one was the most open, attracting responses such as "almost correct" to "alternative solution" for both modified and unmodified solutions. Questions 2 and 4 fell in between. Questions that required an integration of concepts and were experiential in nature (such as 1 and 2) as well as those which required specific knowledge (such as question 4) were suited to the generation of possible explanations (in terms of Dewey's phases). Student reflections suggest that these were open questions where multiple plausible answers were offered by students.

6.5.1 Summary

The ubiquity and popularity of online multimedia (Davis, 2013) makes it important to research its educational value. It is also worth exploring not just conceptual gains or student engagement (Hill et al., 2015; Yeung et al., 2016), but reflection, which is under-researched in the context of online educational video. This study points to some interesting results with regards to the question, solution and reflection style of videos. These typically take a linear,

non-interactive medium and makes it interactive.

Within the first research question, it is worth noting that the vast majority of student answers were designated as not matched with the solutions. It is also worth noting that when the students were asked if they had changed or did not change their answer, most of the students chose the expected option. That is to say, for those students whose answers did not match, most reported that they modified their answers while for those whose answers did match, very few modified their answers. Only very few students whose answers did not match the solutions did not change their answers, self-reporting that they were correct. It seems safe to say that most of the students in this study were able to compare, distinguish, and notice the differences between their answers and the solutions provided.

In answering the second research question, as students reconciled their thinking, the reasons provided for not modifying and modifying their answers were similar or mirrored each other. The categories themselves demonstrate different types of reflection. "Correct", "wrong", and "repeating the solution" illustrate a low degree of reflective thinking involving meaning-making regarding the disciplinary content. "Almost correct" to "alternative answer" appeared in both the modified and unmodified groups and involved reflective thinking regarding relationships in disciplinary content (such that the learner could offer possible alternate explanations). "Don't fully understand" constituted reflective thinking in a disciplined way with an attitude that values personal intellectual growth. "Discontented" could be viewed as emotional engagement. The different types of reflective thinking discussed here are not dissimilar to those reported among adult learners. In particular, the overarching patterns of inward-focused and outward-focused reflection were prevalent (Mezirow, 1998; Hubbs and Brand, 2005; Lebedev and Sharma, 2019).

Different questions in different online physics educational videos serve differ-

ent purposes (Muller and Sharma, 2005; Brualdi Timmins, 1998). The questions in this study ranged from cheeky to inviting a level of informed guessing. Question three, which was mathematical in nature, was perceived as a closed question by students. It did not induce different types of reflective thinking. While the other questions were varied, the categories indicate that they were better aligned with Rodgers' interpretation of Dewey's phases (Rodgers, 2002; Dewey, 1933). The questions were tricky, somewhat cheeky, and mischievous; some were open and some were closed. In this study, such questions induced more reflective activity. Many students rose to the challenge of providing informed guesses or focusing on self learning (Hill et al., 2015; Sharma and Bewes, 2011). All in all, the lesson for physics educators is that they should consider intentionally cultivating contexts for teaching reflective thinking. They could provide mischievous prompting questions which align with Dewey's phases to engage students in reflective thinking. Although this task was worth 0.125% of their total grade for the course, the fact that students were prepared to spend time on their responses to this task is also notable. In particular, the question, solution, and reflection style was rare and running similar studies in different contexts and with different topics would be worthwhile.

Chapter 7

Study Three: Reflection, as Guided with Clue-Containing Questions

This thing all things devours:
Birds, beasts, trees, flowers;
Gnaws iron, bites steel;
Grinds hard stones to meal;
Slays king, ruins town,
And beats high mountain down.

J.R.R. Tolkien

7.1 Introduction

Studies 2 and 3 on reflection in the physics education multimedia context were exploratory in nature. Studies 1 and 2 provided insights, ideas, hypotheses, and new research directions for Study 3. A few themes emerged, both in the literature and within the studies, including the importance of doubt in reflection and how the phrasing of questions affected the type of reflection.

The inspiration for Study 3 arose while considering the literature on misconceptions and how including extraneous materials could mislead students and put them on the wrong path (Muller et al., 2008). It was unclear whether there was an analogy for this within the reflective thinking conceptual framework that had been developed. Previous research indicated that the way questions were phrased influenced the reasons students provided for changing or not changing their answers. The question arose as to whether asking the same question in different ways would affect the type of reflection the students engaged in.

One idea for structuring Study 3 was to treat questions like those in a detective novel. In good detective novels, there is a mixture of clues that lead to the solution and red herrings that mislead readers. Similarly, a question contains clues to its solution, requiring students to act like detectives, using their prior knowledge and the given clues to formulate an answer. Just like in a detective novel, some clues are good (intended to lead to the correct solution) while others are red herrings (intended to lead to incorrect conclusions). This approach mirrors what scientists do in research, where distinguishing between good clues and red herrings is part of the process.

The study was intended to explore these two ideas (student doubt and different types of clues) and to examine how different questions affected the types of student reflection which they engaged in. The structure of the study remained very similar to the previous two studies, but the videos were different, and an additional question was included in the survey. Another significant change was the random assignment of students into three groups, each with different question videos, while all other conditions remained the same. It was crucial that the videos followed the structure of John Dewey's phases of reflection.

The two broad research questions for this study were:

1. What effect do these questions with varying clues have on student answer matching, confidence, and their modification or non-modification of their

answers?

2. Are there differences in the types of reflection that students engage in?

7.2 Context and Sample

This experiment was part of the online pre-laboratory work for second-semester first-year physics students at the University of Sydney, specifically during their study of circuits and electromagnetism. The lectures covered theoretical aspects of circuits, and the laboratory sessions involved constructing various circuits, ranging from simple experiments related to Ohm's law to more complex circuit designs. Students also became familiar with various components, such as resistors, diodes, capacitors, and tools like multimeters and digital storage oscilloscopes. This experiment was conducted as part of the pre-work in the fourth week of the second semester, meaning the students had both theoretical and hands-on experience with circuits.

All students in the course were randomly assigned into three groups by the online learning management software. It was made clear that this activity was assessed based only on participation, not on the correctness of their answers. It was also made clear that their participation in the study was voluntary. The students were unaware that they received different interventions from their classmates. A total of 308 students consented to participate in this study: 102 students were in the *Good clues* group, 102 were in the *No clues* group, and 104 were in the *Bad clues* group. A description of the three groups, along with the intervention and data collection process, is detailed in the next section.

7.3 Methodology

The students were randomly assigned to the three groups and were asked to respond to a question related to circuits. Each of the three groups were given

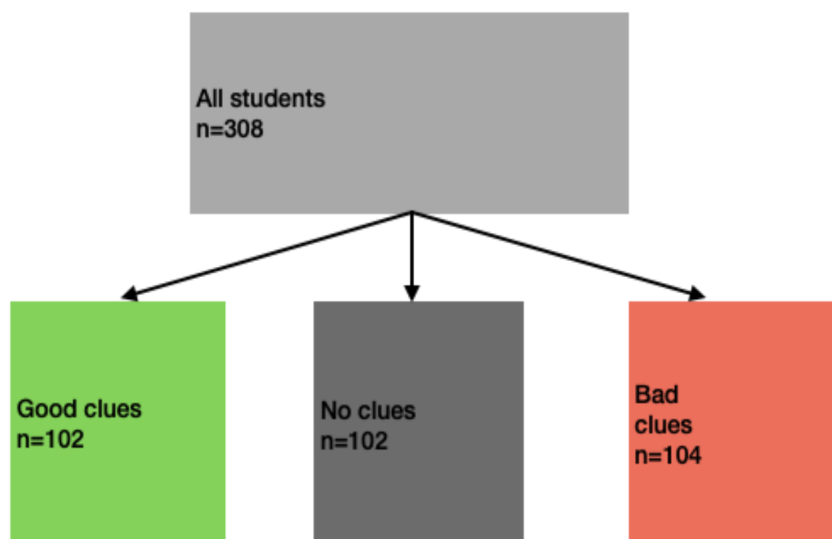


Figure 7.1: Distribution of students into each of the three groups

a variation of the same question, one containing clues that aimed to lead the students to the solution (*good clues*), one which contained no clues (*bad clues*), and one which contained clues which introduced a common misconception and lead the students away from the solution (*bad clues*). Students were assigned to groups via the learning management site Canvas. This was performed as imperceptibly to the students as possible and they did not know that they were receiving a slightly different pre-work from many of their classmates.

The intervention and data collection were carried out using the REDCap secure data collection application. The students logged onto Canvas, clicked on the laboratory pre-work, and were taken to REDCap. The students were asked if they consented to participate in this research and the participant information sheet was made available to them. The ones who did not consent were still required to do the pre-work but were not used in the research. The students watched video one, in which a question about circuits was asked. The design of the videos is discussed further in the next section. After watching the video, they filled out a survey which; 1) asked for consent to be included in the research study, 2) prompted them to write down their answers to the question, and 3) write down their confidence in their answer. Students then clicked on

the “next page” and were taken to page two. After going through to page two, the students could not go back to page one. On page two, the students viewed Video Two, in which the solution to the question was presented. After watching the video, the students filled out another survey, which prompted them to 1) write down if they modified or did not modify their answer, and 2) the reasons they did or did not modify their answer.

The survey design and the creation of the videos is covered in more detail in Chapter 4, but the script for the question videos will be covered briefly as a concrete example of the *Good Clues* and *Bad Clues* that were used.

The *No Clues* script was the basis for all three videos and is as follows:

“Hi everyone I hope you’re all doing well. So we all know that electricity is incredibly dangerous, and we’ve been told since we were kids that electricity and water don’t mix... So how can this man swimming in a pool survive from being struck by two hundred thousand volts from a Tesla coil?”

Within the *Good clues* video, another section was added in which the narrator says “You might notice he’s wearing a metal glove which is touching the salt water, and also an aluminium hat, and there’s also a wire connected to the Tesla coil which is hanging inside the pool”

Within the *Bad Clues* video, the script was modified to read, “A Tesla coil produces very high voltage, but relatively low current — could this be the secret to his survival?”

Page One

7.4 Data Analysis

The data were downloaded from REDCap. This exported it as a .csv file which was imported into Microsoft Excel. Much of the subsequent analysis occurred here (apart from the confidence data which was also analysed with SPSS). The

data cleaning process was relatively straightforward as this was done in the context of an online laboratory pre-work. Given that this is typically assessed, the students took it seriously. The students who did not consent to be a part of this study were not included.

There were four distinct groups of data that were collected as part of this study. The numbers of students whose answers matched or did not match the solution, the confidence of students in their answers, the numbers of students who modified or did not modify their answers, and the reasons that students gave for doing so. Two of these can be treated as entirely quantitative, while the other two required a mixture of quantitative and qualitative data analysis. The specifics are discussed in the next four subsections.

7.4.1 Matched or Not Matched

To quantify the number of students who did or did not match the solution, a matching protocol was developed. For the answer to be marked as “matching”, it needed to mention the most important information, namely, that the swimmer was unharmed, as he was not part of the circuit, or that his surroundings were much more conductive than he was. Variations of this explanation were acceptable, such as “the electricity flowed around him”, “the current never entered his body”, or “the electricity went through the hat, into the pool, and into the grounding wire”. The responses were examined and marked against the matching criteria. After this was done the number of responses that matched the solutions were counted as well as the responses that did not.

7.4.2 Modified or Unmodified

The number of modified or unmodified responses required no extra data analysis. Given that the students reported whether they did or did not modify their answers, analysis was simply a case of counting the numbers in excel. This was

achieved using the COUNTIF function (=COUNTIF(cellrange,“I did change my answer”, =COUNTIF(cellrange,“I did not change my answer”))

7.4.3 Student Confidence

The student confidence was recorded as a number from 0 (not confident at all), to 100 (very confident). As this survey was online, it was possible to collect confidence data in a quasi-continuous manner. Data were exported from Excel, and basic statistical tests and plotting occurred in SPSS. Student confidences was compared across different groups and this was done by examining the mean, standard deviation, standard error of the mean, and a one way ANOVA.

7.4.4 Student Responses

The reasons were analysed qualitatively, in a similar way to what occurred in research phase two. As the codes were developed for both the students who did modify their answers, as well as those that did not, all of the coding was deductive. Despite the coding being deductive, while the data was coded potentially divergent was noted. However, the vast majority of student responses fell into the previously developed codes. The data were coded into the eight codes previously described, including: my answer was **wrong**, my answer was **correct**, I am **repeating the solution**, my answer was **almost correct**, my answer was **almost correct with explanation**, I had an **alternative answer**, I **don't fully understand**, and I am **discontented**. The student responses were coded into these categories. One of the common responses was that something was missed, which was initially coded as a new and separate category. It became apparent that while the exact phrasing was new, it belonged in the **I don't fully understand** code.

The number of students in each of the groups was on the order of 100 and as such the eight codes were collapsed into broader categories, as a way of having

enough students in each categories to make it possible to draw conclusions.

After the initial coding was done, the student responses were read and reviewed thoroughly. The role of qualitative coding is to condense complexity into manageable concepts which have common thematic ties. This compression can result in valuable information being lost. As the student responses were being coded, it became clear that there were in fact different “flavours” present within each code. While all three groups had student responses that fit into the category of **I am discontented**, there were subtle differences in the way that the students responded. These subtle differences were noted and are discussed in the results section.

7.5 Results

There are many results to discuss in this study, which are presented in the same subsections as the data analysis.

7.5.1 Matched or Not Matched

There are different numbers of students whose answers match the solution across the three groups. These results are presented in Fig. 7.2. The number of students who matched the solution was substantially higher in the *Good clues* group compared to the other two groups. In essence, by providing clues which lead the students to the right answer, we made the question easier for the students, which lead to more student writing down an answer that matches the solution. It is worth noting how similar the number of students who matched the solutions were in the other two groups. The number of students whose answers matched the solutions is very similar in both the *no clues* and the *bad clues* groups. This indicates that in this instance it’s not the *bad clues* that threw the students off, but rather the lack of *good clues* that stopped them

from arriving at an answer that matched the solution.

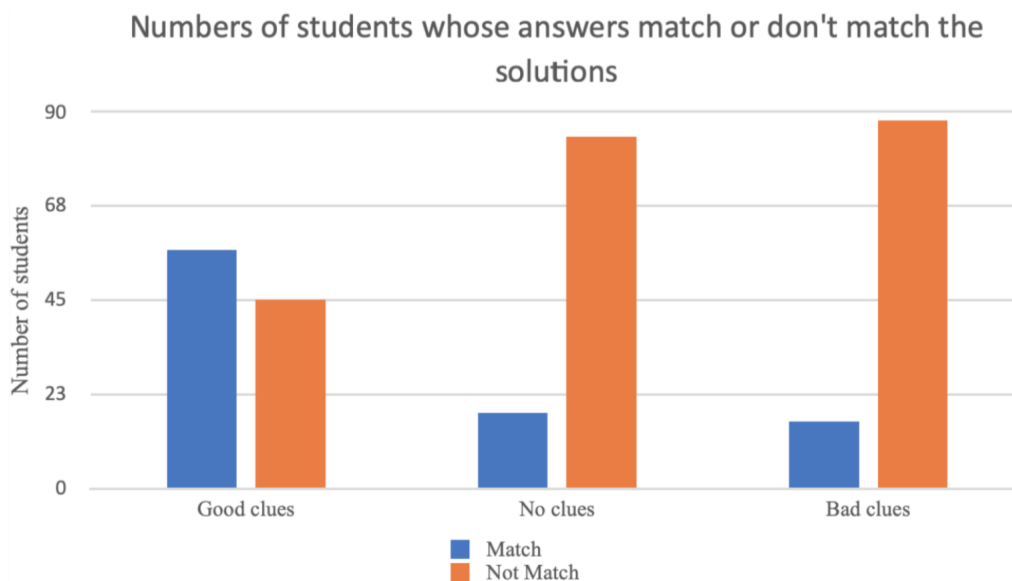


Figure 7.2: The number of students in each group whose answers did or did not match the solution

7.5.2 Confidence and Modifying

There is also variation in the number of students who did, or did not modify their answers for each one of the three groups. This is presented in figure 7.3. The number of students who modified their answers after seeing the solution was lowest in the *good clues* group, in the middle is the *no clues* group, and the *bad clues* group contained the most students who modified their answers. A part of this result was expected; more students in the *good clues* group had an answer that matched their solution, and most of the students whose answers matched the solution did not modify their answers. What is intriguing is that while the percentage of students whose answers did not match was very similar in the *no clues* group and in the *bad clues* group, the number of students who modified their answers is substantially higher in the *bad clues* group. This is worth noting and more will be said about this in the discussion section of this chapter.

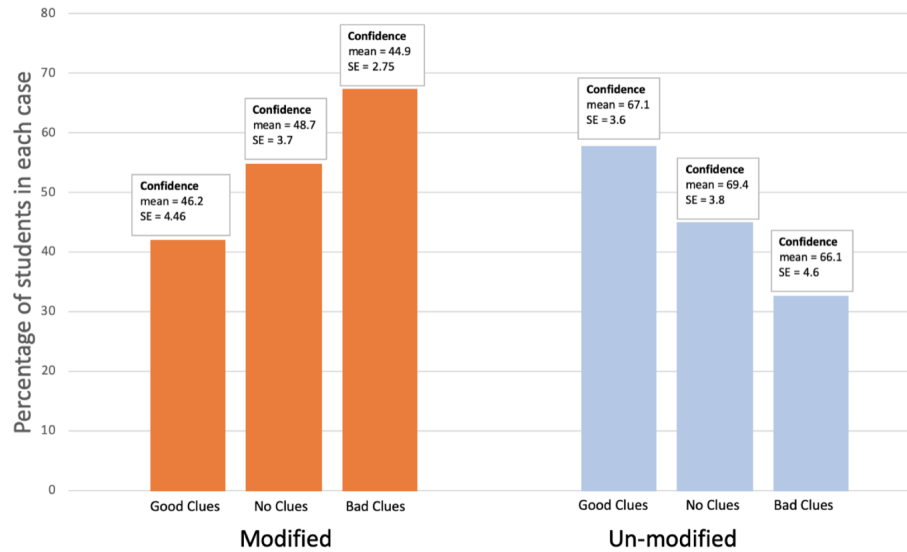


Figure 7.3: Number of students in each group who modified or did not modify their answers, along with their confidence in their answer

Another result that is worth emphasizing is that the confidences of the students in the various groups is not significantly different from one another. The mean confidence for the students who modified was 46.2, 48.7 and 44.9 for the *good clues*, *no clues*, and *bad clues*, respectively, and the standard error of the mean was equal to 4.46, 3.7, and 2.75, respectively. This indicated that these groups were not significantly different from each other in their confidence. The same applied to the students who did not modify their answers. The mean confidence for the students who modified was 67.1, 69.4, and 66.1 for the *good clues*, *no clues*, and *bad clues*, respectively, and the standard error of the mean was equal to 3.6, 3.8, and 4.6. This is an interesting result, which indicates that the initial student confidence in their answer was not influenced by the types of clues the students were given. There is a link between the students' initial confidence and whether they did or did not modify their answers.

7.5.3 Student Reasons

The student responses for modifying, or not modifying their answers could be coded into the same seven types of codes as the previous studies. Due to the smaller number of students in each one of the groups, the categories were also coarse-grained. The categories **almost**, **almost with an explanation**, and **alternative** were combined together, as were the the categories **wrong**, **correct**, and **repeating the solution**. These codes were combined as they shared a theme; in the case of the **wrong**, **correct**, and **repeating the solution** codes, all of these codes discussed the answer correctness, or repeated the solution. The student reflection focused on the content in a rather shallow way; no further explanations were given. For the codes of **almost**, **almost with an explanation**, and **alternative**, the codes also focused on the content and also showed a level of engagement with the physics being presented. These required that the students explain how one answer was similar to another, or to point out that some alternative answer was equivalent. These required deeper engagement with the physics at hand. It is important to note that the data were coded into these distinct codes and then later combined; this coarse-graining did not change how the data were analysed. Instead only how it was displayed was altered. The codes were also compared with Mezirow's taxonomy of critical reflection and were grouped as either outward-looking or inward-looking. The number of each of the students that fell into the various codes, within each one of the groups, is presented in table 7.1

Category	Good clues		No clues		Bad clues	
	mod	un	mod	un	mod	un
1 Outward looking	78		81		58	
1.1 Repeating + Correct	3 13 (16)	33 2 (35)	0 34 (34)	10 15 (25)	1 25 (26)	9 8 (17)
1.2 Almost + Alternative	7 4 (11)	7 9 (16)	3 3 (6)	3 13 (16)	0 5 (5)	4 6 (10)
2 Inward looking	17		19		43	
2.1 Responsibility	3 8 (11)	2 1 (3)	1 10 (11)	0 3 (3)	1 28 (29)	0 1 (1)
2.2 Issues	1 1 (2)	0 1 (1)	0 4 (4)	0 1 (1)	1 6 (7)	0 6 (6)
3 Miscellaneous	3	4	1	1	3	0
	102		102		104	
TOTALS	43	59	56	46	70	34

Table 7.1: Number of students in each of the codes for each group

An interesting result which emerged is that most of the student reflections for all three groups were outward-looking, with the vast majority of students falling into category 1.1. While the numbers of students in the various codes were relatively small, there was a noticeable increase in the of students in the **responsibility** and **issues** codes in the *bad clues* group.

There were hardly any students in the **issues** group within the *good clues* group and 13 (over 10%) in the *bad clues* group. This was also the case for the **responsibility** category, where the numbers of students in the *good clues* and *no clues* groups were both 14, which is less than half of the 30 present in the *bad clues* group.

This indicates that the students in the different groups reflected on their answers differently. Another point of difference between the codes in the three groups, which cannot be captured by the pure numbers of students in each of the categories, is the subtle differences in student reflections between the various codes.

While the categories were broadly the same, the responses within these categories did differ for each one of the three questions. A more in-depth look into these differences is presented in the following paragraph.

7.5.4 Types of Responses

After reading and reviewing the data thoroughly, one of the pieces of data which stood out was that there were a few subtle differences across in the types of student reflection across the codes. A table for the student reasons and some typical examples are presented for each one of the groups in Tables 7.2, 7.3, and 7.4.

	Modified	Unmodified
Correct Wrong	I was wrong.	It was right. Yay! My answer was correct.
Repeating Solution	He is not a part of the circuit	if he wears the metal clothes he will not be part of the circuit
Almost Correct	my answer was only partly correct The explanation in the video is similar with mine, but the video one is more detailed and clear.	It was mostly correct
Almost Correct with Explanation	My answer wasn't specific enough in explicitly stating that the man's body was never a part of the circuit	I had the right idea but I didn't use the words, "he was not part of the circuit." However I realised that the metal glove and wire submerged in the salt water meant that the current bypassed him.
Alternative Answer		
I don't fully understand	I forgot to consider the salt water through which the electricity passed. i did not consider the fact that the human was not part of the circuit and that the salt water is made up of ions so that the water can pass through to the other end of the circuit. I did not consider the ground wire that was hanging inside the water and therefore he was not apart of the circuit	I got the answer correct. However, my answer could have been improved upon by explaining the conductivity of the salty water.
I am discontented	its not pure water in the video. From the video, i know that the body is not a part of circuit, because the electricity flows through metal gloves, aluminum hat and the conduct of salty water into metal wire in the pool.	I'm not sure i understand the question. I am aware that my answer was wrong, but I have not changed it as there is no point in going back to the last page and changing it now.
Misc	salt water nothing is absolutely, even I wear protectives, I still need be careful of the electricity	

Table 7.2: Common student responses for the various categories in the *good clues* group

	Modified	Unmodified
Correct Wrong	Because my answer was wrong I was wrong. Didn't see his metal glove/hat	it was correct. I got the right answer!!
Repeating Solution	He is not a part of conductor. The body is not in the circuit.	I talked about the conductive material that he was wearing and how he wasn't in direct contact with the electricity
Almost Correct	Although I had the general idea for the solution, I didn't quite get the important specifics right. i.e the conducting glove	It was mostly correct. Meant the same thing. Couldn't think of the right words.
Almost Correct with Explanation	I was correct in saying that the electricity never passed through his organs due to them not being in the path of least resistance. However, I did believe that his hand was still part of the circuit, which was not correct as the metal glove and hat completed the circuit.	i think my answer is quite similar.since he touch by hand and other part is fine.i think the idea is the same, charges flow to the water thus he is not really a part of the circuit.
Alternative Answer		The solution in another scenario using the principal of lighting rod, which is quite tricky, because electricity will always go for a smaller resistor. However, in my answer could still be a possible scenario, and either case, the person is safe due to the fact that the circuit across human body doesn't exist.
I don't fully understand	I believe what he says make more sense. I think it might be impossible to charge so much electricity on a man's body. I didn't mention that the suit was grounded to the saltwater and grounding wire.	I did not realise that was a Tesla coil and consider the man as a part of circuit however I am not able to go to the previous page
I am discontented	he didnt really connected with the light	the man in the swimming pool is not involved in the circuit section, which means the clothes are the protections.
Misc		

Table 7.3: Common student responses for the various categories in the *no clues* group

	Modified	Unmodified
Correct Wrong	It was wrong My answer previously incorrect	It matches with the solution. I was correct.
Repeating Solution	The answer was actually because the man was not part of the circuit	
Almost Correct	My answer was not 100% correct	I believe it was somewhat correct.
Almost Correct with Explanation	I was almost correct in that I knew it was about the circuit but I said it wasn't complete rather than he wasn't in it	My answer is almost make sense. The person is protected by his hat then water and then the metal ground.
Alternative Answer		Although the answer provides a valid point, I feel that there is more to the solution than just the one provided.
I don't fully understand	Didn't realise he was wearing a metal glove I didn't realise he was wearing a metal glove/hat. Maybe this was specified in an earlier part of the whole video which we weren't showed in the previous slide? I did not notice that his glove was metal in the previous video, or that the pool was saline I was sort of on the right track with what I wrote before but I didn't know specifics and was very unsure of myself!	I just forgot to include the fact that he was not part of the circuit, i just stated that the electricity was not touching him my answer was right I just didn't explain it very well or in depth. The main idea is that the man isn't part of the circuit and so nothing passes through him, I skipped over that, but it was implied by what I had said.
I am discontented	Couldn't see if he was wearing a glove or not. If id have known that then i would have got the right answer I could not see the tin foil on his hand well due to the lack of lighting in the previous video. I did get the part that there was no current flowing through him but did not realize the exact setup of the circuit. Initial video was not clear on how the circuit was setup. There was no indication he was wearing a metal glove, making the question very difficult to understand	That's pretty much what I said about him being wet although I think the video was misleading, didn't even tell us there was a grounding wire grr his skin did touch the water in 25s

Table 7.4: Common student responses for the various categories in the *bad clues* group

While the categories are broadly the same, there are a few subtle variations. The category where this is most prominent is **Issues** category. A few responses fell into the category of **Issues** in the *bad clue* group; among these, one student

wrote “That’s pretty much what I said about him being wet although I think the video was misleading, didn’t even tell us there was a grounding wire grr”, and “Couldn’t see if he was wearing a glove or not. If id have known that then i would have got the right answer”, another wrote “Initial video was not clear on how the circuit was setup.”, and another wrote “There was no indication he was wearing a metal glove, making the question very difficult to understand”. All of these indicate that the video did not include the relevant information or that a key piece of data was missing for the students to successfully solve the question. In the *good clues* and *no clues* groups, while this type of response (“not enough information” or “if you gave the right clues, I would have gotten it right”) is present, it was not the most frequent response.

7.6 Summary

This study sought to explore whether and how the types of clues given in a question video affected student responses and reflection. The results indicate that the types of clues present in the question video had a significant effect on how students answered the question, and the types of reflections that the students participated in. These results have implications for physics education multimedia and for asking students questions in general. These implications are discussed next.

As noted, there are different numbers of students whose answers matched or did not match the solutions across the three groups. Unsurprisingly, the more students in the *good clues* had an answer that matched the solution. It is worth noting that the number of students whose answers matched the solution was very similar across the *no clues* and the *bad clues* groups. This seems to indicate that in the case of the students’ answers not matching the solution because they were not being tricked by the presence of *bad clues*, but instead by the lack of *good clues*. This could mean that the misconception used as a

red herring was not compelling enough or it could mean that that the question was simply too difficult, without the presence of *good clues*.

The number of students who modified or did not modify in each one of the groups is interesting. Given that more students from the *good clues* group reported changing their answers, it is not surprising that the number who did modify their answers was low; after all, if the answer matched the solution, it's unclear why a student would. What is worth exploring further is the number of students who did, or did not modify their answers within the *no clues*, and *bad clues* groups. Despite there being a very similar number of students who provided an answer which matched the solutions, the number of students who modified is their answer was lower in the *no clues* group, compared to *bad clues*. One potential reason is that the range of answers was higher in the *no clues* group, which means that more answers could be justified as being almost the same as the solution, while the *bad clues* group answered more homogeneously, having been successfully misdirected by the question video. This does seem to be the case, in the qualitative data; there were more students in category 1.2 in the *no clues* group than in the *bad clues* group. This is an interesting result, which may indicate that the students were successfully misdirected by the *bad clues*. This assertion is tentative however, as the number of students is relatively low and the signal is not particularly strong. More in-depth qualitative data collection is required to validate this theory.

Another result of this study is the exploration of student confidence; while there is no statistically significant difference between the student confidence across the three groups, there is a significant difference in the student confidence among those who modified or did not modify their answers. There are two things to note from this result; the first is that the the different levels of clues did not affect the the student confidence in their answers, and the second is that, perhaps unsurprisingly, the students who had a lower confidence

were more likely to modify their answers. The implications of the first point are interesting; the the lack of good clues, or even the inclusion of deliberate red herrings did not negatively affect the student's initial confidence in their answers. Although the number of students who got the solution right was low in these two groups, the students were still confident in their answers.

The results from the qualitative side of the study were also interesting and worth exploring. In the previous two studies, the codes of student reflections were established. While the data were coded deductively, care was taken to make sure that student reflections weren't forced into codes which they did not belong in. Initially, a new group was found in the data; one which was called **I missed something**, where the students indicated that they did not notice a key piece of data. However, after careful consideration it became clear that this was a sub category of **I don't fully understand category**. While this may seem trivial, this was really a significant result. Given that the first two research studies used the same set of videos, this could have meant that the coding was specific to this set of videos. While there are similarities between the videos used (for example, they both followed Dewey's phases of reflection) there were also significant differences. The first set focused on mechanics and was filmed on location in beautiful outside settings, while the second set of videos focuses on a question about electricity and circuits, and was filmed against a green screen. The fact that students were reflecting in a way that could be coded with the same coding scheme is an important result. This lends further credence to the efficacy and usefulness of the categorization framework.

As expected the number of student reflections that fell into each category was different for the three groups, which provided further evidence substantiating that the question was an important factor in determining the types of student reflection. In this case, the type of clues in the question did affect the number of students who were coded into each category. A clear example of this is

the increase in the number of inward-looking reflections in the *bad clues* group. What's also interesting is the difference in the types of reflections that occurred between the three groups. More of the responses in the "I am discontented" category mentioned an issue with the physics in the videos or indicated that if they were given more information they would have arrived at the correct answer. Good examples include the following responses: "I think the video was misleading, didn't even tell us there was a grounding wire grr" and "there was no indication that he was wearing a metal glove making the question very difficult to understand", and also "Initial video was not clear on how the circuit was setup". A difference between the "I am discontented" and the "I don't fully understand" related to who the students held responsible for this lack of information. The students in the "I don't fully understand" category were taking responsibility for their own learning (for example, "I didn't realise he was wearing a metal glove/hat", and "I did not notice that his glove was metal in the previous video, or that the pool was saline").

This study indicates that throwing the students in the deep end in a formative assessment situation is not such a bad thing. Deliberately providing red herrings in a question video seemed to have triggered a different type of reflection in the students, and while a percentage blamed the lack of clues, a larger percentage took note of what they missed. The qualitative data for this study was not as substantial as would have been preferable. A follow up project was planned, and human ethics approval had been granted, to collect more in-depth qualitative data. However, these plans were cancelled due to the COVID-19 pandemic. A follow up with in-depth interviews with a sub-sample of these students would be an interesting research project to undertake.

Chapter 8

Findings, Discussion, and Conclusion

What's in my pocket?

J.R.R. Tolkein

This chapter outlines the primary findings of the three studies and discusses some of the implications of the results for researchers and practitioners. Avenues for further research are also proposed. Each of the studies will be discussed separately followed by the combined conclusions in the final section of this chapter.

8.1 Findings from Study 1

This study aimed to explore the efficacy of YouTube videos (specifically those from the channel Veritasium which regularly features riddles) at stimulating critical reflection among viewers. The videos were structured to align with Dewey's phases of reflective thinking (Dewey, 1933), and the analysis was conducted through the lens of Mezirow's taxonomy of critical reflection (Mezirow, 1997b). The primary research questions focused on the extent to which viewers reported if their answers were correct, their willingness to revise their answers

after watching the solution videos, and the reasons behind their decision to change or maintain their initial answers.

The study utilized a mixed-methods approach, analyzing viewer responses to two Veritasium videos: one presenting riddles and the other revealing their solutions. After viewing both videos, viewers were surveyed to assess whether they had modified their answers and to explore their reasoning for their decision, using an open-ended format to gather qualitative data. The viewers were not requested to write their answers.

The exploratory nature of this study, prompted by the serendipitous alignment of the survey deployment and data collection, meant that the findings could seed further research. The videos were not originally designed for this study but were pre-existing and of high quality, and aligned well with Dewey's reflective phases (Dewey, 1933). This shaped the study, which used high-quality physics education videos whose design matched Dewey's phases of reflection.

The study design involved asking participants only two questions: "Did you change your answer?" and "If not, why not?". Notably, most participants reported changing their answers if they had initially considered them to be incorrect. However, the absence of data on initial participant answers posed a limitation that was later addressed in further research. Nevertheless, the variety of reasons for not changing answers, coded into distinct groups, fit broadly into types of reflection described by Mezirow (Mezirow, 1997b; Hubbs and Brand, 2005). Mezirow's taxonomy of reflection formed the framework for the evaluation of the responses.

The findings indicated significant variation in responses across the four riddles. A majority of respondents (49%–73%) reported changing their answers after viewing the solution videos, suggesting a high degree of engagement and reflective thinking. However, a smaller group (7%–11%) did not modify their answers. The reasons for not modifying provided insights into their reflective

processes. Inductive coding of their reasons highlighted eight distinct categories, ranging from satisfaction with their original answers, to belief in alternative solutions, to misunderstandings or disagreements with the provided solutions.

When analysing the responses using deductive coding, the categories that organically emerged align with types of critical reflection as outlined by Mezirow. Hence the findings highlight the potential of popular media platforms for informal education and the promotion of critical reflection. Furthermore, the categories were clear and distinct. When coded by other researchers, there was agreement that the categories were robust, having an inter-coder reliability higher than 80% agreement.

This study concluded that YouTube videos, when aligned with Dewey's phases of reflection, could effectively stimulate reflection. As a pilot study, this was encouraging; it was clear that appropriate conceptual and evaluation frameworks were found.

Consequently the stage was set for further research. It also became clear that further research should explore these effects across different contexts and with more rigorously designed methodologies. Following the Design-Based Research methodology, the insights from Study 1 were used to iterate and improve on the methodology for Study 2. A more developed methodology was used in Study 2.

8.2 Findings from Study 2

Building on the initial findings of Study 1, the second phase of research sought to validate and expand on the previously observed effects of multimedia on critical reflection but within a formal educational setting. The research questions were similar to those of Study 1, and included the following: "How many students modified or did not modify their answers with when their answers to

questions shown in a video did or did not match the solution provided in another video?”, and ”What reasons do students give for modifying their answers or not modifying their answers? Within this study, the students had to write their answers after watching the questions video.

Study 2 was conducted in a formal academic context, specifically within a first-year physics course at the University of Sydney. This shift from informal learning to a structured university course allowed the research to leverage a more controlled environment which enabled a robust sampling methodology, enhancing the applicability of the results.

A key methodological enhancement in Study 2 was the adoption of a more comprehensive survey approach. Prior to viewing the solution videos, students were required to write down their answers to each riddle, allowing for an objective assessment of the accuracy of their initial responses. This procedural adjustment addressed a significant limitation of Study 1 by enabling a verification of whether the students’ self-reported reflections about their answers’ correctness aligned with the actual solutions provided. Additionally, the survey included questions intended to understand both the reasons for the changes in answers or the motivations for maintaining initial answers. Therefore, the survey provided deeper insights into the decision-making processes than its predecessor.

The findings from Study 2 validated and extended the findings of Study 1. As with Study 1, a majority of students altered their answers after viewing the solutions, and their responses were still able to be categorizable into distinct codes. However, a novel aspect of Study 2 was the observation of similar types of reflection from students regardless of whether they changed their answers. For instance, students often commented on the closeness of their initial answers to the solutions, which was reflected in the categorization of responses into an ”Almost” category. This mirroring effect in the categorizations, where students exhibited reflective thinking irrespective of the direction of their answer change,

highlighted a nuanced aspect of learner engagement with the material.

A particularly intriguing finding from Study 2 was the variation in types of reflection elicited by different questions. For example, the third question of the survey, which was more mathematical in nature, tended to generate responses where a higher proportion of students both correctly matched the solution and reported changing their answers. This contrast with the more conceptual nature of the other questions suggested that the cognitive demands and skills required by different types of problems might influence how students reflect upon and reassess their answers.

The consistent results across different contexts, from informal learning settings to formal educational environments, affirm the potential of multimedia tools to enhance reflective thinking. The nuanced findings regarding the similarity in reflective categories among those who did and did not change their answers, as well as the differential impact of question types, laid the groundwork for the subsequent phase of research. Study 3 was designed to explore these dynamics further, which focused on how specific characteristics of questions influence critical reflection and learning outcomes.

8.3 Findings from Study 3

Unlike the first two studies which utilized existing videos, the videos for this study were custom-made; they were created by the author. Like the video used in the first two studies, these videos were designed to follow Dewey's phases of reflection but focused on a different part of first-year physics, namely, electricity and circuits. After Studies 1 and 2 showed that the types of reflection that the students engaged in was affected by the kind of questions asked, bespoke videos were developed with three different kinds of clues. These types were *no clues*, *good clues* (which led to the correct solution), and *bad clues* (which were designed to lead the students away from the correct solution). The research

questions were crafted to probe the effect that the questions had on student reflection. The two research questions were: "What effect do these questions with varying clues have on student's answers matching, their confidence, and if they modify or not modify their answers?" and "Are there differences in the types of reflection that students engage in?"

The result that more student answers matched the solution in the *good clues* group is a natural outcome. What was more surprising is that the initial confidence levels across the three groups were almost the same. It was expected that the confidence of the students in the *bad clues* group would be significantly lower than those in the other two groups, but this was not the case. The red herrings did not lower the student confidence levels. Another notable finding is that the students across the different groups displayed different types of reflection. It was expected that more students in the *bad clues* group would fall into the **issues** code. While this did occur, more students took responsibility for their learning. This might indicate that including red-herrings and asking tricky and mischievous questions could lead to frustration in some students, but could also encourage others to take responsibility for their learning

Students given *good clues* were more likely to have answers matching the solutions, while those given *no clues* and *bad clues* performed similarly. This suggests that the absence of good clues, rather than the presence of bad clues, led to incorrect answers.

Fewer students in the *good clues* group modified their answers, as their initial responses were often correct. Interestingly, despite similar correctness levels, students in the *bad clues* group were more likely to change their answers than those in the *no clues* group, indicating successful misdirection by the *bad clues*. There was no significant difference in overall student confidence across groups. However, students who modified their answers had lower initial confidence. Importantly, the presence of red herrings did not diminish students' initial

confidence in their answers.

The qualitative data reaffirmed previously established categories of student reflection, showing consistency across different video sets and contexts. The reflections varied significantly with the type of clues provided; there were more inward-looking reflections in the *bad clues* group. Reflections in the "I am discontented" category often blamed the videos for lack of clarity, while those in the "I don't fully understand" category took personal responsibility for the oversight.

This demonstrated that introducing red herrings in formative assessments could foster deeper reflection, encouraging students to evaluate their understandings critically. However, this approach should be carefully managed to ensure it supports learning objectives. This study indicates that throwing students into challenging situations in a formative assessment context does not necessarily have negative outcomes; rather, it may trigger valuable reflective thinking.

8.4 Implications for Practitioners and Researchers

As stated at the beginning of this thesis, **the goal of this thesis is to explore how student reflection manifests itself in the context of multimedia, what it looks like, and how to adapt existing pedagogical multimedia learning approaches to further student reflection.** These three studies facilitated an examination of these ideas and also resulted in new discoveries.

There are a number of implications that arise from these studies which are applicable to both practitioners and researchers. First, the value of this research for practitioners will be discussed.

The work for this thesis began in 2017, before the global pandemic in 2020. The value of multimedia learning was evident then, especially on the internet and for remote and informal learning, which was difficult to overstate. Dur-

ing and after the pandemic, the value of online learning became even more pronounced. Many universities all over the world converted to online or partially online modes of instruction to continue operations. Given how prevalent multimedia learning is, it is important to make sure that these media are as effective as possible. This situation was a stark reminder of the importance of research into multimedia learning as sometimes this might be the only option. Important research has been conducted on making physics education videos more effective (Muller, 2008; Mayer, 2005), and this thesis adds to this literature. The structure of asking students questions, having them write down their answer, presenting the solution, and then asking the students to reflect on whether they changed their answers appears effective in facilitating reflection. At the very least, it is a simple way of increasing interactivity within the video format.

This framework does not apply only to the tertiary learning context. As can be seen from the results of Study 1, this could also be applied to the informal learning and science communication contexts. Many of the science communication videos on YouTube take the form of direct instruction and while there is value in direct instruction, this is an easy and effective way to include more interactivity into a typically linear medium. Furthermore, this framework doesn't only increase the interactivity, but also promotes reflective thinking.

A standout finding which leads to interesting implications is that the students provided similar reasons for both changing and not changing their answers. A student could say that they changed their answer despite their answer being close enough to the solution, or they could say that they did not change their answer because they were almost correct. The implication of this is that asking whether the students changed or did not change their minds is not enough and that the students should be asked to provide their reasons.

Another implication is that the question matters. Which questions are asked

and what kind of clues are provided to the students shape the types of student reflection that occur. Given that different questions seemed to elicit different types of reflection, it was important to consider whether the question was "fit for purpose". For example, it would not be appropriate to include bad clues or red herrings in an exam for physics novices. However this might be a good idea in a formative assessment context which is a space and time where students feel comfortable making mistakes and getting the answer wrong. While the studies found that student confidence was not negatively affected, the studies were explicit that this was a formative assessment and that the students weren't marked on the correctness of their answers. Within such tasks, completing the task was more important than grading the task. This reduced the marking load and provided considerable gains in reflective thinking. This ease of implementation added another form of assessment for practitioners.

This research is also valuable to academics. While the findings are contributions to the field of multimedia learning, a major benefit of the research is the novel student reflection evaluation framework. The development of the categories in Study 1, and their validation in Studies 2 and 3, indicates that looking at student reflection through the lens of Mezirow's taxonomy is appropriate. Due to the the complex and self-referential nature of reflection, it was a difficult to quantify or measure, but Mezirow's taxonomy provided a robust framework for the analysis of student reflection. This is useful to other researchers exploring reflection in other contexts.

8.5 Limitations of the Studies

There are a number of limitations to these studies. One is that the experiments were conducted in only two contexts, namely, social media and a pre-lab of a first year university physics cohort. Furthermore, while the sampling for the university cohort was robust, the experiment conducted in the social media

context relied on convenient sampling, with 2220 responses from millions of viewers. Clearly, this was not a representative sample of the science-video watching public.

The qualitative data collection in these studies was limited to short-answer responses. While these responses provided initial insights into the students' reflective processes, the depth and richness of the data were constrained by the brevity of the answers. Short-answer responses often lack the detailed explanations and nuanced insights that can be obtained through more comprehensive qualitative methods. Notably, no interviews were conducted, which could have provided a deeper understanding of the student thought processes, motivations, and experiences. Interviews allow for more in-depth exploration and can uncover subtleties that short answers might miss. Future studies should incorporate interviews or focus groups to gather more detailed and nuanced qualitative data.

The limited context in which the studies were conducted is another limitation. The learning environment, the nature of the subject matter, and the students' familiarity with both the content and the medium likely influenced the outcomes. While these contexts provide valuable insights, they do not capture the full spectrum of educational environments. For example, the dynamics of a traditional classroom setting differ significantly from those of online learning platforms. Additionally, different levels of prior knowledge and engagement with the subject matter could affect the results. Expanding research to include varied educational contexts, such as different university courses, online learning platforms, and informal learning environments. These would provide a more comprehensive understanding of the impact of multimedia learning and reflective thinking.

The design and implementation of the survey also presented limitations. While the survey effectively gathered data on whether students changed their answers

after viewing the solutions, it did not capture the full range of reflective thinking processes. These studies were also limited by the short-answer format. Future research should consider incorporating a variety of question types, more open-ended questions, and follow-up interviews, to gain a more detailed and comprehensive understanding of students' reflective processes.

By acknowledging these limitations, it's possible to understand the scope and applicability of the findings from these studies better. Addressing these limitations in future research will help to build a more robust and nuanced understanding of the role of multimedia learning and reflective thinking across diverse educational contexts and populations.

This leads to some ideas for further research, which are discussed in the next section.

8.6 Avenues for Further Research

While this project was a step in the right direction for research into physics education multimedia and reflective thinking, there are many questions that have been left unanswered. In this section, some potential avenues for further research are proposed. Over the course of this work it has been established that the “Question-Solution-Reflection” framework is a way of taking a typically non-interactive medium, and using it to encourage reflection. It has also been noted that different questions appear to encourage different types of reflection. While reflection for the sake of reflection is a good thing in and of itself and is a valuable metacognitive skill, it would be interesting to explore the interaction between reflection and gains in student understanding. For example, a study could be designed that compares conceptual gains from videos which adhere to the framework (which is based on Dewey's phases of reflection) compared to other multimedia treatments. The research might question whether there could be a change in conceptual understanding for students. For exam-

ple, it would be possible to take some questions from the Force and Motion Conceptual Evaluation (FMCE) (Thornton and Sokoloff, 1998) or the Force Concept Inventory (FCI) (Hestenes et al., 1992), which are related to common student misconceptions, and design a number of interventions. Some of these could incorporate these phases of reflection and some could not. The research could aim to ask whether the videos which encourage reflection do better than the ones that don't, and also whether encouraging reflective thinking in this multimedia context lead to increased learning.

Further research could consider the relationship between the types of questions and the types of student reflection, asking how different question types (such as conceptual, factual, procedural) affect student reflections, or how does introducing misconceptions affect student reflections. Study 3 scratched the surface of this question and it would be interesting for further research to go deeper. Another factor to explore is prior knowledge. Further research could consider how prior knowledge affects the types of reflection presented, which groups of students the *good clues*, *no clues*, or *clues clues* should be presented, how student confidence in their skill affects their willingness to change their answer, what kind of reflection students engage in, given varying levels of confidence, and whether there is a relationship between self-efficacy, confidence, and reflection.

This research journey was initiated by an interest in critical thinking. Yet, due to the nebulous definitions and lack of appropriate tools to measure critical thinking, reflection was instead studied. Reflection makes up an important part of critical thinking. Following the development of these conceptual and evaluation frameworks for encouraging and measuring student reflection, it would be interesting to use these frameworks to return to the study of critical thinking.

Another more theoretical area of study could be to explore whether student

reflection is domain specific. It is noted in the literature that critical thinking and creative thinking possess both domain independent and domain specific qualities (Tiruneh et al., 2016; Hong and Milgram, 2010). It seems that the reflective thinking is the same; there is a domain independent component and also specific quirks and modifications to the triggers of reflective thinking and what critical thinking looks like in different domains. A number of scholars of Dewey note the similarity between the phases of reflection (as outlined by Dewey) with a method of scientific investigation (Rogers, 2001). Dewey was a proponent of teaching science as more than a collection of facts, and rather as a method. He notes “I mean that science has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed” (Dewey, 1923).

Yet, many philosophers of science now agree that there is no “one scientific method”, but many “scientific methods” and that these are context specific. What the “scientific method” looks like in psychology is different to what the “scientific method” looks like in cosmology, or particle physics, or medicine (Lakatos and Feyerabend, 2019; Feyerabend, 2020). The specific context changes how science is done and what it looks like. Future research might consider how reflective thinking might look in different parts of science, whether the student responses to similar interventions could be different if they were studying psychology and not physics, and whether these interventions would work for instruction in subjects that aren’t science.

Another important point is that within Dewey’s formulation of reflective thinking, the instigating factor is “a perplexing experience or problem”. This experience or problem initiates and is the inciting incident for the reflective process. What is a perplexing experience or what counts as a problem depends on prior experience and context. The experiences that were used in videos were deliber-

ately perplexing to minimize the prior knowledge component. Yet, some things were only surprising, peculiar, perplexing, if one had the requisite knowledge. For example, the rotational curves of galaxies, which perplexed astronomers and point towards the potential existence of dark matter, are only surprising if one is familiar with Newton's laws, Kepler's laws, and the expected distribution of mass in a galaxy. If the graph of the rotation curves of a galaxy is given to someone without this prior-knowledge, they would find nothing perplexing or interesting. In other words, prior knowledge is required for some things to seem perplexing. Future research might ask what the link between prior knowledge and reflective thinking is.

Importantly, this research identified an effective conceptual framework for qualitatively analysing the kinds of student reflection. While this was applied in the context of multimedia learning and physics education, analysing student reflection through the lens of Mezirow's taxonomy would likely be appropriate for other educational learning contexts. There are many avenues for further research that involve using this taxonomy as a tool to explore reflective thinking.

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Chapter 9

Appendix

9.1 Scripts from Videos

9.1.1 Scripts from Study 1 and Study 2

Video 1: Questions

The following is the script for the first Veritasium video, containing questions, as performed by Dr. Derek Muller in the published video:

At the Palace of Discovery in Paris, they have this huge turntable where you can sit and perform experiments. Like in the middle of the turntable, you can put some water and then add liquid nitrogen, and this creates a kind of fog. These tiny water droplets that spread out from the middle, but because the actual linear speed of this turntable is increasing the further out you go well, the vapour falls further and further behind creating a swirl, that looks a little bit like a Hurricane. And that analogy is not by accident, the Earth is after all one giant turntable, and the weather patterns we get are a result of that. When you study Physics in rotating frames of reference, or even just rotating bodies. You find some pretty mysterious and counter intuitive phenomena, which is why I'm dedicating this video to four revolutionary riddles.

Number one: Here I have a ramp or an inclined plane. And just to show you I'm not doing anything funny with it, if I just let a roll of tape go it will accelerate down the ramp. But! Here I have a mystery cylinder and I'm going to place that on the ramp. And we will see that it rolls, and then it stops, and then rolls, and then stops. So my question to you is: What is In the mystery cylinder? What is this object?

Number two: Take a bicycle and have someone support it, so it doesn't fall over or lean it up against something. And then take a bit of string and tie it to the bottom pedal. Now, what I'm going to do is pull backwards horizontally on this string, and I want you to predict what the bike will do. Will it go backwards? Forwards? Or will it just stay there and not move. My intuition would tell me that it would go forward? I think it might not move if you're going to be pulling backwards from a stationary point on the pedal, you're going to be pulling it backwards just as the pedals are trying to spin the wheels forward, so maybe it might not move. Things gonna go forward, I'll go forward. Sure? Yeah, I'm sure. All right three, two, one.

Number three: I want you to think about running two laps of this track now [on] the first lap you can go as slowly as you like, let's call that speed V_1 . But on your second lap, I want you to run faster, such that the total average speed for both laps combined is twice V_1 , twice the speed of your first lap. So the question for you is: How fast do you have to run that second lap, so that your total average speed is two V_1 ?

Number four: Any time a train is moving, either slowly or very fast. There is a part of the train which is actually moving backwards with respect to the ground, that is not backwards with respect to the train, and it doesn't have

to be going so slowly that if you ran backwards you would be going backwards with respect to the ground. It is at any speed, any normal train will have a part of it, which is moving backwards with respect to the ground. My question to you is. Which part is it?

Now with these four riddles, you can make me a video response if you like to tell me about your solutions to them. Or you can simply leave your answers in the comments below and number them 1 2 3 4 so we know which ones you're talking about, and I will post all of the answers up next week at the same time same place. All of my videos are made possible by my Patrons on Patreon. So if you are one of those people thank you so much for your ongoing support. And if you're not, maybe now is a good time to consider becoming one. If you go to Patreon.com/Veritasium you can support me there. Otherwise, if you're interested in more riddle-y puzzling things, you can check out my spinning tube trick, my 5 fun physics phenomena, and, say, the spinning disk trick. And if you haven't subscribed [to] Veritasium already I highly recommend you do that. And since I'll be posting the answers next week I would like for you to ring the bell down below and that will make sure that you're notified when my videos come out. So as always, thanks for watching. Wait that's, that's Michael's line.

Video 2: Solutions

The following is the script for the second Veritasium video, containing solutions, as performed by Dr. Derek Muller and George Hart in the published video:

This video contains the answers to my four revolutionary riddles, so if you haven't seen the riddles yet, you should probably watch them before you watch the answers. It's OK; I'll wait. Just click this card up here [Ticking clock sound]. Now, when I filmed the riddles, I also filmed the solutions at the same

time, but that was before I received your 15,000 comments and dozens of video responses, so I'm re-shooting parts of this solutions video to incorporate the results I saw in the comments and to use some of your video responses to help explain the solutions. Let's get to it!

OK, by looking at the comments, for question 1, over 15% of you said "a cylinder containing sand", Now, this contains some powder. See how it rolls... It, uhh, it doesn't seem to roll... ...very far before it stops, and then it won't roll again because I think the sand just kind of levels off in there. Maybe you were thinking a bigger kind of sand, like these small gravelly stones. Let's try that. That actually rolls pretty well. Nearly 25% of you said, "a cylinder half-full of water," so let's try that. This rolls very well, so it's not water. And nearly 45% of you said, "a cylinder half-full of a viscous liquid." Here, I have a half-full container of honey, so let's see how it rolls. That's not bad; it's rolling and it's stopping, and it's rolling some more... This is a pretty good guess, and I think the behaviour is not exactly the same as the mystery cylinder, but it definitely is similar. And that's no coincidence. The mystery cylinder actually contains honey... and ping pong balls. There are two ping pong balls submerged in this honey. So if I place that on the ramp, the centre of gravity is not above the point of contact with the ramp, and so it rolls forward, but now, because those ping pong balls are in the front, they change the centre of gravity, and so it's exactly over the point of contact, and so it stops briefly. But then, as the viscosity of the honey allows those ping pong balls to move up, the centre of gravity shifts forwards again, allowing this little container to roll. So that is the trick of the mystery cylinder. Pretty easy if you want to try it out at home.

Now, I challenged you to run two laps of this track, where [on] the first lap, you could go as slowly as you like, but [on] the second lap, you had to go much

faster, such that your total average speed was twice the speed of your first lap. Now, when I was first asked this question by Simon Pampena, it took me a long time and scribbling on paper, and just something didn't seem to work out. And that's because... you can't actually do this. It's impossible. I mean, you might think I could run $3V$ for my 2nd lap, and that would mean my total average speed is $2V$. The problem is you can't just add the two speeds together and divide by two, because you spent much more time in your first lap, so that speed is weighted more heavily into the average. So you'd have to run, well, impossibly fast. Let me explain. The velocity of the first lap was the distance around the track divided by t , the time it took you. Now, if you want your total average speed to be $2V$, well then it needs to be $2d \div t$. You need to run twice the distance in the same amount of time it took you to run the first lap. But you've already run that first lap, and so you have no time remaining to run the second lap! Even if you went the speed of light, you would not be able to increase your total average speed up to twice the velocity of your first lap. It is just mathematically impossible! So this may seem like a bit of a trick question, but the point to me is how doable it sounds, how it seems like something you should be able to do, but you can't. It's actually impossible.

Riddle number 4: The question about the train was actually answered pretty well, with most people mentioning something to do with the wheels. But of course, that makes sense, in a series of riddles which are about rotation, rotational motion. Some people though did point out that maybe it was the steam that was going backwards, or maybe air molecules in the train, and that is actually a pretty clever point, however I wouldn't really consider the air in the train part of the train, so indeed, the part of the train that is moving backwards is the flange part of the wheel, which is below the rail. That is the part of the train which is moving backwards. To understand why, you just think

about a spinning wheel. The top of the wheel is moving forwards at speed $2V$, and the bottom of the wheel is not moving forward at all; it is stationary with respect to the track, and that is what we call "rolling without slipping," and that's how most wheels work. At least, that's how they're designed to work. Now, in the case of trains, they have to have flanges so the train doesn't fall off its rails. But of course, when these pieces come around during the rotation of the wheel, they actually extend beyond the rail, and therefore, they are going backwards with respect to the ground. So the part of the train that's moving backwards is always changing, but it's always that part of the flange, that part that extends beyond the wheel that is below the level of the track.

So what happens when you pull the bottom pedal of a bike backwards? Well, about 45% of you thought that the bike would move backwards, about a quarter said it would move forwards, and a quarter said the bike wouldn't move at all, and 5% said it depends on something... So let's give it a shot and see what happens. I'm going to pull backwards on the bike pedal in 3, 2, 1... Woah! The bike did indeed move back, and for virtually all bikes, this is what you will find. But the explanation is not just as simple as "well, the net force on the bike is back, so therefore, it has to accelerate backwards." And to prove that that logic doesn't work, well, just have a look at this video by George Hart.

[George] Watch this. Again, I pull the same pedal backward, but now... the bike moves forward!

[Derek] I'll put a link to the full video here and a link to his website in the description. So the reason the bike moves backwards is because of the way these gears are set up, the diameter of the tire, and also, the distance from this crank to the pedal itself. Because as a bike moves forwards, the pedal, even when you're pushing back on it, never actually moves backwards with respect to the ground; it's always moving forwards.

[George] So if you drag a string behind the pedal of a bike moving forward, the string is always moving forward. Now just play that movie backward in your mind, and it may be clear how pulling the string backward could make the bike move backward. They move forward together, so they move backward together.

[Derek] Another way to think about this is to consider the path traced out by the pedal as the bike moves forward. This is called the trochoid. For all ordinary bikes, the pedals are moving much slower than the tires, so the pedal is always going forward with respect to the ground. But George modified his bike so the ratio of the pedal to the wheel radius was greater than the ratio of the front sprocket to the back sprocket, and this ultra-low gear changes the trochoid so the pedal DOES actually go backwards with respect to the ground as the bike goes forwards. And that's why he could pull back on the pedal and make the bike go forwards. This is the same reason why if you were to pull backwards on the flange of a train wheel, you could actually get the train to move forwards, if you pulled backwards with enough force. For all normal bicycles, pulling back like this on the bottom pedal will cause the bicycle to move backwards, but, depending on the gear ratio, you can get the bike to move forwards. So it was those people who said it depends on the ratio of these gears and the size of this crank to the radius of the back wheel that were actually the most correct.

9.1.2 Script from Study 3 Videos

Good Clues Video

The following is the script for the first video from Study 3, containing questions and good clues, as written by Petr Lebedev and performed by Jules Rankin:

Hi everyone I hope you're all doing well.

So, we all know that electricity is incredibly dangerous and we've been told

since we were kids that electricity and water don't mix. So how can this man, swimming in a pool, survive from being struck by two hundred thousand volts from a Tesla coil? You might notice he's wearing a metal glove, which is touching the salt water, and also an aluminum hat. And there's also a wire connected to the Tesla coil which is hanging inside the pool. So, that's my question to you. How can he be struck by so many volts and yet walk away unscathed. Please post your comments down in the box below.

No Clues Video

The following is the script for the second video from Study 3, containing a question and featuring no clues, as written by Petr Lebedev and performed by Jules Rankin:

Hi everyone I hope you're all doing well.

So, we all know that electricity is incredibly dangerous and we've been told since we were kids that electricity and water don't mix. So how can this man, swimming in a pool, survive from being struck by two hundred thousand volts from a Tesla coil?

So, that's my question to you. How can he be struck by so many volts and yet walk away unscathed. Please post your comments down in the box below.

Bad Clues Video

The following is the script for the third video from Study 3, containing a question and featuring bad clues, as written by Petr Lebedev and performed by Jules Rankin:

Hi everyone I hope you're all doing well.

So, we all know that electricity is incredibly dangerous and we've been told since we were kids that electricity and water don't mix. So how can this man, swimming in a pool, survive from being struck by two hundred thousand volts

from a Tesla coil?

A Tesla coil produces very high voltage, but relatively low current. Could this be the secret to his survival?

So, that's my question to you. How can he be struck by so many volts and yet walk away unscathed. Please post your comments down in the box below.

Solution Video

The following is the script for the fourth video from Study 3, containing the solution, as written by Petr Lebedev and performed by Jules Rankin:

How he survived, is that he was never really part of the circuit. The electricity from the Tesla coil flowed through the metal glove, or hat, through the conductive salty water, and into the metal grounding wire hanging inside the pool. How he survived is that he was never really part of the circuit.

9.2 Human Ethics

The following documents (a participant information statement and an application questionnaire) were completed to satisfy the human ethics requirements of the University of Sydney.

ABN 15 211 513 464

Manjula Sharma
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Telephone: +61 2 9351 2051
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Email: manjua.sharma@sydney.edu.au
Web: <http://www.sydney.edu.au/>**Physics Reflections in Multimedia**
PARTICIPANT INFORMATION STATEMENT**(1) What is this study about?**

You are invited to take part in a research study about educational multimedia. The purpose of this study is to investigate how physics students engage in reflection after watching physics education multimedia. This research will help the understanding of how to design better educational multimedia.

You have been invited to participate in this study because you are enrolled in a first year physics unit. This Participant Information Statement tells you about the research study. Knowing what is involved will help you decide if you want to take part in the research. Please read this sheet carefully and ask questions about anything that you don't understand or want to know more about.

Participation in this research study is voluntary.

By giving your consent to take part in this study you are telling us that you:

- ✓ Understand what you have read.
- ✓ Agree to take part in the research study as outlined below.
- ✓ Agree to the use of your personal information as described.

You will be given a copy of this Participant Information Statement to keep.

(2) Who is running the study?

The study is being carried out by the following researchers:

- Manjula Sharma (Professor, School of Physics, University of Sydney)
- Petr Lebedev (PhD student, School of Physics, University of Sydney)

Petr Lebedev is conducting this study as the basis for the degree of Doctorate of Philosophy at The University of Sydney. This will take place under the supervision of Professor Manjula Sharma.

(3) What will the study involve for me?

If you choose to take part in this study you will be asked to watch two physics videos (4 mins and 8 mins), and answer two short surveys (less than 5 mins each).

Your involvement in the study is voluntary and you may withdraw your participation from the study at any time and withdraw any data that you have provided to that point. There are no penalties for withdrawing from this study.

(4) How much of my time will the study take?

This survey should take about 20 minutes of your time.

(5) Who can take part in the study?

Anyone who is studying a first year undergraduate physics course at the University of Sydney can take part.

(6) Do I have to be in the study? Can I withdraw from the study once I've started?

Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney.

Submitting your completed questionnaire is an indication of your consent to participate in the study. You can withdraw your responses any time before you have submitted the questionnaire. Once you have submitted it, your responses cannot be withdrawn because they are anonymous and therefore we will not be able to tell which one is yours.

(7) Are there any risks or costs associated with being in the study?

Aside from giving up your time, we do not expect that there will be any risks or costs associated with taking part in this study.

(8) Are there any benefits associated with being in the study?

We cannot guarantee that you will receive any direct benefits from being in the study.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise.

Your information will be stored securely and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications.

(10) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?

If you would like to know more at any stage during the study, please feel free to contact Petr Lebedev (pleb0344@uni.sydney.edu.au)

(12) Will I be told the results of the study?

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by answering the relevant question in an online questionnaire. This feedback will be in the form of an email that will summarise the study, and link to the relevant journal article when the study is published.

(13) What if I have a complaint or any concerns about the study?

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney [*INSERT* protocol number once approval is obtained]. As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect people who agree to take part in research studies.

If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** ro.humanethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet is for you to keep

HUMAN RESEARCH ETHICS COMMITTEE FORM

Please Note:

This form was created via the University's online system (IRMA) and the information provided is recorded in the University's research office database.

This information is used to assess the ethics submission under the National Health and Medical Research Council's (NHMRCs) National Statement on Ethical Conduct in Human Research (2007) by the University Ethics Committee and its expert advisers, including the RPAH Clinical Trials Subcommittee.

Sign off by researchers is provided online in IRMA and will not be displayed in this document.

ADMINISTRATIVE DETAILS

Title: Physics Reflections in Multimedia

Chief Investigator: Assoc Prof Manjula Sharma

Primary Faculty/Department: Physics; Faculty of Science

Investigators: Sharma Manjula; Lebedev Petr;

Grants linked:

External Authorities:

Additional Information:

This project aims to study how undergraduate physics students use reflective thinking. Two videos will be shown - one with physics questions, and the second with solutions. A simple survey will be given to examine how they change their minds and how they reflect. The results from this research will help physics educators and science communicators create educational multimedia that encourages reflective thinking.

QUESTIONNAIRE

1 - <div align="left">Welcome to the University of Sydney's Human Ethics Application Questionnaire. Please be aware that there is a limit of fifteen minutes to complete each individual question. If you exceed this time then your answer may not be saved by the system. We recommend that you prepare long answers outside of IRMA before pasting it back into the report questionnaire and/or save your answers regularly. If you choose to edit a previous question, your responses to subsequent questions will be deleted. The restore button can be used to refill your subsequent answers if this happens. For further information on the application procedure, please consult our website or email the Human Ethics



team at ro.humanethics@sydney.edu.au If you experience any technical difficulties, please do not hesitate to contact Research Support using the details below: T +61 2 8627 8183 E research.support@sydney.edu.au

Continue

2 - SECTION A Section A is designed to distinguish between staff and student projects. In addition, this Section also seeks to identify projects that have been approved by other ethics committees. Is this project a University of Sydney student project ONLY (i.e. ethics application restricted to the activities of the student research project)?

Yes

4 - Select appropriate student classification:

PhD

3 - Indicate whether this project has been or will be submitted to any other ethics committees

No

5 - SECTION B Section B is designed to determine whether your study falls within the National Statement's definition of low or negligible risk. Throughout this section, you may be asked specific additional questions where you indicate that your study involves particular participant and/ or project types. Please note that the option "Possible Recruitment" with reference to specific participant populations indicates that these people MAY be recruited into your study, but are not the specific population of interest. If this population is the focus of your study, you should select "Yes". Please answer the following questions Does your research involve women who are pregnant and the human foetus?

No

13 - Does your study involve children and/or young people (i.e. younger than 18 years)?

No

15 - Does your study involve people in existing dependent or unequal relationships with the researcher(s)?

No

29 - Does your research involve people with a cognitive impairment, an intellectual disability or a mental illness?

No

33 - Does your research involve people highly dependent on medical care who may be unable to give consent?

No

38 - Does your study have the potential to discover illegal activity by participants or others? This includes research intending to expose illegal activity, as well as research not specifically designed to, but likely to discover, illegal activity.

No

41 - Does your research involve Aboriginal and/or Torres Strait Islander peoples?

possible recruitment

47 - Does your research involve CALD (Culturally and Linguistically Diverse) people?

possible recruitment

63 - Does your research involve travel overseas?

No



64 - Is your study likely to cause or elicit distress in participants due to its subject matter, the procedures involved, information that might be revealed about the participant or related persons, or in some other way?

No

78 - Does your study involve research that could jeopardise a participant's employment?

No

79 - Is your proposed research a clinical trial? A clinical trial is a form of research designed to find out the effects of an intervention, including a treatment or diagnostic procedure. A clinical trial can involve testing a drug, a surgical procedure, other therapeutic procedures and devices, a preventive procedure, or a diagnostic device or procedure.

No

84 - Does your study involve the use of human tissue?

No

138 - Does your study involve human genetics or human stem cells?

No

185 - Does your study involve limited disclosure involving active concealment and/or planned deception?

No

186 - Does your study involve research that poses a risk to the physical or emotional safety or welfare of a University of Sydney student researcher (e.g. honours student or postgraduate student)? If you are a student and your research takes place off-campus a completion of a safety protocol may be necessary.

No

192 - Does your research involve any of the following: ☐ Collection of biological samples (e.g. blood, saliva, bodily fluids). ☐ Physical screening (e.g. blood pressure, cholesterol, physical fitness, MRI scans). ☐ Physical exertion? (i.e. physical activity, exercise).

No

200 - Does the research ONLY involve existing collections of data or records about human beings (collected with appropriate ethical approval)?

No

201 - Is there a foreseeable risk of more than 'discomfort'? For a useful description of the differences between harm, discomfort and inconvenience please refer to the National Statement on Ethical Conduct in Human Research, Chapter 2.1

No

196 - SECTION C The questions in Section C are designed to determine whether there are any conflicts of interests which may compromise the research process. Are any "conflict of interest" issues likely to arise in relation to this research?

No

209 - Do the researchers have any affiliation with, or financial involvement in, any organisation or entity with direct or indirect interests in the subject matter or materials of this research? (Note that such benefits must be declared in the Participant Information Statement)

No

211 - Do the researchers expect to obtain any direct or indirect financial or other benefits from conducting this research? (Note that such benefits must be declared in the Participant Information Statement)

No

213 - Have conditions already been imposed OR are likely to be imposed in the future, upon the use (e.g. publication), or ownership of the results (e.g. scientific presentations) or materials (e.g. audio-recordings), by any party other than the listed researchers?

No

215 - SECTION D The questions in Section D are specifically directed at the consent process. Describe how you will identify and select potential participants for recruitment into the study. You should include information about how you will obtain contact details for potential participants.

The researchers will seek volunteers from the 1000 students who study physics at a first year undergraduate level at the University of Sydney. Before the regular physics laboratory online pre-work, the students will be asked if they want to participate in a survey relating to physics education multimedia. It will be explicitly stated that this survey is voluntary, and will not affect their grade. It is anticipated that the sample size will be around 500 students, which will allow for the aims of this study to be achieved and is large enough for statistical analysis to be conducted that can be used to draw quantitative conclusions.

217 - Describe how and where initial contact will be made with potential participants and how you will avoid real or perceived coercion. Copies of all relevant correspondence (e.g. email, letter of introduction, covering letter, circular/flyer etc.) need to be uploaded with your application. If you are using email addresses please outline how their use will not be in breach of privacy or spam legislation.

The participants will be taken from the pool of students studying first year physics at the university of Sydney. Before the regular physics laboratory online pre-work, the students will be asked if they want to participate in a survey relating to physics education multimedia. It will be explicitly stated that this survey is voluntary, and will not affect their grade.

The Participant Information Statement and the survey will be distributed online to the participants who have volunteered to take part. The following statement appears in the Participant Information Statement:

- Being in this study is completely voluntary and you do not have to take part. Your decision whether to participate will not affect your current or future relationship with the researchers or anyone else at the University of Sydney.

218 - If a participant, or person on behalf of a participant, chooses to withdraw from the research, what specific consequences should they be made aware of, prior to giving consent? These details should be included in the Participant Information Statement.

There are no consequences for withdrawing from the research.

219 - Will participants receive any reimbursement of out-of-pocket expenses, or financial or other "rewards" as a result of participation?

No

220 - How will consent be obtained (more than one may apply)

Return of a Survey

222 - Please clarify your response to the question above and justify with reference to the National Statement (e.g. sections 2.2.5, 3.1.16, 5.2.16). For instance, if you indicated that consent will be written and oral, does this refer to all participants undergoing written and oral consent or does it refer to different consent processes for different participant groups? You should also justify why you have chosen these forms of consent. If you are using oral consent, explain how it will be recorded (e.g. in field notes, using tape recording).

Return of Survey



223 - Will there be participants who are not fluent in English or who have difficulty understanding English?

No

224 - Will a Participant Information Statement be provided? If so, please attach this in the Documents tab.

Yes

230 - Is there an intention to recruit participants who have a physical impairment or disability that may affect the consent process (e.g. blind/vision impaired/deaf/hearing impaired/speech impaired)?

No

232 - SECTION E The questions in Section E relate to how you will protect participants'™ privacy and the confidentiality of their information in your research project. Will any part of the project involve recordings (e.g. audio, video, online surveys)?

Yes

235 - Which of the following recordings will be used in the project? More than one may apply.

Online surveys

236 - Outline how these recordings will be used and why they are necessary to achieve the aims of the research project. If your project involves online surveys, state where the surveys will be hosted and comment on any security, data ownership and privacy constraints associated with this survey host.

The online survey is paramount to the research. It will be stored internally on the school of physics servers, as they are encrypted and password protected. This storage method is compliant with

234 - Will you be collecting information/data about a participant from a third party (i.e. another individual)? Please note that this DOES NOT include agencies or organisations.

No

237 - The following questions will establish whether the HREC needs to apply federal or state/territory privacy legislation when reviewing your ethics application. Will you use, collect or disclose information about human participants from an agency, authority or organisation? This includes Commonwealth agencies, private sector organisations, state/territory agencies and international organisations. For instance, you may be using information from a medical practice, a hospital, a university, a state or federal government department. You should say "yes"™ even if it is your own organisation (e.g. your medical practice).

No

241 - Is the research project likely to produce information or results that are of personal significance to individual participants? For instance, a project may reveal that participants are at risk of developing a particular disease, provide insight into their intellectual/other abilities, or indicate that they have physical or mental health problems.

No

335 - Is the research project likely to reveal a significant risk to the health or wellbeing of persons other than the participant (e.g. family members, colleagues, community members)?

No

319 - Does this project involve the use of information that you or your organisation had collected previously for another purpose?

No

344 - Describe how the overall results of this research project will be disseminated (e.g. journal publications and book chapters, conference presentations, student theses, creative works).

This research will be a chapter in a PhD thesis. It will also be published as a journal paper, and presented at conferences.

347 - Will the confidentiality of participants and privacy of their data be protected in the dissemination of overall research results? Please note that if you propose to identify individuals in publications, you should select "no" here and obtain their consent for this. Please also note that if you have obtained personal information without individual consent under a waiver of consent, you can only publish this information in de-identified form.

Yes

349 - Explain how confidentiality of participants and privacy of their data will be protected in the dissemination of research results.

The data will be completely de-identified.

350 - Will the information generated in this research project be used for any purpose(s) other than those outlined in this application? For example, will data be retained and used in future research projects, used to establish a database/research register, provided to a third party or to a public data sharing resource? Please note that this question does not refer to the use of the data for the purposes of this project (e.g. publication of results).

No

351 - Outline how feedback concerning the overall results of the project will be made available to participants (e.g. via a lay summary or newsletter). If participants are not to receive feedback, please justify why not.

The overall results will not be worthwhile to the students, as they already know how they answered the questions, and what the correct answer is.

353 - Describe where study materials will be stored DURING the project (including electronic and hard copy files, consent forms, audio recordings, questionnaires, interview transcripts, video recordings, photographs etc). Please include building and room numbers for hard copy materials.

All the materials (online surveys) will be collected and stored securely using REDCAP which is recommended by the university for managing participant data.

REDCap: Research Electronic Data Capture (REDCap) is a secure web-based database application maintained by the University of Sydney. It is ideal for collecting and managing participant data and administering online surveys, with features supporting longitudinal data collection, complex team workflows and exports to a range of statistical analysis programs.

354 - Describe where study materials will be stored upon COMPLETION of the project (including electronic and hardcopy files, consent forms, audio recordings, questionnaires, interview transcripts, video recordings, photographs etc). Please include building and room numbers for hardcopy materials. Note that on conclusion of the project a copy of all materials must be kept in an accessible and secure location on University premises.

All the materials (online surveys) will be stored securely using REDCAP which is recommended by the university for managing participant data.

REDCap: Research Electronic Data Capture (REDCap) is a secure web-based database application maintained by the University of Sydney. It is ideal for collecting and managing participant data and administering online surveys, with features supporting longitudinal data collection, complex team workflows and exports to a range of statistical analysis programs.

355 - Outline the security measures that will be used to protect study materials from misuse, loss or unauthorised access during and after the project (e.g. removal of identifiers, secure storage, restriction of access to appropriate personnel etc).

All the materials (online surveys) will be stored securely using REDCAP which is recommended by the university for managing participant data. Only Manjula Sharma and Petr Lebedev will have access to this data.

REDCap: Research Electronic Data Capture (REDCap) is a secure web-based database application maintained by the University of Sydney. It is ideal for collecting and managing participant data and administering online surveys, with features supporting longitudinal data collection, complex team workflows and exports to a range of statistical analysis programs.

356 - Specify how long study materials will be retained for after project completion. Please note that the options provided below are intended to facilitate compliance with relevant legislation from the State Records Authority of NSW. Data from research involving children; and from clinical trials, scanning and radioactivity studies, clinical studies, genetic manipulation, human tissue studies, and psychological research that has potential long term effects must be retained for a minimum of 20 years or until participants are 25 years of age (whichever is longer). Data from other types of studies must be retained for a minimum of 5 years. For some types of research (e.g. oral history, gene therapy) or where it is intended to reuse data in the future, it is appropriate to retain data in perpetuity (i.e. indefinitely).

5 years

357 - Explain why this storage period has been chosen.

5 years because it is non-medical data.

358 - At the end of the project, will study materials/information be stored in individually identifiable or re-identifiable form? Please note that this does not refer to the consent forms. Individually identifiable information is that from which the identity of a specific individual can reasonably be ascertained. Re-identifiable information has had identifiers removed and replaced by a code, so it is possible to identify individuals by using the code. Non-identifiable information has had all identifiers irreversibly removed or was never identifiable (see Chapter 3.2 of the National Statement for more information).

No

359 - If they are not to be kept in perpetuity, how will project materials ultimately be disposed of?

The surveys will be deleted from the server.

361 - SECTION F The questions in Section F concern risks to both participants and others connected with the study. Participation in research can involve potential harm to participants including physical, psychological, reputational, financial, spiritual, emotional and social distress. Please outline any potential harm and justify it with regard to the potential benefits of the project. What steps will the researchers take to minimise potential harm endured as a consequence of participation? (e.g. by providing access/information to counselling)

This research can not cause any physical, psychological, reputational, financial, spiritual, emotional and social distress.

362 - Are there any other risks involved in this research? For example, to the research team, the organisation, others? What are these risks? Explain how these risks will be negated/ minimised/ managed.

There are no other risks

363 - SECTION G The questions in Section G concern details of the research study. Please answer the following questions. The nature of this project is most appropriately described as research involving (more than one may apply):

Questionnaire/survey

364 - Are you doing research in a context which requires you to get permission from an appropriate authority e.g. a school, corporation, NGO, or similar?

No

365 - Outline in lay language the theoretical, empirical and/or conceptual basis, background evidence for the research proposal with reference to the relevant literature (include at least four research citations). Note, that your study should be "based on a thorough study of the current literature, as well as previous studies" (NS 1.1 c).

Multimedia is a very useful educational tool, though its effectiveness is highly context dependant (Mayer 2005). YouTube is used to

teach a wide range of subjects, from Chemistry (Smith, 2014) and Physics (Riendeau) to Sociology (Tan and Pearce, 2017), and Art (Sweeny, 2009).

While there are some studies on the effectiveness of multimedia in physics education (Muller, 2008) there is a limited research on how people reflect while engaging with multimedia. Reflection is a

critical part of learning enabling learners to correct distortions in our beliefs and errors in problem-solving (Mezirow, 1990). This study probes the role of reflection in physics education multimedia. With responses from around 500 students, we will categorise ways in which students reflect and critically think. We will then be able to undertake a mixed methods analysis of the student's responses, quantitatively comparing self-reported confidence, interest, with the categories of reflection.

By conducting this study, we will be able to understand how to better design physics education multimedia that encourages reflection, which is part of critical thinking, and a valuable learning tool.

367 - Outline in lay language the methodology for the research proposal. Note, that your study should be "designed or developed using methods appropriate for achieving the aims of the proposal" (NS 1.1 b). Your response should include:â€¢ Aims and hypotheses/research questionsâ€¢ Research plan including duration of the study and/or timelineâ€¢ Participant characteristics including sex, age range and inclusion/exclusion criteria (if relevant)â€¢ The intended sample size with a justification, and/or the participant sampling/selection strategy (as relevant to your study)â€¢ Details of where the study will be undertaken (location/site/URL)â€¢ Details of how data will be collected and analysedâ€¢ Potential significance of the study

Aims and hypotheses/research questions

The aim of this research is to analyze how undergraduate physics students respond to Question and Answer based physics videos. The specific focus is on how students reflect on their answers, and how they justify changing or not changing their answers, and how confidence, and type of question affects these changes.

Our research questions are:

Research question one: After watching a YouTube educational video, do viewers self-report a shift in their understandings?

Research question two: What are the self-reported reasons for this shift in understanding?

Research plan including duration of the study and/or timeline

The collection of data for this research will be undertaken during one voluntary pre-lab online survey. The students will watch two videos (two in total, 4:23 minutes and 8:50 minutes) and conduct two short surveys (less than 5 minutes each). The total survey should take no more than 20 minutes.

After the data is collected, it will be analysed with a mixed-methods approach, with the aims of publishing a scientific paper in the middle of the year.

Participant characteristics including sex, age range and inclusion/exclusion criteria (if relevant)

Sex and age range will be that of first year physics students. This research is most applicable to physics educators which is why this cohort was chosen. The only inclusion criteria is that the volunteers are doing a first year physics course at the University of Sydney. The age of most of the participants will be 18/19.

The intended sample size with a justification, and/or the participant sampling/selection strategy (as relevant to your study)

As there are approximately 1000 first year undergraduate physics students, we hope to have a sample size of 500 volunteers. This large sample size allows us to conduct a mixed methods

approach to our data analysis and will yield more reliable scientific results. The first year physics cohort is large and varied – we aim to represent this diversity in our research.

Details of where the study will be undertaken (location/site/URL)

The survey for the study will be given out as a voluntary online pre-lab. Before the pre-work, the volunteers will click through to the RedCap site where the survey will be administered. After the data is collected, the results will be securely stored on RedCap.

Details of how data will be collected and analyzed

The data will be collected via online survey. It will be analyzed with a mixed methods approach, both quantitatively and qualitatively. The qualitative data will be inductively and deductively coded, and checked for validity by inter-coder reliability tests.

Potential significance of the study

This study aims to understand how physics undergraduate students reflect, and which aspects of educational videos encourage reflective thinking.

- 1) The conceptual advancement is in terms of the nature of the questions, and what responses they elicit.
- 2) The ways in which people reflect
- 3) The role which reflection plays in learning

The practical applications of this research is for helping design more effective multimedia for physics educators and science communicators that encourages more reflective thinking in the audience.

The practical application of this research is to help design multimedia that is targeted at encouraging reflection. This research will be useful for physics educators and science communicators.

207 - <div align="left">Thank you for completing the University of Sydney's Human Ethics Application Questionnaire. After selecting 'Completed' below, please remember to attach any documents relevant to your application in the next tab. After completing your application, return to the 'Coversheet' tab and press the 'Submit' button. You will receive an email shortly after confirming your submission. Once again, if you require further information on the application procedure, please consult our website or email the Human Ethics team at ro.humanethics@sydney.edu.au. If you experience any technical difficulties, please do not hesitate to contact Research Support using the details below: T +61 2 8627 8183 E research.support@sydney.edu.au</div>

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LIST OF ATTACHED DOCUMENTS

Date Uploaded	Type	Document Name
22/12/2017	Participant Info Statement	Participant Information Sheet