

# Barker

Science

Science  
Extension  
Journal



Scientific Research  
in School

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## Mission

An Anglican community inspiring  
every learner  
every experience  
every day

## Vision

To be a leader in Christian education  
that is characterised by a global vision  
that inspires hope

## Values

Commitment  
Compassion  
Courage  
Integrity  
Respect





*We acknowledge the Dharug, Guringai and Darkinjung people who are the traditional custodians of the land on which Barker College and Darkinjung Barker stands. We pay respect to the elders past and present of the Dharug, Guringai and Darkinjung nations and extend that respect to other Aboriginal people within the Barker College community.*

# Introduction



Science is far more than understanding facts and explanations, it is about a way of developing and disseminating knowledge.



The students have explored the history and philosophy of science and used their understanding to carry out a large-scale investigation, culminating in a report.

We are immensely proud of our students who have done just that through the inaugural year of Science Extension course.

I am amazed by the quality of these reports as they rival work produced by university student researchers many years their senior. They reflect not only deep scientific thought but also represent the creativity and interests of students themselves as researchers.

These students have been doing genuine research with consequential applications in medicine, agriculture, education, chemistry, engineering, biology and beyond. These journal articles serve as contributions to the literature as our students are even now participating in the progress of science.

Congratulations to each and every student, to their families who supported them and to the Science Extension teachers for supervising, guiding and encouraging them.

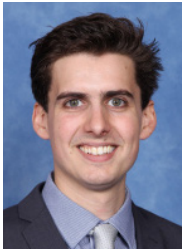
A handwritten signature in black ink that reads "Phillip Heath".

**Mr Phillip Heath AM**  
*Head of Barker College*

Along the way they have learnt what it is to be a research scientist with the associated challenges and rewards. They have acquired a new, relevant skill set that will benefit them in the years ahead, particularly if they choose to study STEM-based courses at a tertiary level. I am thankful for the work of Dr Hill, Dr Terrett and Dr Gates who have supervised these students on their research journey, pioneering this exciting course. I hope you enjoy reading these diverse reports in our historical, first ever Science Extension Journal.

A handwritten signature in black ink that reads "R. J. Paynter".

**Mr Robert Paynter**  
*Head of Science*



**Dr Matthew Hill**

*Director of Research in Learning &  
The Barker Institute*

*Physics Teacher*



**Dr Katie Terrett**

*Chemistry Teacher*



**Dr Alison Gates**

*Agriculture & Science Teacher*

Undertaking proper scientific research takes curiosity, capacity and commitment. These students found research questions that they were passionate about and worked hard to implement the scientific research process to answer them. They demonstrated a high capacity for scientific thinking, inquiry and communication resulting in these high-quality journal articles. It was a joy and a privilege to work with these fine young scientists, we are incredibly proud of them, and we are excited to share their work with you in this journal.

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**Editors**

Dr Matthew Hill  
Dr Katie Terrett  
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# Contents

## Part 1: Chemistry

Antibacterial activity and chemical degradation pathways of propyl isothiocyanate Sean Cheng	01
Effects of a teacher's displayed enthusiasm on student results in Chemistry education Jordan Guyot	07
Effect of temperature on viscosity of polyvinyl borate Harry Clark	15
Synthesis of a pyrimethamine analogue and statistical analysis of analogue structure Lucas Sach	21

## Part 2: Biology

Filtering water using plant xylem Harry Chalmers	31
Leaf me alone! The effect of non-naturally occurring physical stimulus on the growth of plants Georgia Pallas	39
The intention experiment: The effect of intention on the growth of cherry radish seeds Sami Lindsay	45
Contralateral vs Ipsilateral in free throw performance Russell Chen	51
The relationship between age and infection rate of Invasive Meningococcal Disease Stuart Paine	57
The effect of solution concentration on maximum height of capillary rise, with specific reference to the fertilizer Ammonium Dihydrogen Orthophosphate Nicholas Fakira	63

## Part 3: Physics

The efficiency of ducted propellers Alexander Marlin	71
The casino's gambit: The randomness of three different manual shuffling practices Akilan Rajan	77
Motivation style and the academic performance of Physics students Nicholas Vasiliev	83
The phenomenon of frisbee ricochets Duncan Chen	89







# Chemistry

Chemistry is concerned with the study of the composition, properties and reactivity of matter.

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The researchers have developed projects that cover topics from human medicine to Chemistry Education. Sean's project tested the efficacy of a compound as an anti-microbial agent. In the end, he found that the compound did not display antimicrobial properties, but we all gained knowledge from the method and rigour of the scientific method which he employed. Jordan's project used a fascinating method to evaluate the role of teacher enthusiasm in Chemistry instruction. Jordan deserves special commendation for the extraordinary passion and dedication he showed in his research. Harry tested the relationship between temperature and viscosity in a polymer, dramatically improving its usefulness in real world applications. Lucas' project proposed a chemical solution to the problem of reduced efficacy in anti-malarial medications. By beginning the synthesis of a compound that comprises a structural change to an existing anti-malarial, Lucas has made some crucial first steps towards proposing an advancement to an anti-malarial agent.

Traditionally these kinds of Chemistry research projects have sat well outside the realm of the secondary Chemistry classroom. The combination of a well-resourced, dedicated laboratory space, staff expertise and passionate students has resulted in some amazing achievements in the inaugural year of Science Extension. We congratulate our researchers on these impressive scientific contributions.



# Antibacterial activity and chemical degradation pathways of propyl isothiocyanate

Sean Cheng

Barker College

Propyl isothiocyanate is an analogue of the well-researched antibacterial agent allyl isothiocyanate, that is found in plants of the Brassicaceae family. K-12 E. coli was inoculated into Mueller Hinton agar in order to test the effectiveness of propyl isothiocyanate as an alternative antibacterial agent, determined by the zone of inhibition. All concentrations of propyl isothiocyanate displayed no antibacterial activity in this experiment, as no zone of inhibition was observed. However, Chemical degradation pathways of propyl isothiocyanate are proposed, based on reported research on the decomposition of allyl isothiocyanate in water.

## Literature review

Based on data collected between 2006-2010, there are an estimated 4.1 million cases of foodborne gastroenteritis that occur in Australia each year. (Australian Government Department of Health 2014). Between 2001 and 2013 a total of 107 bacterial toxin-mediated outbreaks were reported, affecting 2,219 people, including 47 hospitalisations and 13 deaths. (May, Polkinghorne, & Fearnley 2016). Antibiotics are the most common and effective treatment of bacterial infections in humans, however, as a result of the increasing antibiotic resistance of many bacterial strains the need for new antibacterial agents has increased.

The emergence of antibiotic-resistant microbial strains is not exclusive to hospital environments (Munita & Arias 2016). In fact, the evolution of antibiotic resistance over the past few decades has become one of the greatest public health threats of the 21st century. As a result of this increase, untreatable infections have become prevalent, particularly in developing countries where infection rates are higher and fresh produce is less available (United Nations 2015). Many research groups have attributed this scenario to a lack of available, affordable and effective antibiotics. Due to this, research efforts around the world are focusing on the discovery of new antibiotics which function via novel modes of action (Munita & Arias 2016).

Numerous chemical compounds can stop the growth of bacterial cultures. However, the usefulness of these compounds depends on a multitude of factors such as the potential toxicity to humans, availability, cost and

environmental risks (Nowicki et al. 2016). A group of chemical compounds of interest in the scientific community is the isothiocyanate group (1), as they naturally occur in plants of the *Brassicaceae* family (Figure 1) (Dufour, Stahl & Baysse 2015). Isothiocyanates are also of particular interest as a significant additive effect has been observed between isothiocyanates and antibiotics (Dufour, Stahl & Baysse 2015), creating the potential for reduced dosages of antibiotics with the same potency. This may decrease the likelihood of antibiotic resistance developing within a microbial strain. (Dufour, Stahl & Baysse 2015).

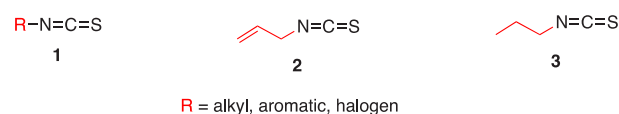


Figure 1: General structure of the isothiocyanate functional group (1), allyl isothiocyanate (2), and propyl isothiocyanate (3).

One of the most common and well investigated isothiocyanates is allyl isothiocyanate (2) (Figure 1) (Olaimat & Holley 2013). This compound is isolated from plants such as cabbage, horseradish and cauliflower (Shelef 1984). It is a well-recognised antimicrobial agent in both liquid and vapour forms (Lin, Preston III & Wei 2000), and it is effective against a variety of microorganisms such as *Escherichia coli* (Luciano & Holley 2009). The mechanism of allyl isothiocyanate's (2) microbiocidal activity is still unknown (Luciano & Holley 2009), however, multiple research papers have proposed chemical mechanisms to

explain its antibacterial activity, such as the Kawakishi research group who have reported that allyl isothiocyanate can inhibit microbial growth by altering the structure of essential proteins present in bacterial strains (Kawakishi & Kaneko 1985; 1987). In particular, proteins such as bovine serum, albumin, insulin, ovalbumin and lysozyme were shown to be compromised at the disulphide bonds in the presence of allyl isothiocyanate (Kawakishi & Kaneko 1987).

In contrast, the results of this work are questioned by Luciano & Holley (2009) who report that Kawakishi & Kaneko did not look at the reaction of allyl isothiocyanate (2) with microbial proteins under realistic biological conditions, with the reactions being analysed at temperatures over 37°C with intensive stirring, facilitating allyl isothiocyanate protein interactions. Another research group tested the inhibition of oxygen uptake with a range of isothiocyanates (1) against three species of yeast. Kojima and Ogawa (1971) observed significant enzymatic inhibition of cytochrome c oxidase by allyl isothiocyanate. More recent studies by Luciano & Holley (2009) show that allyl isothiocyanate was able to inhibit specific enzymic activity in *E.coli* through interfering with the function of both thioredoxin reductase and acetate kinase. Many more papers attempt to describe the antibacterial mechanism of allyl isothiocyanate, including suggestions that allyl isothiocyanate (2) attacks the active site of enzymes, alters protein structures, interferes with bacterial enzyme activity, respiration, metabolism and the transcription of genes (Dufour, Stahl & Baysse 2015). It is clear from the number of conflicting reports that there is still more research needed to confirm the true mode of action of compound 2, which is currently poorly understood.

The use of allyl isothiocyanate (2) as a food preservative is already approved in Japan, as long as it comes from a natural source (Nadarajah et al. 2005). However, in its pure extracted form, it is highly volatile, highly toxic, carcinogenic and is hazardous to the aquatic environment (GHS Classification Guidance by the Japanese Government 2013). Its shelf life is also limited as it decomposes at room temperature over time, further affecting its practicality when being used as a food preservative. As a result, this investigation has focused on a synthetic compound known as propyl isothiocyanate (3, Figure 1). The molecular structure of compound 3 is very similar to that of allyl isothiocyanate, except for the carbon-carbon double bond which is replaced with a single bond. The risks involved with the handling and use of compound 3 are

significantly less than those for compound 2 as it is only flammable, corrosive, and a mild irritant (National Center for Biotechnology Information 2019). In addition, the cost of purchasing the propyl isothiocyanate analogue (3) is significantly less than the price for the allyl isothiocyanate (2). These factors all make the propyl isothiocyanate an attractive candidate for a cheaper and less toxic antibacterial agent. As there is no detail in the literature about the antibacterial activity of compound 3 (Nowicki et al. 2016), the purpose of this project is to investigate the potential of this compound as a potential new antibiotic candidate.

### Scientific research question

Does propyl isothiocyanate (3) have comparable antibacterial activity to allyl isothiocyanate (2) against K-12 *E. coli*?

### Scientific hypothesis

That propyl isothiocyanate (3) will display antibacterial activity against *E. coli*, measured by the zone of inhibition.

### Methodology

#### Chemicals

Propyl isothiocyanate (3) and dimethyl sulfoxide (DMSO) were purchased from Aldrich Chemical Co. (Milwaukee, WI, USA).

#### Bacteria

K-12 *E.coli* was purchased from Southern Biological (Knoxfield, Victoria, Australia)

Tetracycline test antibiotic was purchased from Southern Biological (Knoxfield, Victoria, Australia)

18 plates of Mueller Hinton agar were prepared by lab staff, according to the manufacturer's instructions.

6mm discs were created using sterile filter paper and a hole punch.

#### Sterilisation

Methylated spirits were used to wipe the bench. A Bunsen burner was used to sterilise the inoculating loop and metal forceps.

#### Serial Dilutions

A standard solution of propyl isothiocyanate was prepared by dissolving 0.50 g of propyl isothiocyanate (3) into 100 mL of DMSO and 150 mL of water in a volumetric flask. This created a stock solution of concentration 2000 mg/L. Serial dilutions were carried out into 20 mL volumetric flasks by pipetting 10 mL of solution and 10 mL of distilled water to create solutions with concentrations as listed in Table 1.

Table 1: Concentrations of propyl isothiocyanate (3).

Solution	Concentration (mg/L)	Total Volume (mL)
1	2000	20
2	1000	20
3	500	20
4	250	20
5	125	20
6	62.5	20
7	31.25	20
8	15.625	20

Each solution was poured to fill a separate petri dish and sufficient sterile filter paper discs (6 mm in diameter) were placed in the solution.

*Inoculation and plating*

Each agar plate was flooded with 1.50mL of bacterial suspension. The plates were then rocked in order to evenly distribute the suspension, and an inoculating loop was used in order to spread out the residual bacteria suspension. All apparatus was re-sterilised between each agar plate. The lids were removed and the plates were placed inside a fume hood to dry for 15 minutes. Agar plates were removed from the fume hood and the lid was placed back onto each petri dish. A marker was then used to draw two lines on the lid of each agar plate, creating a total of 4 cross sections for each plate (Figure 2). 18 plates were then labelled for each different concentration, making sure to write on the bottom side of the agar plate in order to ensure clarity for measurements. Metal forceps were sterilised using a Bunsen burner and allowed to cool. The forceps were used to transfer a single sterile filter paper disc to each zone of all the discs, sterilising the forceps between each addition. A total of four discs were placed in each agar plate. A control agar plate was set up to include a negative control (a blank sterile filter paper disc), a positive control (a sterile filter paper disc with tetracycline antibiotic), a dimethyl sulfoxide control (a sterile filter paper disc saturated in dimethyl sulfoxide solution) and the propyl isothiocyanate (3) solution (a sterile filter paper disc saturated in propyl isothiocyanate concentration of 250 mg/L). After the plates were sealed and labelled, plates were placed in an incubator at 35-37°C for 24 hours.

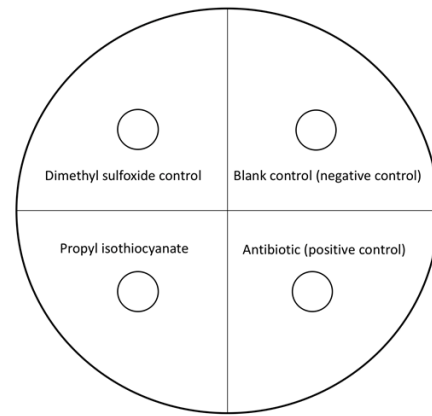


Figure 2: Example agar plate displaying 4 divided areas.

*Determination of inhibitory concentration*

The annular radius was measured using vernier callipers. If the annular radius was measured to be greater than or equal to 6 mm then the concentration was deemed to be antibacterial by CDS standards (Bell et al. 2018).

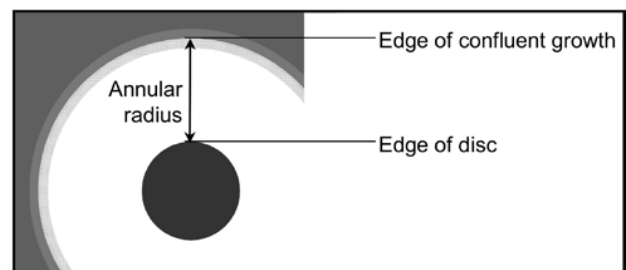


Figure 3: Measurement of annular radius (Source: Bell et al. 2018 pp. 19).

**Results**

Table 2: Zone of inhibition of propyl isothiocyanate against K-12 E.coli at different concentrations.

Concentration (mg/L)	Zone of inhibition
15.625	No inhibition
31.25	No inhibition
62.5	No inhibition
125	No inhibition
250	No inhibition
500	No inhibition
1000	No inhibition
2000	No inhibition
Undiluted propyl isothiocyanate	No measurable bacterial growth

Tests of each concentration were repeated 8 times, all showing no signs of antibacterial activity.



Figure 4: Control plate with DMSO, propyl isothiocyanate, blank disc and tetracycline



Figure 8: Comparison of controls (left) and test plates (right)

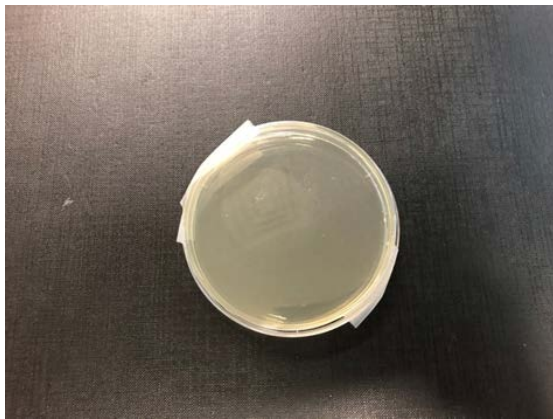


Figure 5: Blank control plate



Figure 9: Test plate of undiluted propyl isothiocyanate, showcasing complete inhibition of bacterial growth.

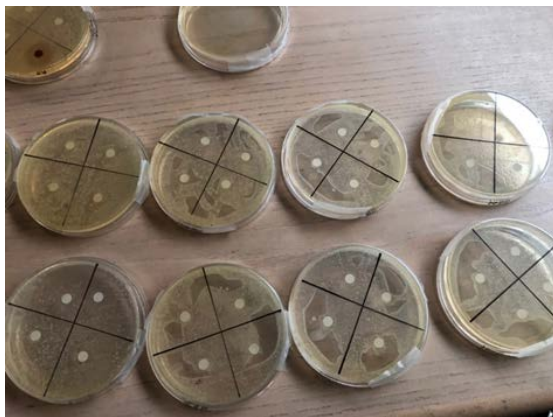


Figure 6: Test plates with varying concentrations.



Figure 7: Example close up of 125mg/L concentration.

## Discussion

As seen above in Figures 4-9 and Table 2, all concentrations of propyl isothiocyanate (3) displayed no antibacterial activity in this experiment, as no zone of inhibition was observed. All control plates were successful with the positive control (tetracycline) displaying a clear zone of inhibition (Figure 4), and the blank control plate exhibiting no bacterial growth (Figure 5). Despite the clear structural similarities between propyl isothiocyanate (3) and allyl isothiocyanate (2), the propyl analogue (3) appears to be a much less effective antibacterial agent. This may be a result of the absence of the carbon-carbon double bond present in the allyl variant (2), which may be essential for the activity of this compound. A one-way ANOVA with post-hoc test would have been appropriate to analyse the significance of the variance between each concentration, in the case where antibacterial activity was measured. However, as there was no observable zone of inhibition, this was not conducted.

Interestingly, Luciano & Holley (2009) suggest that allyl isothiocyanate (2) undergoes degradation in water whereby the decomposition products are not responsible for the antibacterial activity of this compound. Related degradation pathways may also be occurring when the propyl isothiocyanate is dissolved in water, and subsequent testing would need to occur in order to

confirm the presence of any decomposition products. During the creation of the propyl isothiocyanate (**3**) standard solutions, a large amount of heat was generated along with a substantial amount of gas. This could be an indication that a reaction is taking place between the propyl isothiocyanate and either water or dimethyl sulfoxide. It is reasonable to suggest that the lack of antibacterial activity for propyl isothiocyanate (**3**) may be a result of either the different side chain, or maybe a result of compound degradation, similar to the degradation pathways reported for the allyl analogue (**2**). Several studies on the degradation pathways of allyl isothiocyanate (**2**) have been reported in the literature (Pechacek, Velisek & Hrabcova 1997) and hence, it is possible to speculate on the possible decomposition pathways for propyl isothiocyanate (**3**).

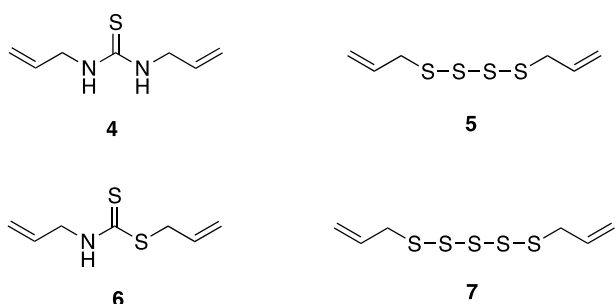


Figure 10: Identified degradation products of allyl isothiocyanate (**2**)

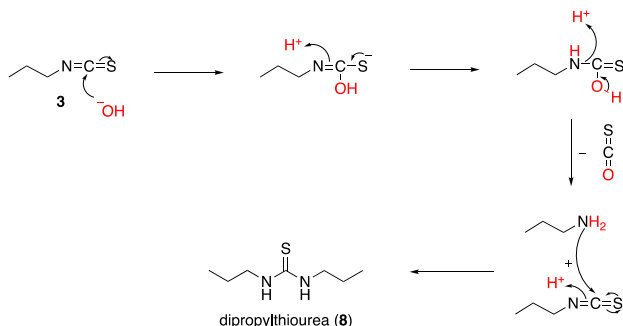


Figure 11: Proposed degradation pathway for formation of dipropylthiourea (**8**) from propyl isothiocyanate (**3**).

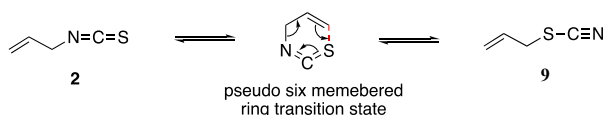


Figure 12: Rearrangement pathway from allyl isothiocyanate (**2**) to allyl thiocyanate (**9**).

The major degradation pathway proposed by Pechacek, Velisek & Hrabcova (1997) of allyl isothiocyanate (**2**) to allyl thiocyanate (**9**) depicted in (Figure 12) occurs through a cyclic six-membered ring transition state involving an allylic shift (Pechacek, Velisek & Hrabcova 1997). Smith and Emerson (1960) observed this to be especially characteristic in organic solvents. As this pathway requires the carbon-carbon double bond

it is highly unlikely that the propyl isothiocyanate (**3**) analogue has undertaken this degradation pathway.

On the other hand, Figure 11 displays a degradation pathway for the formation of dipropylthiourea (**8**) from propyl isothiocyanate (**3**), via the addition of a hydroxide ion to the carbon atom of the isothiocyanate functional group (Pechacek, Velisek & Hrabcova 1997). This is a more likely degradation pathway as the formation of dipropylthiourea (**8**) is not reliant on a carbon-carbon double bond, characteristic of allyl isothiocyanate (**2**). The presence of hydroxide ions is also accounted for through the addition of water during the serial dilutions when creating the standard solutions. This may explain the positive results of propyl isothiocyanate (**3**) being completely antibacterial as seen in Figure 9. However, as no zone of inhibition could be measured further testing should be conducted to determine the role of the solvent and the antibacterial properties of propyl isothiocyanate. Furthermore, studies designed to confirm the identity of the possible degradation products of propyl isothiocyanate are recommended. Degradation conditions would need to be analysed and products isolated and purified. After purification, analysis of products could be undertaken. Analytical techniques such as mass spectroscopy (MS), infrared spectroscopy (IR) and Nuclear Magnetic Resonance (NMR) spectroscopy could be used in order to confirm the proposed degradation pathway of propyl isothiocyanate.

The lack of antibacterial activity for propyl isothiocyanate (**3**) is not unexpected as the discovery of new antibacterial compounds can take decades (Nowicki et al. 2016). Nonetheless, this experiment is an important step towards gaining a better understanding of the isothiocyanate class of compounds and the discovery of new analogues with favourable properties. Further studies involving different isothiocyanate analogues could also be undertaken in order to provide greater insight into the chemical properties that affect antibacterial activity.

## Conclusion

Propyl isothiocyanate (**3**) did not display antibacterial activity against *E. coli*, measured by the zone of inhibition. Each concentration of propyl isothiocyanate (**3**) did not have a measurable zone of inhibition, including the undiluted sample as there was no observable bacterial growth. This result can be explained through either the allyl isothiocyanate's carbon-carbon double bond being essential to exhibit antibacterial activity or the possible degradation of propyl isothiocyanate when reacted with hydroxide ions in solution. Although propyl isothiocyanate (**3**) did not have a comparable antibacterial activity to allyl

isothiocyanate (2), a possible degradation pathway of the formation of dipropylthiourea (8) has been hypothesised, suggesting propyl isothiocyanate has the potential to be antibacterial in its pure extracted form.

### Acknowledgements

I would like to thank Dr Terrett and Dr Hill for their thoughtful insights on this paper, more specifically Dr Terrett with her extensive chemistry knowledge, and Dr Hill for his assistance in the statistical analysis and reference formatting. I would also like to thank Mrs Ellis for her technical assistance, and I express much gratitude to the lab staff for their preparation of the agar plates.

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# Effects of a teacher's displayed enthusiasm on student results in Chemistry education

**Jordan Guyot**

Barker College

This study investigates the impact of a teacher's displayed enthusiasm on high school students' learning of theoretical content in Chemistry. Currently, there are limited studies about the effect of teacher displayed enthusiasm on secondary-school students' learning outcomes. This study focuses on how Year 10 students at a co-educational secondary school in the North of Sydney, Australia, exposed to teaching of new content (from the Preliminary HSC Chemistry syllabus), learn based on varying amounts of displayed enthusiasm. Two groups of students (n=147) completed a conceptual pre-test, observed a video of relevant teaching with either a high or a low level of displayed enthusiasm, then completed the same conceptual test as a post-test and a reflection survey. A one-tailed t-test revealed that the treatment group exposed to high displayed enthusiasm teaching had significantly higher gains than the low displayed enthusiasm group. Secondary tests found that high ability students had greater gains than lower ability students ( $t=8.268$ ,  $p<0.0001$ ) and that high enthusiasm improved recall of knowledge, but had a smaller effect on students' ability to apply that knowledge to new situations.

## **Literature review**

Nobel Prize winner Carl Wieman wrote 'a successful science education transforms how students think, so that they can understand and use science as scientists do' (Wieman 2007, p9). To achieve this, he proposed that a scientific approach should be taken to science education (Wieman 2007). To investigate the impact of displayed enthusiasm in high school chemistry classes, the academic perspectives on student learning, and characterisations of teacher enthusiasm must be considered.

## ***Student Learning***

A variety of factors influence student learning, including the quality of course materials, features of the teacher and their teaching style, the impact of fellow students, third parties and, of course, student-related factors, such as attendance, gender, relevant academic background, previous academic achievement, and relevant learning experience (Cheung, & Kan 2010). One of the primary factors in student learning is the student's in-class engagement (Martin & Bolliger 2018; Kipp & Rice 2019). Student engagement can be defined in three dimensions: behavioural, emotional, and cognitive (Fredericks, Blumenfeld, & Paris, 2004). Behavioural engagement is the student involvement and participation throughout the course and can be

characterised by factors such as paying attention and asking questions (Birch & Ladd 1997). Emotional engagement is the students' feelings such as anxiety and excitement (Taylor & Statler 2013), and cognitive engagement is the investment students make towards their learning and commitments (Connell & Wellborn 1991).

## ***Teacher Enthusiasm and Student Learning***

Unsurprisingly, teachers play a vital role in facilitating student behavioural, emotional and cognitive engagement (Roorda et al. 2011, Durlak et al. 2011). It has been found that a wide range of teaching behaviours including teacher enthusiasm, voice volume/inflection, positive feedback, and use of inquiries all have positive correlations with student academic engagement (Ortiz 1997). Of these, the factor with the highest correlation to academic engagement according to Ortiz (1997) was teacher enthusiasm.

Research on teacher's enthusiastic behaviours that actively promote student learning of content are relatively scarce. The literature has offered two main explanations of how teacher enthusiasm may positively effect student learning. The first involves a teachers' enthusiastic displays (e.g. gestures and body movements) and may increase students' attention by

catching students' attention over classroom disturbances. The second proposes that students may adopt the enthusiastic attitudes of their teachers (Keller et al. 2014; Keller et al. 2013; Collins 1978; Frenzel et al. 2009).

Recently it has been proposed that there is a multicomponent conceptualisation of teacher enthusiasm, which encompasses an *experiential* component as well as a behaviourally *displayed* component (Keller, Becker & Frenzel 2016). *Experiential enthusiasm* is how much interest the teacher internally feels about the subject whereas *displayed enthusiasm* relates to the following teacher qualities: vocal delivery, levels of eye movement and contact, use of demonstrative gestures, use of body movements, use of facial expressions, selection of words, and over-all energy level (Frenzel et al. 2019). *High displayed enthusiasm* contains high levels of these traits, whilst *low displayed enthusiasm* contains low levels of these traits. Recent studies suggest that the experiential (or internal) component has a positive relationship with students' performance (Mahler, Großschedl & Harms 2018). However, there are mixed results as to whether the displayed component of a teacher's enthusiasm, which is the demonstrated external enthusiasm that can be observed by the students, affects student learning outcomes. It has been found that displayed enthusiasm does benefit elementary students (Gillett & Gall 1980) and students with disabilities (Brigham, Scruggs & Mastropieri 1992; Wood, 1999; Brigham 1991). Other studies found either no link or a very weak link between the displayed enthusiasm and student performance (Bettencourt, Gillett, & Damien Gall 1983; Motz, de Leeuw & Carvalho 2017).

There has not been any reported research into displayed enthusiasm and the effect on learning science (particularly for secondary school students) and so this study will focus on the impact on teacher displayed enthusiasm on secondary school students' ability to learn scientific concepts, specifically in the field of Chemistry.

A particularly interesting study conducted by Frenzel et al. (2019) involved 483 university students studying Education or Economics. Students were randomly allocated to a six minute lecture on 'the effectiveness of learning strategies students typically use and some tips on how to prepare for exams' (Frenzel et al. 2019, p258) which had either high or low displayed enthusiasm. In that project, the researchers also examined a second factor related to ascribed intrinsic or extrinsic motivation but this is outside the scope of this investigation. The lectures were followed by a questionnaire which asked about the students'

perception of the teacher's displayed enthusiasm, which confirmed that students perceived the teacher's enthusiasm the way they were intended to. The study herein will involve a similar treatment (students randomly assigned to a lecture with either high or low displayed enthusiasm) but rather than measuring whether a student noticed displayed enthusiasm, the students in this study will be tested on whether they have learned and understood the scientific content by completing a pre and post test on Chemistry concepts.

### Scientific research question

Does a higher level of displayed enthusiasm from a teacher increase students' learning of Chemistry content?

- Are there different responses to teacher displayed enthusiasm with regards to gains in the areas of recall and application of Chemistry knowledge?
- Are there different responses to displayed enthusiasm from students with lower or higher academic ability?

### Scientific hypothesis

That higher levels of displayed enthusiasm of Chemistry teachers will lead to an increase in student learning of a Chemistry concept.

### Methodology

#### *Ethics Statement*

This research was conducted in consultation with the Director of Research in Learning & The Barker Institute, Barker College which involved receiving ethical approval. Through this process, risks within the data collection phase and analysis were foreseen and hence, mitigated. The activity was conducted by teachers during a normal Year 10 Science lesson constituting a regular teaching activity. Only students who gave informed consent for their data to be used were included in the study and all analysis was conducted on anonymous data. Data was collected through a secure online website (Canvas) before it was downloaded to the researcher's computer with a backup file stored with the Director of Research in Learning & The Barker Institute.

#### *Preparation*

Figure 1 describes the process of planning the intervention. A 13 question quiz was created based on the Chemistry concept 'orbital notation', which would be used for the pre-test and the post-test, hereby named the 'Orbital Conception Test' (OCT) [Appendix A]. A reflective survey was created to gather data on the way students perceived the enthusiasm of the teacher in the learning instruction [Appendix B]. Two videos with varying displays of enthusiasm from low [Appendix C]



Figure 1 - Flowchart of planning phase

to high [Appendix D] were created, using criteria as described in Figure 2. Participants were recruited evenly from A and B stream Year 10 Science classes at Barker College which represented students of higher and lower science ability, respectively, based on Year 9 assessment marks. Eight classes participated, equalling a total of 157 students. The classes were run using the online learning platform, Canvas. Each class was randomly assigned to a video, ensuring there was an equal number of A and B stream classes in each group. Randomisation was ensured as each class had a video of either high enthusiasm or low enthusiasm randomly assigned by a teacher that had no connection to the students. A common instruction sheet was used in all classes.

**Data collection**

Figure 2 outlines the procedure used to collect data. Firstly, students were given instructions on how to complete the experiment. These were both given by a teacher, and were presented online on the page that the students were to complete. Students were then given the OCT prior to learning of content, which is exactly the same as the post-test, containing questions on the Chemistry concept orbital notation. The purpose of the pre-test is to allow comparison with the results of the post-test. Following the pre-test, students were given an educational video recording of instruction on the concept and application of orbital notation with either high or low levels of displayed teacher enthusiasm, where displayed enthusiasm manifested as described in Figure 2.

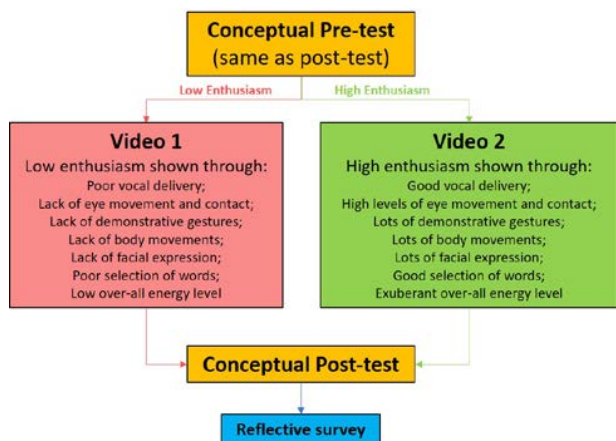


Figure 2 - Diagram of data collection method.

Subsequently, students were instructed to make another attempt at the OCT. This was used in comparison with the pre-test to determine the results. Following the conceptual post-test, students were given a reflective survey regarding the enthusiasm perceived by the student.

**Data analysis**

The data was cleansed of students who did not attempt both tests. Average gain of both groups were calculated using  $Gain = \frac{Post\% - Pre\%}{100\% - Pre\%}$  (Hake 1998). A one-tailed t-test was then used with the average gain of both groups tested to determine whether the null hypothesis (that greater gains were not observed for the students who received the high-enthusiasm instruction) can be rejected. The reflection surveys were qualitatively analysed to ensure the students’ perception of the displayed enthusiasm matched the intention of the video (similar to Frenzel 2019).

**Results**

The results and analysis sections have each been divided into three parts to answer the primary research question (whether high enthusiasm produces greater gains) and the two secondary research questions (relating to recall vs application, and higher vs lower ability students).

*Part 1: Gains on Orbital Conceptual Test Low Enthusiasm vs High Enthusiasm*

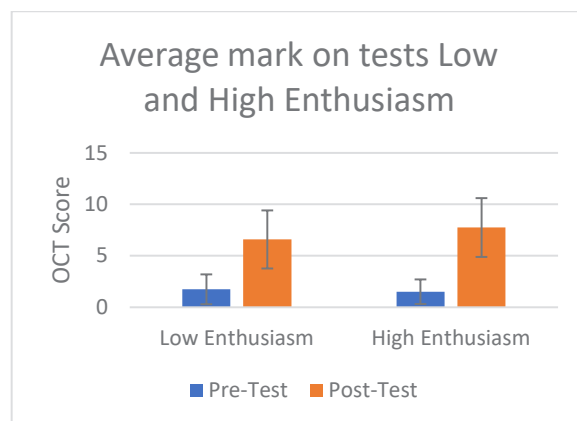


Figure 3 - Graph representing the average mark on both the Pre-test and the Post-test for both enthusiasm streams, error bars represent one standard deviation (After: Hill, Sharma and Johnston 2015, p9)

Table 1 - Mean scores and standard deviations on the OCT for both enthusiasm streams (After: Hill, Sharma and Johnston 2015, p9)

	Low Enthusiasm (n=71)		High Enthusiasm (n = 76)	
	Mean	$\sigma$	Mean	$\sigma$
<b>Pre-test</b>	1.75	1.45	1.51	1.19
<b>Post-test</b>	6.59	2.82	7.75	2.86

As seen in Figure 3 and Table 1, the mean scores for the conceptual pre-test were very similar between Low Enthusiasm and High enthusiasm groupings (1.75/13, 1.51/13 respectively) with a very similar standard deviation (1.45, 1.19 respectively).

Both groups of students benefitted from the instruction. Each group increased their score in the post-test. However, the mean post-test scores for the high enthusiasm treatment group (7.75/13) are higher than the mean post-test scores for the students in the low enthusiasm treatment group (6.59/13). The greater benefit of the high enthusiasm treatment can best be demonstrated through calculating and comparing the normalised gain for each treatment (Hake, 1998).

Table 2 - Learning gains for the OCT for both enthusiasm streams (After: M Hill, M D Sharma and H Johnston, 2015, p9)

	Low Enthusiasm	High Enthusiasm
	(n = 71)	(n = 76)
<b>Gain (g)</b>	0.43	0.54
<b><math>\sigma</math></b>	0.25	0.25

Table 3 - Results from one tailed T-test for significance in gains between enthusiasm groups, calculated from results in Table B

<b><math>H_a</math></b>	$M_1 \leq M_2$
<b><math>H_o</math></b>	$M_1 > M_2$
<b><math>\alpha</math></b>	0.01
<b> t </b>	2.666
<b> t<sub>c</sub> </b>	2.352
<b>p</b>	0.0043

As seen in Table 2, for this particular group of students the mean learning gains for High Enthusiasm were larger than the mean gain for Low Enthusiasm.

Hence, a one-tailed t-test was completed as seen in Table 3 to see if there was a significant difference between the mean gains of high enthusiasm ( $\mu_1$ ) and low enthusiasm ( $\mu_2$ ) ( $H_n = \mu_1 \leq \mu_2$ ) ( $H_a = \mu_1 > \mu_2$ ). The test revealed that the high enthusiasm treatment had significantly larger gains than the low enthusiasm treatment (t=2.666, p=0.0043).

This has expanded on literature which was unclear about the effect of displayed enthusiasm on student learning by showing that displayed enthusiasm does beneficially impact the learning of high school students studying science.

*Part 2: Benefits to Recall and Application from low or high enthusiasm.*

The OCT can be divided into two sections. Questions 1-6 involved *recalling* information from the lesson. Questions 7-12 involve *applying* the processes of deducing orbital notation for various elements. By comparing the gains for the separate sections of the OCT for each treatment group it can be determined whether there are particular benefits to either treatment.

Table 4 - Enthusiasm stream ability to recall (questions 1-6) and apply (questions 7-12)

		Low Enthusiasm (n = 85)		High Enthusiasm (n = 62)	
		Mean	$\sigma$	Mean	$\sigma$
<b>Recall Questions</b>	Pre-test	0.82	0.74	0.62	0.69
	Post-test	3.32	1.49	4.21	1.42
	<b>Gain</b>	0.48	0.32	0.66	0.28
<b>Application Questions</b>	Pre-test	0.92	1.04	0.84	0.86
	Post-test	3.06	1.72	3.24	1.81
	<b>Gain</b>	0.40	0.40	0.46	0.35

As seen in Table 4, high enthusiasm students were better at recalling what they had learnt (Gain = 0.66) compared to Low enthusiasm (Gain = 0.48). Somewhat surprisingly, high enthusiasm were only slightly better at applying new information (Gain = 0.46) compared to low enthusiasm students (Gain = 0.40).

According to the descriptive statistics, high enthusiasm teaching tends to be more memorable than low enthusiasm teaching, hence the much larger gain as seen in table 4. However, the enthusiasm levels of the teacher

do not have a clear impact on a student’s ability to apply newfound information to specific questions as seen in the OCT. Further inferential statistics may be applied, but are not in the scope of this paper’s secondary research question.

Part 3: Impact of the treatments on A stream (high ability) vs B stream (low ability)

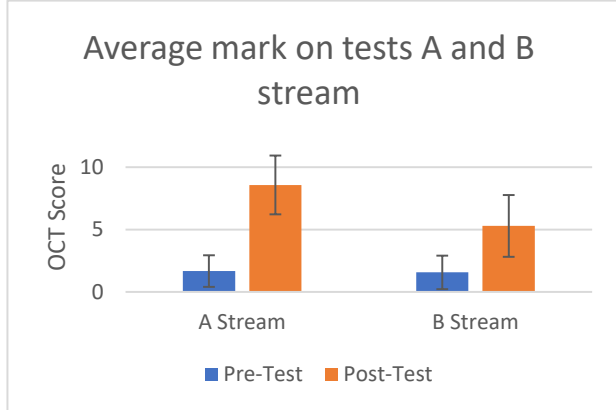


Figure 4 - Graph representing the average mark on both the Pre-test and the Post-test for both enthusiasm streams, error bars represent one standard deviation (After: Hill, Sharma and Johnston 2015, p9).

Table 5 - Mean scores and standard deviations on the OCT for both class streams

	A stream (n = 71)		B stream (n = 76)	
	Mean	σ	Mean	σ
<b>Pre-test</b>	1.54	1.17	1.44	1.24
<b>Post-test</b>	7.92	2.18	4.88	2.29

As seen in Table 5, A stream and B stream students scored very similarly in the conceptual pre-test according to the mean (1.54/13, 1.44/13 respectively) and standard deviation (1.17, 1.24 respectively). However, whilst both groups had a higher mean score in the conceptual post-test, A stream mean scores were much larger than B stream mean scores (7.92/13, 4.88/13 respectively) with similar standard deviations (2.18, 2.29 respectively) regardless of their enthusiasm stream.

Table 6 - Learning gains for the OCT for both class streams (After: M Hill, M D Sharma and H Johnston, 2015, p9)

	A stream (n = 85)	B stream (n = 62)
<b>Gain (G)</b>	0.61	0.32
<b>σ</b>	0.21	0.21

Table 7 - Results from one-tailed T-test for significance in gains between enthusiasm groups, calculated from results in Table 6

<b>H<sub>a</sub></b>	$M_1 \leq M_2$
<b>H<sub>o</sub></b>	$M_1 > M_2$
<b>α</b>	0.01
<b> t </b>	8.268
<b> t<sub>c</sub> </b>	2.352
<b>p</b>	< 0.0001

As seen in Table 6, for this particular group of students the mean learning gains for A stream students were larger than the mean gain for B stream students

Hence, a one tailed t-test was completed as seen in Table 7 to see if there was a significant difference between the mean gains of A stream ( $\mu_1$ ) and B Stream ( $\mu_2$ )( $H_n = \mu_1 \leq \mu_2$ )( $H_a = \mu_1 > \mu_2$ ). The test revealed that A stream students had significantly larger gains than B stream students (t=8.268, p<0.0001).

This supports the literature review, where it was found that student involvement through behavioural engagement (Birch and Ladd 1997), emotional engagement and cognitive engagement (Connell and Wellborn 1991) had a large impact on student ability to learn.

Table 8 - Class stream ability to recall (questions 1-6) and apply (questions 7-12)

		A stream (n = 85)		B stream (n = 62)	
		Mean	σ	Mean	σ
<b>Recall</b>	Pre-test	0.71	0.69	0.73	0.73
	Post-test	4.40	1.25	2.94	1.38
	<b>Gain</b>	0.70	0.24	0.40	0.27
<b>Application</b>	Pre-test	0.95	0.91	0.77	0.95
	Post-test	3.86	1.54	2.18	1.57
	<b>Gain</b>	0.55	0.37	0.26	0.29

As seen in Table 8, A stream was overall able to recall (Gain = 0.70) and apply (Gain = 0.55) their new skills, compared to the B streams ability to recall (Gain = 0.40) and apply (Gain = 0.26) newfound information.

According to the descriptive statistics, A stream students are better at both recalling and applying the newly learnt information than B stream students. This shows that while teacher enthusiasm does have an impact, student ability also has a large impact on whether they can both recall and apply information.

## Discussion

The discussion will consider implications for teaching, research, and similar studies.

### *Implications for teaching:*

This research suggests that students, when encountering new Chemistry concepts, learn more effectively when their teacher has a higher level of displayed enthusiasm. While this is not necessarily surprising (many teachers would easily believe that this is true), the distinction between experiential and displayed enthusiasm is important. Teacher education training should include providing evidence to teachers of the importance of both facets of enthusiasm and explicitly identify characteristics of displayed enthusiasm. While many teachers are passionate about their subject (which helps them to have experiential enthusiasm) there is no guarantee that this also results in displayed enthusiasm and this research shows that not showing displayed enthusiasm negatively affects student learning. Sometimes teachers give lessons about things they are not passionate about, or they may be tired or under external pressures. Even during these times, they should be encouraged to find ways to show displayed enthusiasm for the benefit of their students.

### *Implications for research:*

The secondary research questions have some interesting implications for research. Lower ability students have low learning gains regardless of the level of teacher displayed enthusiasm, therefore more research needs to be done into why this is the case. The OCT also gave the opportunity for the comparative gains on recall and application questions. While no significant difference was found, a larger population may allow for a relationship to be determined. This is particularly important as education has moved towards application of knowledge rather than just recall.

### *Limitations of this study:*

While the research had a good, large and random sample size, the length of the videos were not the same. This does not invalidate the study as exactly the same content was introduced to the students. The researchers, especially the teacher recruited to present in the videos invested substantial effort to try and have two videos the same length. However, the displayed enthusiasm was unable to be shown without allowing the video to go for longer. One example of this was variation in pace to

demonstrate enthusiasm and interest which contributed to the increased time. It can be argued that a longer video is a necessary consequence of showing a higher level of displayed enthusiasm which means that while it is not ideal, it is entirely appropriate for this study. That being said, future research could try and reduce the time difference to confirm the results of this study. Additionally, this study was limited to the testing of orbital notation, bringing in to question whether we could see the same thing in other chemistry topics, as well as the study's application to other areas of science.

## Conclusion

The present study aimed to find the effects of varying teachers' displayed enthusiasm on student learning of content. It was found that high displayed enthusiasm instruction had significantly larger gains for students in the OCT ( $t=2.666$ ,  $p=0.0043$ ). This indicates that if a teacher employs a high level of displayed enthusiasm, students may learn the content more effectively. It was additionally found that high displayed enthusiasm teaching tends to be more memorable than low enthusiasm teaching, yet enthusiasm levels of the teacher do not have a clear impact on a student's ability to apply newfound information to specific questions. In addition, it was determined that student ability did influence the student gains on the OCT, regardless of enthusiasm treatment. It was found that high ability students had greater gains than lower ability students ( $t=8.268$ ,  $p<0.0001$ ). While this study extends current research into the effects of displayed enthusiasm on learning into high school science there is considerably more work to be done to further validate and understand these findings.

## Acknowledgements

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# Effect of temperature on viscosity of polyvinyl borate

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The cross-linked polymer made from sodium tetraborate (borax) and polyvinyl acetate (PVA), known as polyvinyl borate, acts as a viscoelastic gel at room temperature. In theory through the decreasing of the temperature of the polymer, its viscosity will exponentially change. Cross-linked polymers currently have very little real-world application partly due to the lack of understanding of their properties, however this experiment intends to shed some light on how they can be used in varying temperatures in the future. Through the development of polyvinyl borate's knowledge, the usage of the polymer as a multifaceted plastic can be drastically broadened.

## Literature review

A polymer is a long chain of repeating chemical subunits known as monomers. These subunits can be repeated hundreds or even thousands of times in a single polymer and can form by naturally occurring, such as silk or starch and can also be synthetically produced, such as polyvinyl acetate (PVA), formed from vinyl acetate monomers (Figure 1). PVA has the chemical formula  $(C_4H_6O_2)_n$ , and each monomer has a molecular mass of 86.088 g/mol.

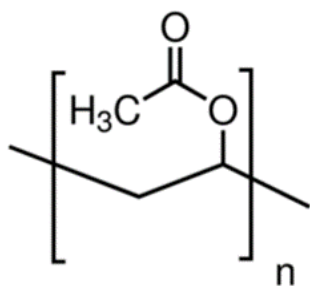


Figure 1: Chemical structure of the polymer polyvinyl acetate (PVA).

Some polymers have the unique ability to form crosslinks between polymer chains. These crosslinks are covalent or ionic bonds which can form when the polymers is combined with a catalyst and heated (Chemistry in Focus, pg 383). PVA can be combined with a number of different catalysts to form crosslinks. Crosslinks are the formation of covalent bonds between segments of two polymer chains that result in the connection of the two chains in a 3-dimensional field. One example is sodium tetraborate (borax), however, the crosslinking in this case results in a highly viscous, non-Newtonian fluid (Osswald and Rudolph, 2014). This means the fluid does not abide by Newton's law of viscosity which states that a fluid will remain at the

same viscosity regardless of any stress it undergoes. On the contrary, non-Newtonian fluids have varying viscosities under different loads of stress (Osswald and Rudolph 2014). With larger amounts of rapid stress the fluid will act more solid (having a larger viscosity) and the fluid becoming more free flowing (a smaller viscosity) for lower levels of stress over longer durations.

The degree of cross linking in PVA is affected by the pH of the solution, concentration of the reactants, temperature of the solution during formation and the volume and pressure of the system. To ensure maximum cross linking for PVA, the reaction solution should have a pH between 9.3 to 11, as this has been shown to correlate with an increase in the degree of crosslinking (RSC Adv., 2017, 7, 7483). PVA is a biodegradable, biocompatible polymer with renewable and desirable biological properties, it has previously been combined with other polymers and naturally occurring reactants for use as a wound dressing and other protective coverings due to its mailability (Arabian Journal of Chemistry, Volume 8, Issue 1, January 2015, Pages 1-14). This non-Newtonian fluid provides a variety of unique characteristics that can broaden the usage of PVA in many fields of work, such as the biomedical and construction industries, as well as possible military uses such as light weight malleable protective materials.

There have been several investigations reported in the literature into the effect of temperature on the viscosity of non-Newtonian fluids in general, but as reported by Ellahi R, due to the variety and complexity of non-Newtonian fluids there is no single model that describes all of their properties (Applied Mathematical Modelling, Volume 37, Issue 3, 1 February 2013, Pages 1451-1467). By determining the effect of temperature

on the viscosity of a cross-linked PVA polymer, this will add to the current knowledge in this area of research.

The viscosity of the polyvinyl borate polymer can be affected most importantly by the temperature of the fluid as this results in a varying viscosity recording. As shown by Covitch and Trickett (2015), an oil-based polymer (polyalkylmethacrylates) that has undergone crosslinking had the property of increasing viscosity as the temperature decreases from 100 degrees to 40 degrees Celsius. In this case, these oil based polymers have much higher boiling points (around 160 degrees) resulting in a linear viscosity vs temperature graph:

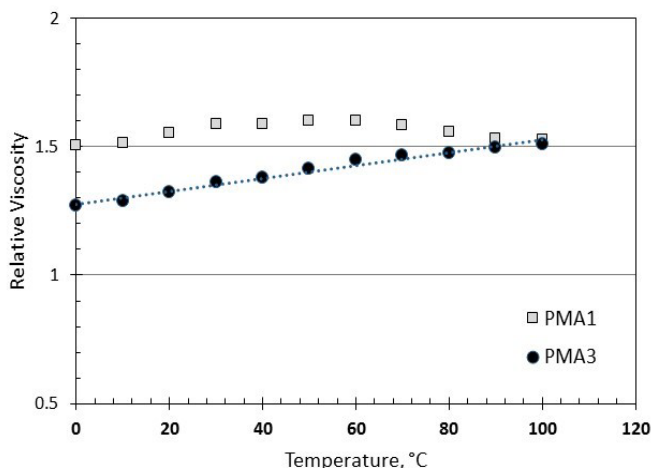


Figure 2: Viscosity vs Temperature graph of PMA1 and PMA3

It is interesting to note that polyvinyl acetate that has been cross-linked has not undergone the same studies to ascertain the relationship between temperature and viscosity. This study will focus on this area to add to the understanding of the effect of cross-linking and the change in viscosity as a result of temperature changes. In particular, it is most interesting to simulate temperatures which may be applicable to real world applications.

### Scientific Research Question

How does temperature effect the viscosity of a cross-linked polymer comprised of polyvinyl acetate and sodium tetraborate?

### Scientific Hypothesis

If the temperature in a closed system containing a sodium tetraborate & polyvinyl acetate polymer (polyvinyl borate) is decreased, the viscosity of polyvinyl borate will decrease in an exponential relationship.

### Methodology

Viscosity was measured using the basic method of timing a weight as it travels a set distance through the substance that is being investigated.

To calculate viscosity:

$Viscosity = [2(ps - pl)ga^2]9v$  Pa/s (pascal per second)

Where,

$ps$ – density (g/ml) of the sphere (remains constant, mass/volume[ $v=4/3 \times \pi \times r$  cubed])

$pl$  – density of the liquid (mass/volume)

$g$  – acceleration due to gravity (9.8m/s)

$a$  – radius of the sphere (remains constant)

$v$  – velocity of the sphere (displacement/time) (is measures as the time taken for the sphere to pass through the polymer in m/s)

50% w/v PVA solution was made by mixing polyvinyl acetate (PVA) (50 g, 1.16 mol) with 50 mL of water at 40°C, to ensure the crosslinking correctly forms. A 4% sodium tetraborate solution was made by mixing borax powder (10 g, 0.026mol) with 250 mL of water at 40°C in a 1:25 w/v ratio, creating a  $1.05 \times 10^{-4}$  mol/L solution. The two solutions were then mixed in a 500 mL beaker at 20°C, in a 4:1 v/v ratio respectively to create the cross-linked PVA polymer. The polyvinyl borate polymer (100 g) was placed in 3 individual 250 mL measuring cylinders. Three 1 cm intervals were marked on the test tubes from starting 5cm from the top. The polymer was then heated to an initial temperature of 60 °C by placing the test tube in boiling water whilst measuring the temperature using a thermometer and thermal radar for specific temperature readings. A spherical glass marble of with a radius of 1.16 cm and a mass of 19 g was placed in each test tube and the time taken for the marble to travel 1cm was recorded, for each of the 3 marked intervals. This was repeated in three different samples, finding the average time taken for the marble to travel 1 cm in the polyvinyl borate polymer. This average was taken and used in the equation for viscosity.

(All measurements can be found in Appendix B)

The temperature was then decreased by 5 °C by placing the test tubes in cold water, repeating the measurement of the time taken for the marble to pass the set distance for each 5 degree variation. This process was continued until the lowest temperature of 10 °C was reached. This incrementation allowed for the repetition to be precise and the reading to be highly accurate.

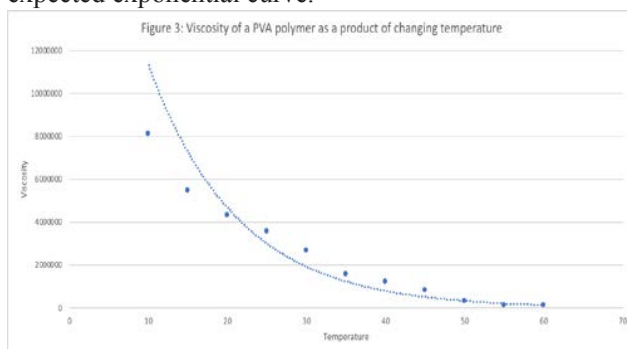
### Results

Table 1 contains the average time taken for the ball bearing to travel through the polyvinyl borate at ranging temperatures. The time was then taken and impute into the stated viscosity equation (appendix B) to receive the average viscosity values in Pa s.

Table 1: Averaged results, including viscosity calculations.

Temperature (°C)	Time (s)	Viscosity (Pa s)
60	11	103806.7
55	13	122680.64
50	31	292546.14
45	86	811579.62
40	125	1179621.54
35	163	1538226.49
30	283	2670663.17
25	377	3557738.57
20	455	4293822.41
15	577	5445133.04
10	859	8078048.32

The average viscosity values were then placed into a graph and an average curve of best fit was computed, resulting in an exponential curve. This coincides with the literature review, which directs the results to the expected exponential curve.



These results are consistent with the results received from Covitch and Trickett’s experiment on Yubase 6 and Yubase 4.

**Discussion**

Assuming that Viscosity is in an exponential relationship with temperature it would match the general form of the equation:

$$V = \alpha e^{\beta T} \quad - (1)$$

Where V is viscosity, T is temperature and  $\alpha$  and  $\beta$  are constants.

By taking the natural logarithm of both sides, equation 1 can be converted into a linear relationship between the variables  $\ln(V)$  and T.

$$V = \alpha e^{\beta T}$$

$$\ln(V) = \ln(\alpha e^{\beta T})$$

$$\ln(V) = \ln(\alpha) + \beta T \quad - (2)$$

$\ln(\text{Viscosity})$  was calculated for each data point (Table 2) and then a graph of  $\ln(v)$  vs T was plotted (Figure 5).

Table 2: results after conversion into a linear function.

Temp (°C)	Ln(Viscosity) (Pa s)
60	11.55029
55	11.71734
50	12.58638
45	13.60674
40	13.9807
35	14.24614
30	14.79784
25	15.08464
20	15.27269

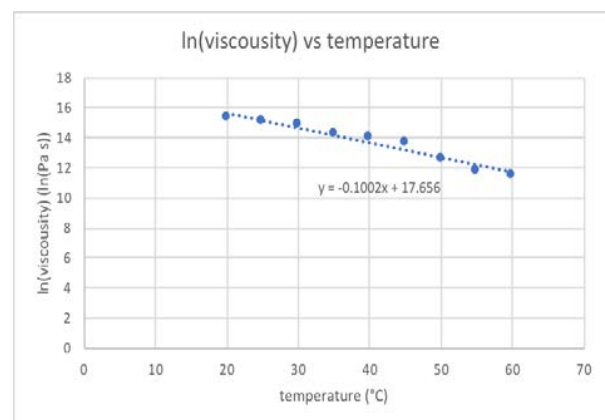


Figure 5: Graph of  $\ln(\text{viscosity})$  vs temperature.

This linear relationship allows for a Pearson's R Correlation test to be used to measure goodness of fit of the linear relationship between  $\ln(v)$  and T, and therefore the goodness of fit of the exponential relationship between V and T. The results of the Pearson's R Correlation test showed that there was a very strong significant correlation between  $\ln(v)$  and T ( $r = 0.967$ ,  $r^2 = 0.937$ ,  $p = 8.08E-05$ ). The  $r^2$  value of 0.937, meaning that 93.7% of the variance in the  $\ln(\text{viscosity})$  can be correlated to the variance in temperature.

This correlation test has proven that there is a very strong correlation between exponential curve and the data points received from the original experiment.

The equation of the exponential relationship can be derived from the equation of the line of best fit.

$$\ln(V) = -0.1002T + 17.656$$

$$V = 46548251.54e^{-0.1002T}$$

This knowledge was then used to determine if an exponential curve of best fit was most appropriate. It is easier to communicate the goodness of fit of an exponential relationship if the variables are plotted as a linear relationship. This further reinforced the selection of an exponential curve of best fit due to the high  $r$  values received.

As polyvinyl borate was tested in much lower temperatures, due to its lower melting point, than that tested by Covitch and Trickett the results are expected to differ largely, it is predicted to experience rapid change in the hotter temperatures resulting in an exponential viscosity vs temperature graph, similar to that received in Covitch and Trickett's experimentation with "Yubase 4" and "Yubase 6".

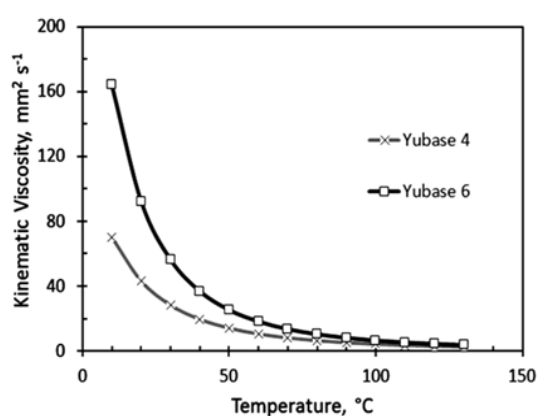


Figure 4: Effects of temperature on the viscosity of Yubase 4 and Yubase 6.

As polyvinyl borate has a low melting point and therefore requires less energy to reshape it, as the plastic is biodegradable it can act as a reusable, malleable material for storage and other cold climate uses. As stated by Geng et al (2016) "several drawbacks of PVAc, including deficient mechanical properties, a high water or humidity sensitivity and a poor performance at elevated temperatures, pose limitations in some applications." however, through the crosslinking of borate with PVAc the new polyvinyl borate compound has the unique ability of remaining highly viscous in colder climates it would be ideal for hard plastic usage in colder conditions. It is also biodegradable and can act as an environmentally friendly alternative to the modern cold storage plastics. There is limited modern world application for polyvinyl borate in warmer temperatures as this is yet to be tested.

Further research into the quantification of the degree of crosslinking could open up the notion of increasing or decreasing the degree of said crosslinking resulting in varying properties, such as using the polymer as a surfactant for crude oil pipes in transference, (Hoyt, Applications of non-Newtonian fluid flow). Research

into controlling the degree of crosslinking can result in many pathways into controlling the properties of the polymer leading to the manipulation of polyvinyl borate to allow for many different uses. Investigation into the effects of higher temperatures on the same polymer may also prove beneficial in determining applications in warmer climates, this could be highly useful due to the biodegradable nature of polyvinyl borate.

The accuracy of the experiment was constricted by the access to equipment, this could have been increased by the use of a viscometer. A viscometer is a scientific instrument used to measure the viscosity of liquids with high levels of accuracy. The use of this viscometer would allow for precise readings of the average viscosity rather than using the equation to derive viscosity. The experiment could have been further improved through the use of a pH probe to determine the exact pH of the solution which allows for the maximum amount of cross-linking to be certified rather than using the mathematical conversion of concentrations to pH. The use of a closed heating system such as a large industrial oven could allowed for increased accuracy through the total, equal heating of the polymer rather than the use of heated water as a bathing mechanism.

## Conclusion

The results received prove that the viscosity of polyvinyl borate is affected by temperature in an exponential relationship. This relationship was further reinforced by the use of the linear derived equation and testing its correlation to prove the goodness of fit of the exponential relationship. This exponential relationship means that the polymers viscosity is more drastically affected at lower temperatures. This rejects the null hypothesis, that is that the relationship is not exponential, as there is a 93% chance that the temperature exponentially effects the viscosity of polyvinyl borate. The conclusive summary determines that through the experiment the greater knowledge of the properties of polymers, specifically polyvinyl borate, has been added to and a further depth on understanding of real world applications for polymers has been revealed.

## Acknowledgements

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# Synthesis of a pyrimethamine analogue and statistical analysis of analogue structure

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Since its introduction in 1951, the efficacy of pyrimethamine as an anti-malarial agent has declined significantly due to a mutation in the dihydrofolate reductase enzyme of *Plasmodium Falciparum*, the most common malaria pathogen. The present study highlights the potential to overcome this decrease in drug efficacy by changing the nature of the substituents on the pyrimethamine rings. This report describes efforts towards the synthesis of iodopyrimethamine, utilising an established synthetic pathway for the synthesis of pyrimethamine. The first step of this synthesis was successfully undertaken to afford 3-oxo-2-(4-iodo) phenyl pentanenitrile as a mixture of tautomer forms. Statistical analysis was utilised to investigate the effect of differing substituents around the pyrimethamine ring, using biological data from previously reported studies.

## Literature review

Malaria, caused predominantly by infection from *Plasmodium falciparum*, results in 219 million infected individuals each year and 435 000 of those infections result in death (WHO 2018). The distribution of global malaria cases is heavily localised in the Africa region but remains a significant burden globally (Wirth et al. 1998) (Figure. 1).

Estimated country share of total malaria cases 2017  
Source: World malaria report 2018

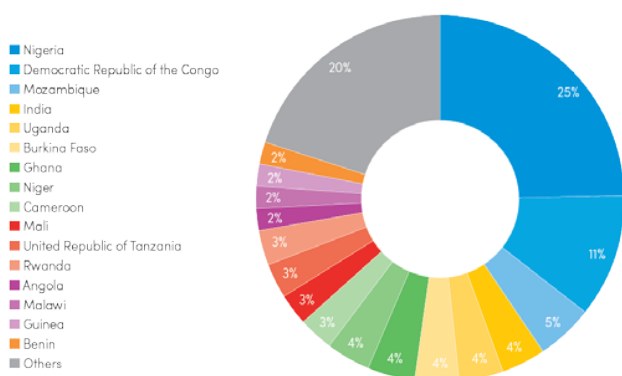


Figure 1: Countries most significantly affected by malaria

The prevalence of malaria related deaths threatens to worsen as global temperatures rise (Yi et al. 2019) and the occurrence of resistance to antimalarial drugs increases (Tarnchompoo et al. 2018). Malaria is primarily caused by *P. falciparum* and *P. vivax*, pathogens that are transmitted by the female Anopheles mosquito when it bites humans (WHO, 2019). The effect of the plasmodium on the human body occurs in two different stages: The first is the exoerythrocytic stage, in which the plasmodium undergoes asexual

reproduction. The second, called the erythrocytic stage, occurs when the plasmodium enters the blood stream and begins its gametophyte stage (Figure 2) (Centres for Disease Control and Prevention, 2018). This two-stage process of infection as well as the presence of multiple disease-causing organisms makes malaria an extremely difficult disease for targeted treatments. Malaria's widespread effects and specifically that of *P. falciparum* warrant a need for high potency drug solutions (Centres for Disease Control and Prevention, 2018).

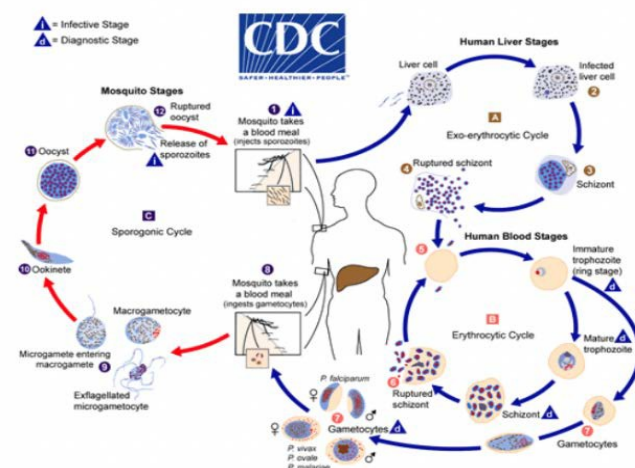


Figure 2: Plasmodium infection cycle in humans

The antimalarial drug pyrimethamine (Figure. 3), a specific derivative of 2,4-diaminopyridine is sold under the trade name Daraprim. This drug was first synthesised in 1951 (Falco et al. 1951) and has been used as a prominent anti-malarial and anti-protozoal agent since that time. The emergence of the HIV

epidemic has led to a large population of immunosuppressed patients and these individuals are most at risk of infection from microorganisms such as *P. carinii*, which results in pneumonia and *Toxoplasma gondii* which results in toxoplasmosis (Malcom et al. 1997). Moreover, these patients are also at an increased risk of contracting malaria from infection by *P. falciparum*. These three micro-organisms have been effectively treated with pyrimethamine in the past.

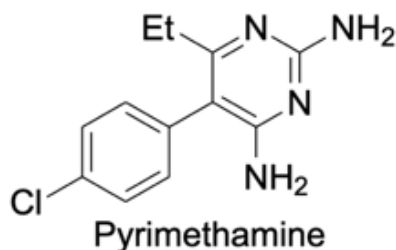


Figure 3: Most common diaminopyrimidine used as an antimalarial agent.

The mechanistic function of pyrimethamine against these three micro-organisms is due to its inhibition of key enzyme pathways within the organisms (Tropak et al. 2015). The particular target is the dihydrofolate reductase enzyme (DHFR), which catalyzes the hydrogenation of dihydrofolate to form tetrahydrofolate with NADPH (Figure 4). This pathway is part of the biosynthesis of purines, a class of precursor molecules necessary for DNA and RNA synthesis. However, a mutation in the DHFR gene which has appeared since this drug was first introduced has rendered pyrimethamine ineffective against these three micro-organisms (Okombo et al. 2018). To combat the high incidence of malaria and toxoplasmosis occurring worldwide (Imwong et al. 2017), it is imperative that research is undertaken to understand the complex interactions which occur between the various forms of the DHFR enzyme and the pyrimethamine inhibitor.

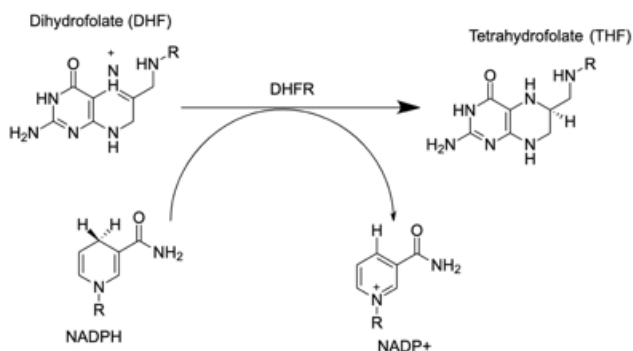


Figure 4: Bio-synthetic pathway of DHFR catalysed hydrogenation of dihydrofolate

Pyrimethamine is a pyrimidine-2,4-diamine, substituted at the C5 position by a *p*-chlorophenyl ring. (Figure 5). This phenyl ring and specifically, the R4 and R3 positions are the most common locants for variations to be introduced during synthesis. There have been a variety of analogues reported in the literature, each with varying structural alterations and resulting levels of enzyme inhibition. The variation in effectiveness of a specific analogue as an antagonist of DHFR, and hence the inhibition of the pathogen allows us to further understand the interaction between both the wild-type and mutated enzyme and the pyrimethamine analogues. The majority of analogues which have been synthesized include various combinations of halogen substitution on the phenyl ring. Other analogues consist of more complex methylbenzoprism substitution allowing further insight into the interaction of the antagonist and the various forms of DHFR.

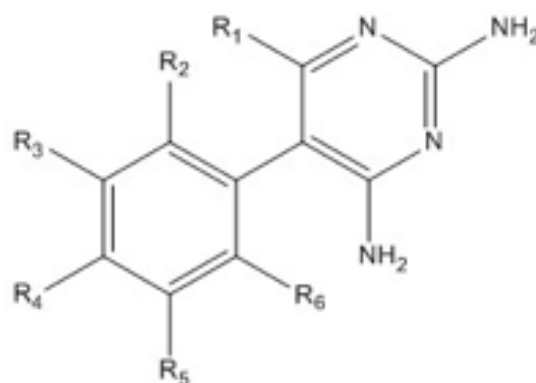


Figure 5: General structure of pyrimethamine analogues.

Pyrimethamine's direct interaction with *P. falciparum* DHFR is a multi-faceted process and the exact structure of the bio-functional enzyme is not known. However, modelling has been undertaken to determine the binding interaction of pyrimethamine with the enzyme active site (Birdsall et al. 1990). The purpose of an antagonizing agent is to mimic the bonding of the original compound, in this case; dihydrofolic acid (DHF). When comparing the basic structure of DHF (Figure 6) and pyrimethamine it is evident that the pyrimidine ring present in both compounds is integral to effective binding with the DHFR enzyme (Khilya et al. 2018).



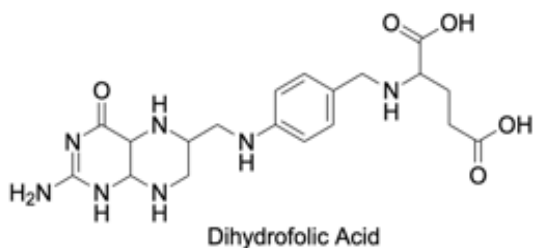


Figure 2: DHF structure

Pyrimethamine is able to bind to DHFR and stabilize the folded enzyme within the endoplasmic reticulum (Birdsall et al. 1990). In wild-type DHFR the key interaction with pyrimethamine is the hydrogen bonding at the active site. The enzyme-inhibitor complex is formed by the two amino groups on the heterocyclic pyrimidine component directly forming three hydrogen bonds with the active site amino acids D290, D240 and E491 (Figure 7). Whilst the two amino functional groups on the ring interact with R211 and D354 (Figure 7), the ethyl group on the pyrimidine ring is most commonly found in the non-polar pocket of W405 and W424 (Figure 6) (Tropak et al. 2015).

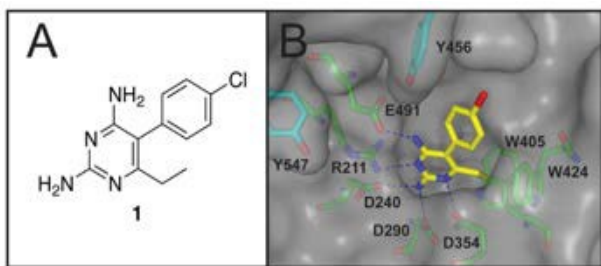


Figure 7: 3D modelling of inhibitor system with pyrimethamine and wild-type DHFR ligand. b) Modelling of enzyme-inhibitor complex at the active site. (Tropak et al. 2015)

The mutation with the greatest implication for decreasing activity of pyrimethamine is the point mutation known as S108N. This leads to an active site structure whereby a steric clash exists between the R4 chlorine atom and an amino acid that wasn't present in the wild-type DHFR (Tropak et al. 2015). Studies indicate that substitution at the R4 position with alternative atoms or functional groups may greatly increase binding affinity (Tarnchompoo et al. 2002). There has been significant

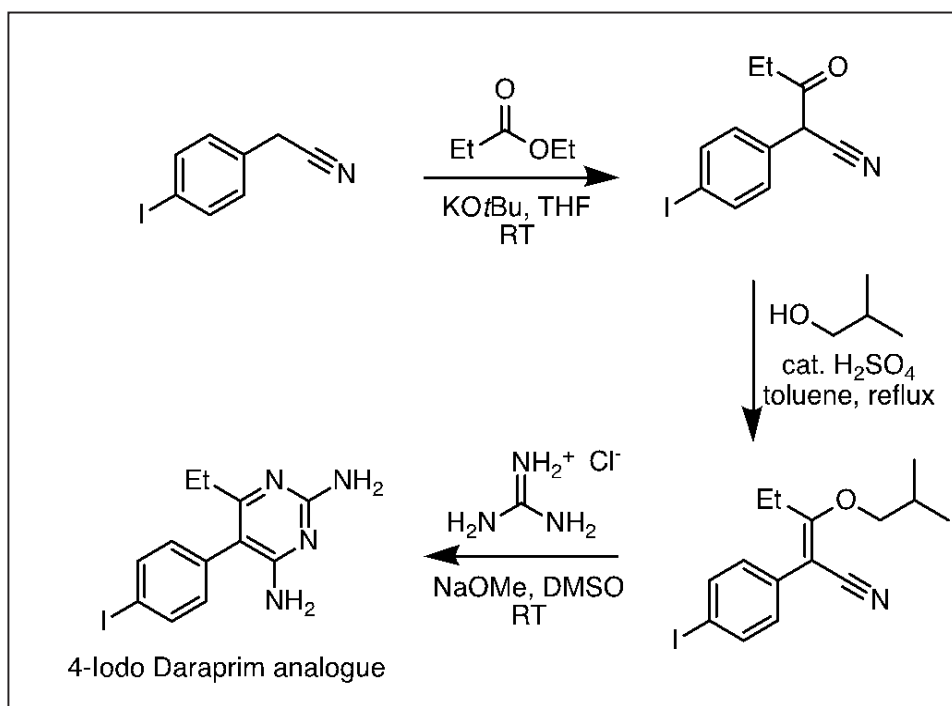


Figure 8: 2016 Synthesis pathway adapted to analogue

effort into the synthesis of various analogues as well as the collection of biological data by the testing of analogues against both mutant and wild-type *P. falciparum* (Tarnchompoo et al. 2002). This data is collected in the form of an IC<sub>50</sub> value that refers to the concentration of a compound required to inhibit an organism by half.

With the need for an effective inhibitor of mutated DHFR (Muiruri et al. 2018), this research aims to Synthesize one such derivative, as well as conduct statistical analysis on the biological data available for pyrimethamine analogues which have been synthesized to date. A particular point of interest was the effect of an analogue of pyrimethamine that consisted of an iodine atom rather than a chlorine atom at the R4 position. To undergo this change we propose to follow the synthetic pathway proposed by Sydney Grammar School in 2016 used to synthesize pyrimethamine (Figure 8). This synthesis was conducted successfully by students at Sydney Grammar school with the goal of demonstrating how pyrimethamine could be synthesized at a cheaper price than the market value of commercial Daraprim.

This iodinated analogue is of interest due to the different atomic radii of chlorine and iodine as well as the potential for utilizing cross-coupling reactions at the C-I bond (Dohi et al. 2011) to streamline the synthesis of a library of analogues from a single starting compound. This ability to functionalize the R4 position (see Figure 5) with a carbon-carbon bond opens up possibilities for different binding interactions and possible increases in binding affinity.

### Scientific research question

Can iodopyrimethamine be synthesised following a published synthetic procedure used for the synthesis of pyrimethamine?

What attributes of pyrimethamine analogous result in more active drug analogues against the most common malarial pathogen *P. falciparum* (based on reported IC<sub>50</sub> data)?

### Scientific hypothesis

That iodopyrimethamine can be synthesised from the condensation reaction between 4-iodophenylacetonitrile and ethyl propionate.

That pyrimethamine analogous that exhibit long chain substitutions at the R4 position and contain more sites for hydrogen bonding interactions will be shown to be more effective antimalarial agents when tested against *P. falciparum*.

### Methodology

*General experimental details:*

<sup>1</sup>H and <sup>13</sup>C NMR spectra were recorded at 300 K using a Bruker Avance DRX400 NMR spectrometer. Residual chloroform ( $\delta$  7.26) was used as an internal reference for <sup>1</sup>H NMR spectra. The data is reported as chemical shift ( $\delta$ H ppm), relative integral, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constant (J Hz), and assignment. Atom labels on structures are to illustrate <sup>1</sup>H NMR spectral assignments and do not necessarily correspond to the IUPAC names given. The solvent peak for chloroform ( $\delta$  77.0) was used as an internal reference for <sup>13</sup>C NMR spectra.

Analytical thin layer chromatography was performed with Merck Kieselgel 60 F254 (0.2 mm) pre-coated aluminium sheets, and visualisation was achieved by inspection under UV light.

Throughout the reaction process Thin Layer Chromatography (TLC) was conducted to gauge the progress of the reaction and determine the point of completion. TLC analysis was conducted with hexane and DCM in a 1:10 ratio.

*Synthesis of 3-oxo-2-(4-iodo) phenyl pentanenitrile:*

4-Iodophenylacetonitrile (250 mg, 1.03 mmol, 1 equiv.), ethyl propionate (102 mg, 0.876 mmol, 1.1 equiv.) and potassium tert-butoxide (289 mg, 2.58 mmol, 2.5 equiv.) were combined in THF (2.5 mL) at room temperature, with stirring in a round bottom flask. The reaction mixture turned to a dark red and heated up rapidly. When the mixture appeared homogenous (30 minutes) stirring was turned off. The reaction was sealed and left for 5 hours in a fume hood. This was completed twice with slight alterations in favour of a more substantial yield. The first reaction was conducted over a period of 16 hours with stirring. The second reaction was only

carried out for 4 hours with stirring for the first 30 minutes to limit the amount of dissolved oxygen introduced to the reaction system.

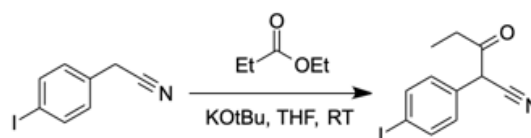


Figure 9: Synthesis step undertaken.

The reaction mixture was worked up by the addition of 1.0 M HCl (15 mL) to the reaction vessel. The acidified reaction mixture was transferred to a separating funnel and the aqueous layer was extracted with DCM (3 x 20 mL). The combined organic layer was washed with brine and dried with anhydrous sodium sulfate, filtered and concentrated *in vacuo* to afford a red oil. TLC analysis was conducted with 10:1 hexane : DCM as the eluent. TLC analysis indicated that the majority of the starting material had reacted.

### Results

The synthesis of 3-oxo-2-(4-iodo) phenyl pentanenitrile was undertaken in accordance with the three-step synthesis that requires any analogous substitutions to the benzene ring to be present on the starting material and from there the heterocyclic diamine motif is constructed. Limiting factors such as time constraints as well as access to analytical equipment meant only the first step of the synthesis was completed. It was concluded by both <sup>1</sup>H and <sup>13</sup>C NMR that the desired product was synthesised, however, it was found that the product mixture contained both keto and enol tautomers in equilibrium.

NMR analysis of the crude product was undertaken with both <sup>1</sup>H NMR and <sup>13</sup>C NMR to confirm the chemical structure as well as information regarding the sample's purity (Gottlieb et al 1997).

## NMR Data for 2-(4-iodophenyl)-3-oxopentanenitrile

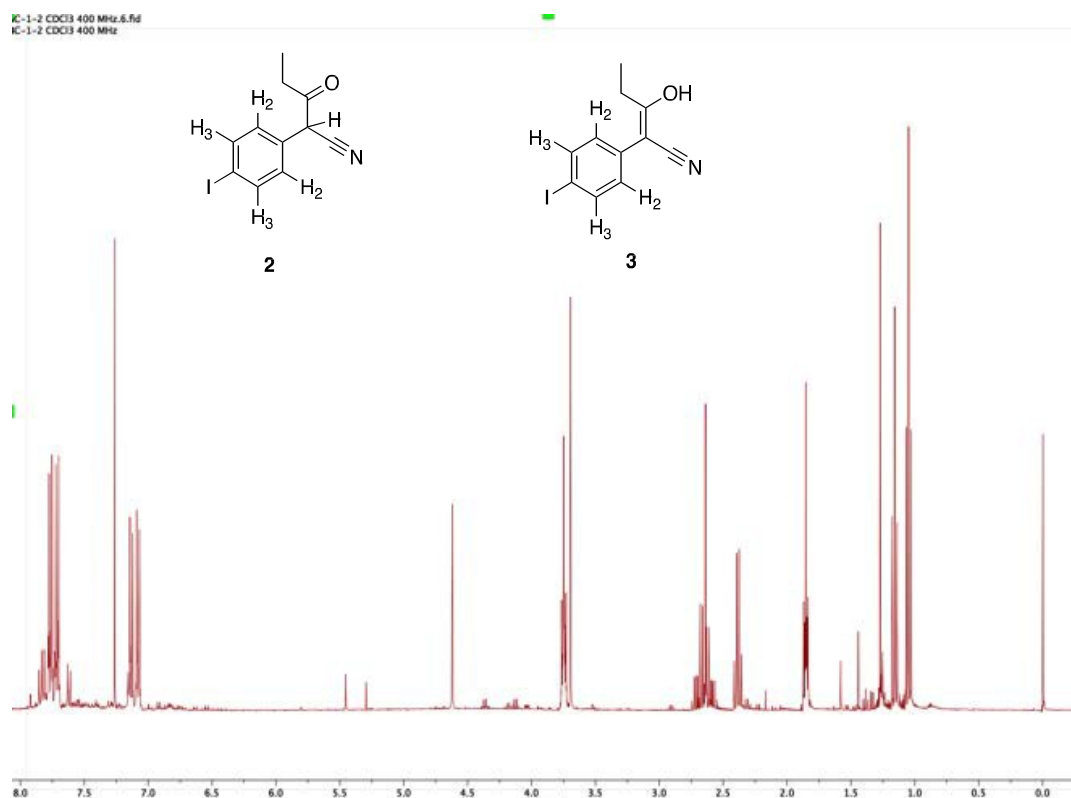
<sup>1</sup>H NMR

Figure 10: <sup>1</sup>H NMR Spectra - <sup>1</sup>H NMR (400MHz, CDCl<sub>3</sub>) δ 7.76 (2H, d, J=0.021Hz, 2-H<sub>3</sub>), 7.71 (2H, d, J=0.021 Hz, 3-H<sub>3</sub>), 7.13 (2H, d, J = 0.020 Hz, 2-H<sub>2</sub>), 7.08 (2H, d, J = 0.021 Hz, 3-H<sub>2</sub>), 4.62 (1H, s, 2-CH), 2.65 (2H, m, J=1.45Hz, 2-Et-CH<sub>2</sub>), 2.39 (3H, q, J=, 3-Et-CH<sub>2</sub>), 1.16 (3H, t, J=, 3-Et-CH<sub>3</sub>), 1.05 (3H, J=, 2-Et-CH<sub>3</sub>).

## C NMR

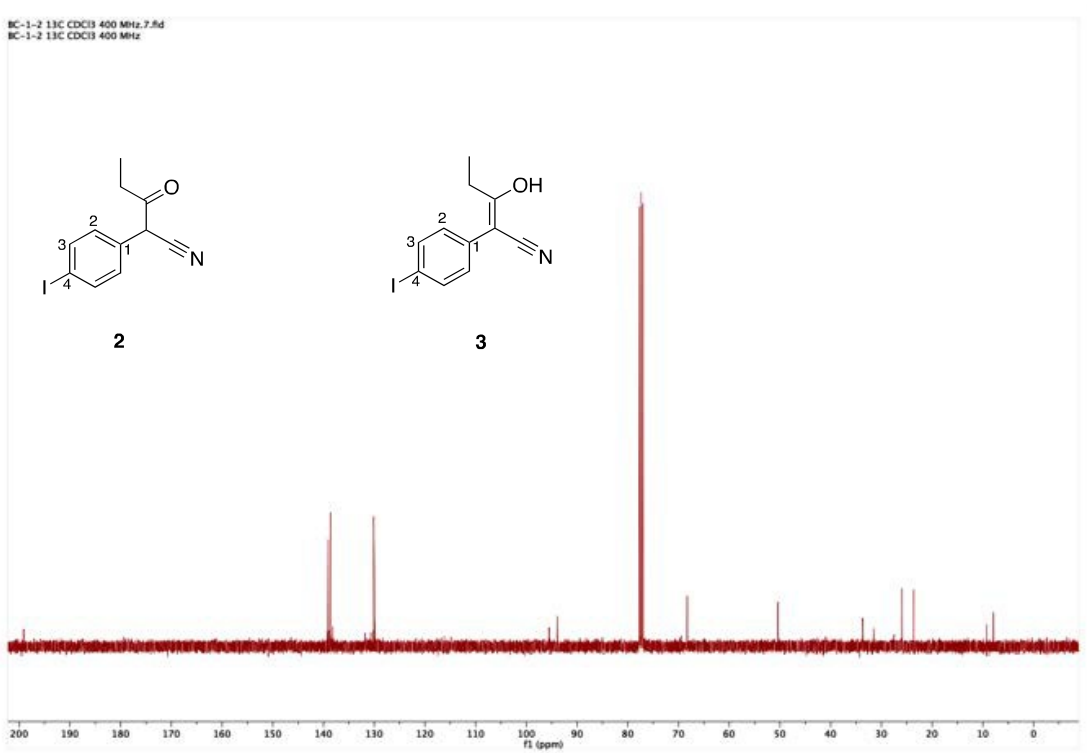


Figure 11: <sup>13</sup>C NMR (100.6 MHz, CDCl<sub>3</sub>) δ 198.7 (C=O), 138.7 (Ar-CH), 138.5 (Ar-C), 138.2 (Ar-CH), 137.8 (Ar-C), 129.9 (Ar-C), 129.8 (Ar-CH), 129.6 (Ar-CH), 129.5 (Ar-C), 95.1 (3-C=C), 93.5 (3-C=C), 50.1 (2-C-H), 33.3 (CH<sub>2</sub>), 23.2 (CH<sub>2</sub>), 8.83 (CH<sub>3</sub>), 7.59 (CH<sub>3</sub>).

## Discussion

### NMR Structural Studies

Analysis of the products resulting from the first step of the synthesis to produce 3-oxo-2-(4-iodo) phenyl pentanenitrile indicated the presence of the desired compound. Analysis was conducted with only <sup>1</sup>H NMR and <sup>13</sup>C NMR, while providing information on the synthesised compound, further analysis such as InfraRed (IR) and Mass Spectroscopy is required to provide complete structural confirmation. The NMR analysis conducted indicated that the product exists as two tautomers in equilibrium with each other, both the Keto (2) and Enol (3) forms are present in the NMR (Figure 12). The <sup>1</sup>H NMR shows duplication of the phenyl ring hydrogen environments as well as the ethyl group hydrogens, the 4.62 peak also indicates the enolic hydrogen environment characteristic of the enol form (3).

The keto form (2) is the desired product required for the subsequent step and is generally the favoured product of the equilibrium. In the presence of acidic environments, the equilibrium is shifted in favour of the enol form. This may be explained by the fact that the NMR solvent, deuterated chloroform (CDCl<sub>3</sub>) is acidic and hence, this tautomerisation may be promoted during NMR analysis.

There also appears to be impurities present in the mixture which are expected as the crude mixture has not undergone purification.

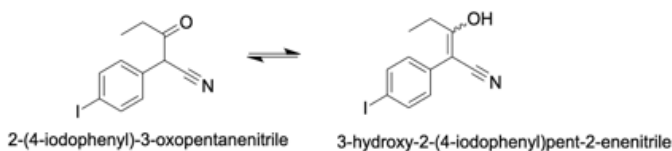


Figure 12: Keto and enol tautomers at equilibrium

### Statistical Analysis of Pyrimethamine Structural Analogues

A statistical analysis was conducted to determine the various aspects of the analogues that result in increased or decreased inhibitory ability on malarial pathogens.

In the pursuit of understanding the structural implications of pyrimethamine analogues on both Wild-Type DHFR and S108N mutated variants in *P. falciparum* a data base was constructed cataloguing the various functional groups at the R1-R5 position (Appendix 1). This structural information was paired with corresponding IC<sub>50</sub> values (Tarnchompoo et al. 2002).

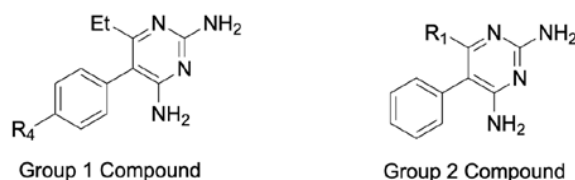


Figure 13: Group 1 and 2 general structure and locus of variance

A two-tailed t-test was conducted comparing the difference in IC<sub>50</sub> value between analogues possessing a R4 functional group of hydrogen and R4 functional groups other than hydrogen (Figure 13). Group 1 compounds possess an ethyl group at R1 and a non-hydrogen functional group at R4 (Figure 13). Group 2 compounds had hydrogen at R4 position and various long chain functional groups at the R1 position. Significance between the IC<sub>50</sub> values of the groups may provide insight into the enzyme interaction at these locants. The mean and standard deviation of these groups is shown (Table 1).

Table 1: Group 1 and 2 general structure and locus of variance

	Mean (IC <sub>50</sub> )	Standard Deviation
<b>Group 1</b>	20.2667	13.7862
<b>Group 2</b>	13.0909	13.6818

The mean of group 1 is higher than that of group 2 however the standard deviation is similar. To determine if the difference is significant a two-tailed t-test was conducted (Table 2).

Table 2: Inferential Statistics of Group 1 and 2 compounds

<b>Null Hypothesis</b>	=
<b>Alternate Hypothesis</b>	≠
<b>T<sub>crit</sub></b>	2.11
<b>T<sub>stat</sub></b>	0.083
<b>P value</b>	0.935
<b>Alpha Value</b>	0.05

Since it is observed that the P value = 0.935 > alpha value = 0.05, it is concluded that the null hypothesis cannot be rejected and there is therefore no significant difference between the two groups' means. This conclusion indicates that the R4 functional group has no major interactions with the mutant DHFR enzyme, the same is true for the R1 substituent.

The interaction between the enzyme and the molecule is largely focused at the 2,4-diaminopyrimidine group (Figure 6), however, the introduction of larger more intrusive groups at the R4 position may decrease

bonding affinity and hence increase  $IC_{50}$ . Upon individual inspection it can be said that compounds that exhibit the most effective  $IC_{50}$  value (Appendix 1) possess a hydrogen at the R4 position (Figure 13) and a variety of R5 functional groups (Figure 5). It can also be said that the R1 group (Figure 13) varies in its significance with some larger chain analogues exhibiting a low  $IC_{50}$ . It is possible that larger chain groups are more effective at mimicking the binding mechanism of DHF (Figure 7) (Sharma et al. 2014).

#### Limiting factors

The completion of the synthesis of iodopyrimethamine was limited by multiple factors. Due to the high cost of 4-iodophenylacetonitrile, only 1 g of this starting material was available for research, hence, the two reactions carried out to synthesise 3-oxo-2-(4-iodo) phenyl pentanenitrile (Step 1 of 3), only used 250mg each. This small quantity as well as the hygroscopic nature of potassium tert-butoxide resulted in a low product yield and therefore difficulty in continuing the subsequent synthetic steps. In addition, limited access to analytical equipment also hindered rapid synthetic progress.

**Further Research** From the research conducted, it cannot be determined whether or not the 4-iodopyrimethamine analogue can be synthesised successfully. Due to the success of the first step, the proposed synthetic pathway is likely to be viable. The cataloguing and analysis of the previously synthesised analogues also allows us to determine which aspects of the molecules are more effective such as the presence of a long chain group at R1 resulting in no significant increase in inhibition.

In order to fully understand the effect and applicability of iodine substitution at the R4 position of pyrimethamine, the synthesis must first be completed. This will likely involve initial optimisation of the first step as well as purification of the desired 3-oxo-2-(4-iodo) phenyl pentanenitrile product. Once this has been achieved, biological testing of iodopyrimethamine against *P. falciparum* and other disease-causing micro-organisms can be undertaken. After testing its efficacy against mutant *P. falciparum*, it may be possible to use the iodopyrimethamine analogue as a precursor for cross coupling reactions to synthesise more complex analogues with different binding potentials to DHFR, which may exhibit higher binding affinity and therefore more effective inhibition.

#### Conclusion

The research conducted resulted in the successful synthesis of 3-oxo-2-(4-iodo) phenyl pentanenitrile via the 2016 synthesis pathway (SGS, 2016). The process

was conducted utilising analytical thin layer chromatography as well as structural conformation via  $^1H$  NMR and  $^{13}C$  NMR. These techniques confirmed the desired product was synthesised and existed in a tautomerisation equilibrium. The synthesis pathway could be completed in future research and be used to provide biological data on its effectiveness on malarial pathogens. The synthesis of the iodopyrimethamine also allows for the possibility of investigating cross coupling reactions and their implications on enzyme binding activity. The statistical analysis conducted compared the average  $IC_{50}$  value of two groups of analogues to determine the significance of positional substitution of functional groups and no significant difference could be found.

#### Acknowledgements

The contributions of Dr Terrett were significant to this research in assistance with both the completion of the synthesis as well as guidance during the process of constructing the report. Dr Terrett sacrificed huge amounts of time to assist me with research project and her help was imperative to its completion. Dr Motion from Sydney University assisted greatly with analysis and access to equipment and literature. Finally, Dr Hill and Dr Gates were also extremely helpful in understanding statistics and scientific concepts necessary for the completion of the research report.

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# Biology

**Biology is the study of living things, astounding in the breadth of opportunities it offers for student investigation.**

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From human biomechanics to agricultural production, our researchers have explored questions from across the spectrum of the discipline. Harry's project is about the capacity of plant vessels (xylem) to act as filters. Drawing from existing work about gymnosperms (non-flowering plants), Harry has investigated whether angiosperms (flowering plants) behave in the same or different ways. Also interested in plant biology, Georgia's project explores the impact of touching plants on their growth and productivity. Her project uncovers significant implications for horticultural production systems. Sami's "Mind Over Matter" project got right to the heart of the Science Extension course and sought to apply the scientific method to a question that might be normally considered beyond the realm of science. Sami developed a method to test and analyse the impact of giving thoughtful intention to plants on their growth yielding some fascinating results. Inspired by his observation of the game, Russell investigated the role of eye dominance in basketball skill. He had to work hard to develop a method to observe and record students playing basketball to test his compelling hypothesis. Fascinated by a vast public data set, Stuart's work explores the infection rates of meningococcal disease particularly with respect to the age at infection. Finally, Nick draws our attention back to the plant world where his biochemistry project explores the effect of fertiliser concentration on capillary rise and the potential consequences for plant growth.

We hope these projects challenge, fascinate and provoke you in the same way that they have inspired us.





# Filtering water using plant xylem

Harry Chalmers

Barker College

This report compares the effectiveness of both angiosperm plants and gymnosperm plants for filtering contaminated water. A pigment-based dye was used as a model for biological contaminants such as bacteria and viruses. The dye was diluted in water and then passed through the angiosperm and gymnosperm filters and the percentage concentration of dye in the filtrates was then measured using colourimetry. The results demonstrated that the gymnosperm filters were significantly more effective at filtering out the dye from the water than the angiosperm filters. It was identified that the cause of this difference was due to the structural differences in the xylem of the two different plants as gymnosperm plants have shorter xylem vessels which result in more points of filtration, whereas angiosperm plants have longer vessels and therefore less points of filtration.

## Literature review

A major cause of human mortality is the absence of clean water for drinking and sanitation for large portions of the developing world as seen in Figure 1, in which all of Africa and large parts of South America and Asia are affected. In 2017, the World Health Organisation (WHO) estimated that 785 million people did not have access to a simple water source that contained potable water (WHO 2019). There are also additional threats to

these people due to environmental factors such as climate change, and it is predicted by the WHO that by 2025, 'half of the world's population will be living in water-stressed areas' (WHO 2019).

## Deaths from unsafe water, sanitation and hygiene

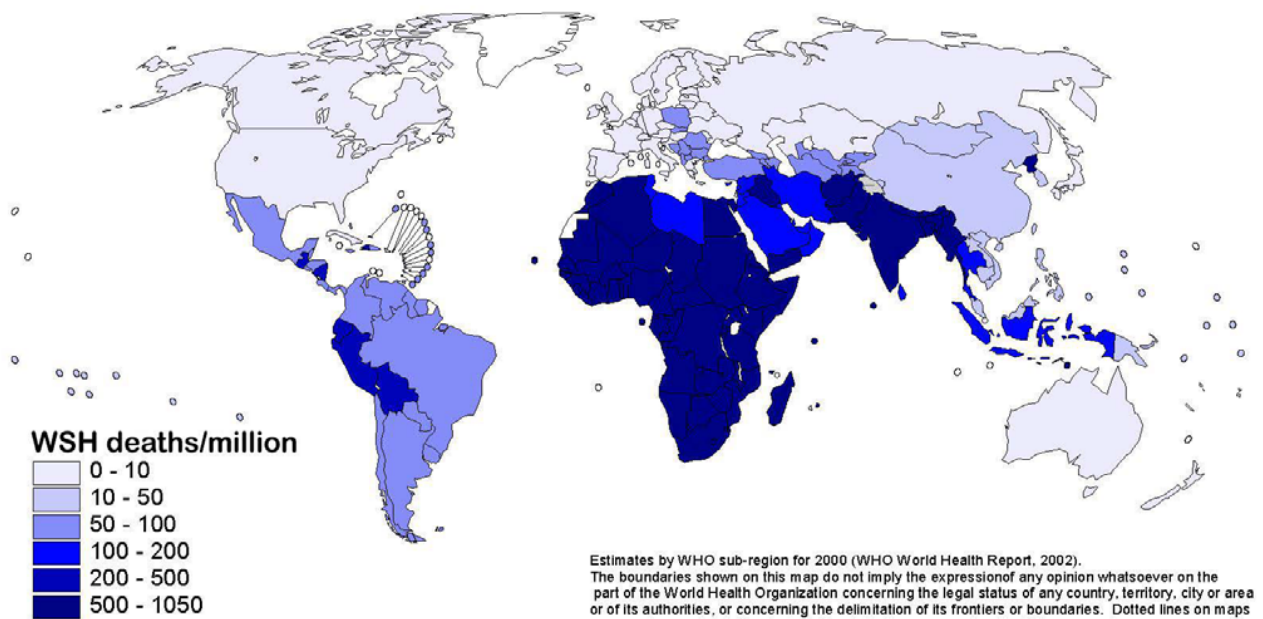


Figure 1: Global deaths caused from unsafe water (WHO 2015)

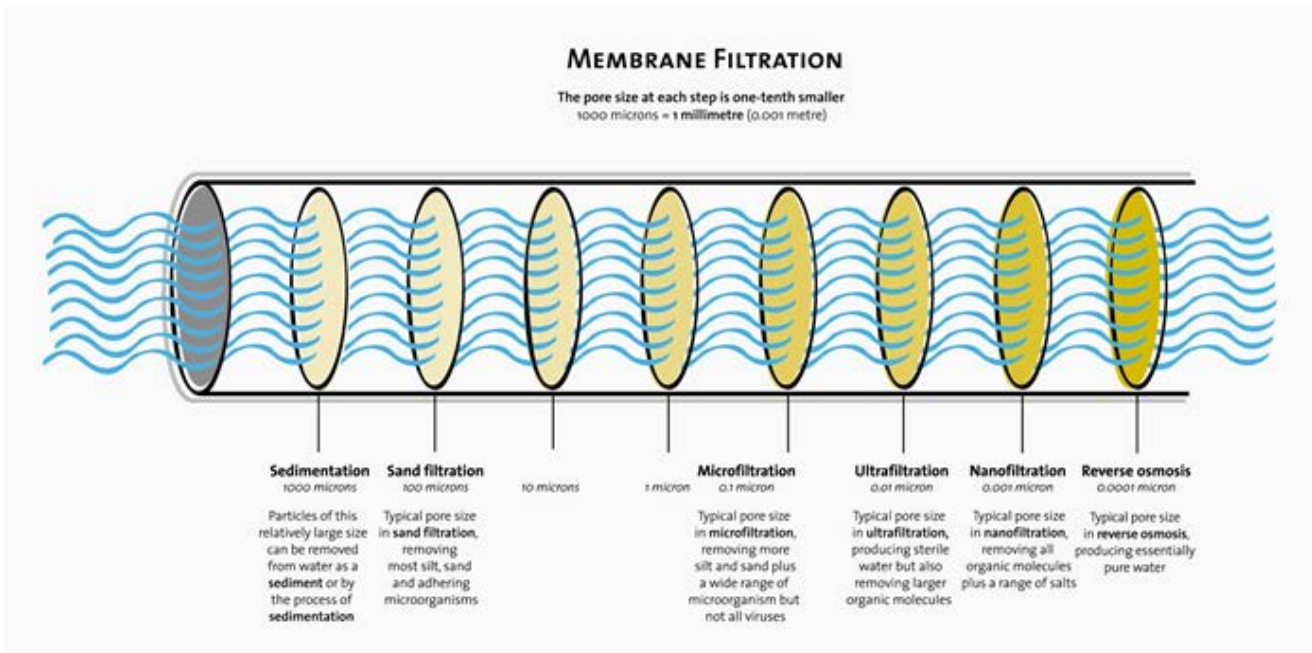


Figure 2: Membrane filtration device (SDWF 2016)

This is due to increasing global temperatures causing increased evaporation of existing water bodies, as well as rising sea levels contaminating fresh water sources with salt water. For water to be safe for human consumption, it must be potable which is outlined as having “acceptable quality in terms of its physical, chemical, and bacteriological parameters” (Gadgil 1998, pp. 253-286). Amongst the most common microbial contaminants, there are some that can have serious detrimental effects on human health, causing diseases such as polio, typhoid, cholera, and diarrheal causing diseases (Gadgil 1998). These infections are most commonly the result of humans drinking water which is contaminated with faeces and this is the situation facing 2 billion people worldwide (WHO 2019). In 2019, the WHO also reported that there were an estimated 485 000 diarrheal deaths each year with 297 000 of those deaths being children under the age of 5. The same report also stated that these deaths could have been prevented if there had been clean water available for drinking and sanitation purposes.

Common methods utilized worldwide to treat water and remove possible biological contaminants include filtration, chlorination, boiling/pasteurization and UV disinfection (Shannon et al. 2010). The use of chlorine to disinfect water by killing microbiological contaminants is efficient and cost effective for large scale use but when it is utilised on a smaller scale, such as in villages and towns, it can become prohibitively expensive (Gadgil 1998). In these situations, it is also noted that “controlling water quality at the point-of-use is more effective”, due to possible contamination in distribution structures, pipeline corrosion and microbial

regrowth (Madaeni 1999, pp. 301-308). Boiling is the most widely used method of point-of-use water decontamination of biological contaminants and is very effective in general, however, the quantity of fuel required to boil sufficient amounts of water for long periods of time can become expensive for families in developing countries (Clasen et al. 2008). Similar issues apply to UV-disinfection methods as there are also significant costs associated with obtaining the UV equipment for each family, maintaining it, and the electricity required (Gadgil 1998). Filtration methods are widely utilized as an alternative or supplement to both chlorination and UV disinfection. In particular, membrane filtration is capable of removing large pathogens from water samples, such as bacteria as seen in Figure 2, but many smaller pathogens are able to pass through (Madaeni 1999).

The vast majority of membrane filters are polymer based products made by the petrochemical industry. The production and use of these filters bear high costs, high amounts of non-biodegradable waste and the requirement for high pressure pumping which prevents their large scale use in developing countries (Loo et al. 2012). Due to the absence of a sustainable, inexpensive, and effective filtration method to remove biological contaminants from drinking water, more options need to be explored (Pandit & Kumar 2015).

With 30% of global land covered by forest, plants provide a plentiful source of biodegradable, renewable and sustainable materials with numerous applications (Berglund & Burgert 2018). In general, plant and tree stems have many structural features that have the

potential for nanotechnological applications (Berglund & Burgert 2018). Plants have developed unique, water conducting channels called xylem, which efficiently move water from the roots of the plant to the leaves (Sperry 2003). The evolution of xylem over millions of years has resulted from the need for water to ascend up the plant stem with minimal resistance, while also ensuring the presence of nanoscale pores, called pits, are not large enough to cause cavitation and potential plant death (Sperry 2003). The size of these pores in xylem can range from a few to 500 nanometers (Choat, Cobb & Ransen 2008) which according to Lee et al. (2014, pp. 2) provides an “ideal [structure] for filtering out pathogens.” Due to these structural characteristics of plants, they provide a possible cheap, inexpensive and sustainable solution to water filtration issues in the developing world (Pandit & Kumar 2015). It was demonstrated by Lee et al. (2014) that a xylem filter could be constructed from branches from a white pine tree which was capable of filtering the water through the 3cm piece of wood at a rate of several litres per day with an estimated rejection of bacteria of at least 99.9% (Lee et al. 2014). The use of these filters in rural communities in Africa was tested and showed that it was capable of removing more than 99.9% of *E. coli* bacteria from water (Siwila & Brink 2019).

The efficacy of gymnosperm plant xylem for filtering biological contaminants in water, has been clearly demonstrated by Lee et al. (2014), who used dye as a proxy for biological contaminants. Plant species are divided into two groups which include angiosperm plants, which are flowering plants, and gymnosperm plants, which are flowerless plants (Soltis, Soltis, & Edwards 2005). It can be reasonably assumed that angiosperm xylem will also be able to perform this filtration function, which would be more beneficial than gymnosperms to people lacking access to water as angiosperm plants make up approximately 80% of plant types globally (Sperry 2003). However, given the structural differences in the xylem of gymnosperms and angiosperms, that include gymnosperms having more points of filtration, their relative efficacy (i.e. how they compare to each other) remains untested. This gap in the literature forms the premise for the research question.

### Scientific research question

What is the relative efficacy of angiosperm xylem and gymnosperm xylem in filtering biological contaminants from water?

### Scientific hypothesis

If angiosperm wood is used as a filter to remove dye from water, then it will be less effective than gymnosperm plants due to the larger xylem vessels.

### Methodology

#### Materials

- 10 cm long clear PVC tubing with diameter of 1.3cm (Purchased from Bunnings Warehouse)
- 5 angiosperm branches with a length of 10cm and a diameter of 1cm (Purchased from Bunnings Warehouse)
- 5 gymnosperm branches with a length of 10cm and a diameter of 1cm (Purchased from Bunnings Warehouse)
- Epoxy (Purchased from Bunnings Warehouse)
- 10 hose clamps with a diameter of 1.3cm (Purchased from Bunnings Warehouse)
- 10mL of Art Spectrum pigment-based red drawing ink (Purchased from Officeworks)
- 10mL measuring cylinder
- 20mL volumetric flask
- 2mL pipette
- 1L of distilled water
- Cuvettes
- Colorimeter

#### Calibration curve

Various percentage concentrations, according to the values in Table 1, of the pigment-based red dye, acting as a proxy for biological contaminants, were made up with distilled water in 20 mL volumetric flasks.

A sample of each percentage concentration of dye was placed into a plastic cuvette. The colorimeter lamp was set to 490 nm and calibration was carried out with distilled water. The absorbance for each concentration was recorded and graphed to construct a calibration curve.

#### Preparation of filters

To construct the filters, 10 branches were excised, 5 from gymnosperm and 5 from angiosperm plants. The branches were then cut to 10cm sections with a diameter of 1cm without the bark. 10 cm lengths of clear PVC tubing, with a diameter of 1.3cm, were attached to the pieces of wood and fixed in place using epoxy and a hose clamp as seen in Figure 3. Whilst the filters were not being used, they were kept in water to ensure the xylem did not dry out.



Figure 3: Angiosperm xylem filters with clear PVC and hose clamp attached to the branch.

**Filtration experiments**

A solution with a 5% percent concentration of dye was made up. Each of the filters were taken out of the water and the wood section was placed inside a test tube (Figure 4). 10 mL of the dye solution was poured into the top of the PVC tubing of the filters and was left to filter for approximately one hour. After this time, the dye solutions had passed through the filters, and the filtrate solutions were collected (Figure 5).

The collected filtrate solutions were poured into cuvettes, as seen in Figure 6 and placed in a colorimeter set to 490 nm. The absorbance values were recorded and, using the calibration curve, the percentage concentration of dye remaining in each filtrate solution was determined.



Figure 4: (Left) One of the gymnosperm filters with the dye solutions at the top.

Figure 5: (Right) One of the angiosperm filters with the dye solutions at the top.

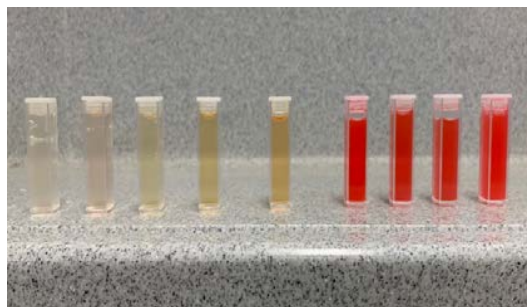


Figure 6: The filtrate solutions that have been placed in the cuvettes (5 to the left are gymnosperm filtrates and 4 to the right are angiosperm filtrates)

**Calibration curve**

Table 1: The absorbance of 490 nm light at different percentage concentrations of dye.

Percentage concentration	Trial 1 absorbance	Trial 2 absorbance	Trial 3 absorbance	Average absorbance
0.01000000	1.229	1.230	1.219	<b>1.226</b>
0.00500000	0.652	0.649	0.653	<b>0.6513</b>
0.00250000	0.406	0.412	0.413	<b>0.4103</b>
0.00100000	0.128	0.126	0.136	<b>0.1300</b>
0.00010000	0.009	0.016	0.015	<b>0.0133</b>
0.00012500	0.034	0.023	0.031	<b>0.0293</b>
0.00025000	0.031	0.032	0.025	<b>0.0293</b>
0.00001250	0.000	0.000	0.000	<b>0.0000</b>
0.00000625	0.000	0.000	0.000	<b>0.0000</b>

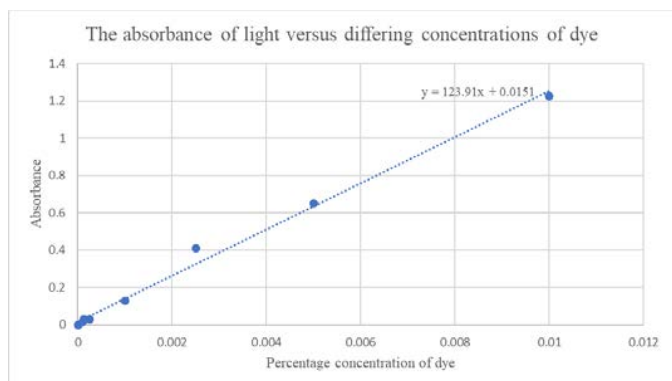


Figure 7: Calibration curve for dye.

**Filtration through gymnosperm and angiosperm wood filters**

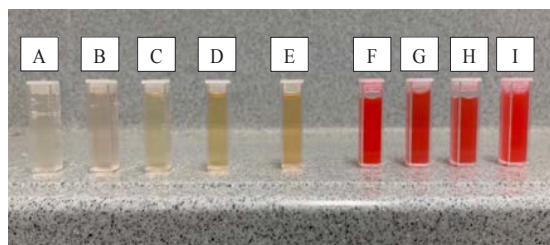


Figure 8: The filtrate solutions that have been placed into cuvettes. The five to the left are the gymnosperm filtrates and the four to the right are the angiosperm filtrates.

**Angiosperm:**

Table 2: Absorbance values for the angiosperm wood filters and percentage concentration of the filtrate.

Species of wood	Absorbance	Percentage concentration
Angiosperm species 1 (F)	1.701	$x = \frac{1.701 - 0.0151}{123.91}$ $x = 0.0136$ $x = 1.36\%$
Angiosperm species 1 (G)	1.170	$x = \frac{1.170 - 0.0151}{123.91}$ $x = 0.00932$ $x = 0.932\%$
Angiosperm species 1 (H)	1.285	$x = \frac{1.285 - 0.0151}{123.91}$ $x = 0.0102$ $x = 1.02\%$
Angiosperm species 2 (I)	1.603	$x = \frac{1.603 - 0.0151}{123.91}$ $x = 0.0128$ $x = 1.28\%$
Average absorption:	1.440	

Calculation of percentage concentration from average absorbance value for angiosperm filtrate using the equation from the calibration curve (Figure 7):

$$y = 1.440$$

$$x = \frac{y - 0.0151}{123.91}$$

$$x = \frac{1.440 - 0.0151}{123.91}$$

$$x = 0.01149745783$$

$$x = 1.150 \times 10^{-2} = 1.15\%$$

**Gymnosperm:**

Table 3: Absorbance values for the gymnosperm wood filters and percentage concentration of the filtrate.

Species of wood	Absorbance	Percentage concentration
Gymnosperm species 1 (A)	0.046	$x = \frac{0.046 - 0.0151}{123.91}$ $x = 0.000249$ $x = 0.0249\%$
Gymnosperm species 1 (B)	0.082	$x = \frac{0.082 - 0.0151}{123.91}$ $x = 0.000540$ $x = 0.0540\%$
Gymnosperm species 1 (C)	0.084	$x = \frac{0.084 - 0.0151}{123.91}$ $x = 0.000556$ $x = 0.0556\%$
Gymnosperm species 2 (D)	0.151	$x = \frac{0.151 - 0.0151}{123.91}$ $x = 0.00110$ $x = 0.110\%$
Gymnosperm species 2 (E)	0.251	$x = \frac{0.251 - 0.0151}{123.91}$ $x = 0.00190$ $x = 0.190\%$
Average absorption:	0.1228	

Calculation of percentage concentration from average absorbance value for gymnosperm filtrate using the equation from the calibration curve (Figure 7):

$$y = 0.1228$$

$$x = \frac{y - 0.0151}{123.91}$$

$$x = \frac{0.1228 - 0.0151}{123.91}$$

$$x = 0.00086917924$$

$$x = 8.692 \times 10^{-4} = 0.0870\%$$

Statistical analysis:

Table 4: Descriptive statistics comparing Angiosperm and Gymnosperm plants concentration of filtrate

	Angiosperm plants	Gymnosperm plants
Sample size	4	5
Mean percentage concentration of filtrate	1.15	0.0870
Standard deviation	0.204	0.0653

Two tailed independent t-test

t-statistic: 11.13

t-critical: 2.365

p = 0.000011

$\alpha = 0.001$

$H_0$  = There is no statistically significant difference between the mean concentrations of filtrate for the angiosperm and gymnosperm groups.

$H_A$  = There is a statistically significant difference between the mean concentrations of filtrate for the angiosperm and gymnosperm groups.

Discussion

According to the statistical analysis (Table 4), we can reject the null hypothesis and accept the alternate hypothesis ( $T_{crit} = 11.13 > 2.365$ ,  $p = 0.000011 < 0.001$ ). Hence, we can say that there is a statistically significant difference between the dye filtering capabilities of the two types of wood filters. By inspection, we can see that the mean concentration for angiosperm filters is higher than for the gymnosperm filters and hence that the filtering capability of the gymnosperm filters are significantly greater than for the angiosperm filters. This confirms the original hypothesis, which was that “if angiosperm wood is used as a filter to remove dye from water, then it will be less effective than gymnosperm plants due to the larger xylem vessels.” There is a possibility that this is a false positive, but this is unlikely as the p is very small compared to the alpha value. This is also backed up by the t-value (11.13) which is greater than the t-critical value (2.365).

The cause for the differing results is due to the structural differences in the angiosperm xylem and the gymnosperm xylem (Figure 9). Gymnosperms have xylem conduits that are made up of single dead cells and are called tracheids, with their diameters reaching a maximum of 80 micrometres and a maximum length of

10 millimetres (Sperry 2003). The xylem conduits of angiosperm plants are called vessels and are made up of several single file cells, which reach a maximum diameter of 0.5 millimetres and have lengths that range from several metres to a few millimetres (Sperry 2003). As seen in Figure 9, the xylem vessels are parallel to one another and are joined to adjacent conduits by “pits” (Choat, Cobb & Ransen 2008). It is at these pits in the xylem where filtration occurs as they are nanoscale pores, designed to prevent bubbles passing from one conduit to another, but they are also effective in filtering out microscopic particles (Choat, Cobb & Ransen 2008). Since the xylem vessels of angiosperm plants are significantly larger than the gymnosperm plants, a large thickness, consisting of several metres, will be required to achieve any filtration due to the varying number of points for filtration, as demonstrated in Figure 9. Due to this structural difference in the xylem of the different types of wood, it is proposed that this causes the different types of wood to filter out differing quantities of dye.

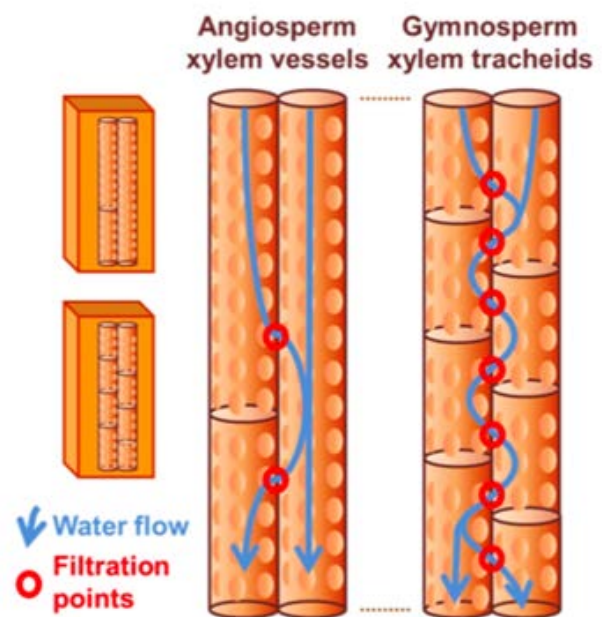


Figure 9: Angiosperm xylem and gymnosperm xylem (Lee 2014).

There were many limitations of this experiment to accurately measure the effectiveness of each wood filter. One key limitation is first observed in Figure 8 in cuvettes D and E, where there was an orange colour to the water that was filtered through the gymnosperm filter where the water should have been clear. Provided all the wood filters used were from the same species, this concentration could have been measured separately and subtracted from the final concentration of each filtrate which would make the results more accurate. However, not all the woods were the same as this experiment

endeavoured to attain an average effectiveness of each group of plants, so this was not feasible. As this error occurred in most of the filters, this does not ruin the investigation as there is a clear difference in the effectiveness of the filters. The inability to measure the particle size of the dye that passed through the filters is also a limitation in determining the effectiveness of the filters in filtering out different biological contaminants that have specific sizes. However, the effectiveness of gymnosperm wood in filtering out bacteria was already determined by Siwila & Brink (2019), and as the angiosperm allowed significant amounts of the dye through the filter, it can be assumed that it is no more effective at filtering out different sizes of particles than gymnosperms.

Despite the fact that angiosperms are less effective at filtering out dye from water than gymnosperms, they make up approximately 80% of plant types globally (Sperry 2003). For this reason, the angiosperm subgroups, which include *Monocotyledons* and *Dicotyledons*, should also be investigated further to determine the most effective group in filtering biological contaminants out of water. As noted above, in Figure 9, and by Sperry (2003), the structure of angiosperm features xylem vessels that range in lengths from a few millimetres to several metres so future investigation should include larger filters so that there are more points of filtration. Further investigations into the filtering effectiveness of differing subgroups of gymnosperms should also be undertaken, including *Cycadophyta*, *Ginkgophyta*, *Gnetophyta* and *Pinophyta* to determine if there are certain groups that are more effective at removing smaller contaminants than others. Testing the effectiveness of woods commonly accessible in developing countries where the filters could be utilised would be necessary as well. Measuring the flow rate of the water through the different types of wood would also be needed to determine the viability of the filters as practical water filters, as in this experiment, small amounts of water (approx. 5ml) took approximately 2 hours to pass through the 10 cm pieces of wood. The use of pigment-based dye as a proxy was accurately used to represent biological contaminants, as demonstrated by Lee et al. (2014), however future research should also involve the use of actual biological contaminants such as bacteria and viruses. This would enable the filters ability to filter out viruses and other contaminants to be investigated which would test its practical use and determine the overall efficacy of this filter.

## Conclusion

Plants contain xylem which are porous and have potential for use in filtering contaminated water. This experiment investigated the effectiveness of angiosperm wood and gymnosperm wood in filtering dye, representative of a biological contaminant, out of water. Wood filters were constructed and dye solutions were passed through them. The filtrates were then placed in cuvettes and the concentration of the dye was determined using the absorbance value of each filtrate and a calibration curve that had been previously constructed. There was a statistically significant difference in the concentration of red dye that passed through the filters. Statistical analysis also confirmed this observation and supported rejection of the null hypothesis and therefore acceptance of the alternate hypothesis that the angiosperm filters were less effective than the gymnosperm filters in filtering out the dye. There is a need for research in several areas which include the use of the sub groups of both angiosperm plants and gymnosperm plants as well as looking into the use of larger angiosperm filters due to the structure of their xylem which would allow more points of filtration. The success of xylem filters could lead to their widespread use in developing countries but before that there is greater research needed.

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# Leaf me alone! The effect of artificial physical stimulus on the growth of plants

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There is copious anecdotal evidence regarding people talking to, singing to and patting their plants in order to encourage them to grow (Evans 2013). This research applies the scientific method to that issue, investigating how physical touch affects the growth of plants. Rainbow Silverbeet seedlings were used for this experiment, grown over a three-week period. Seedlings were grown in three trays comprising two treatment groups and a control. One treatment group was exposed to air current by exposure to a fan and the other treatment group was exposed to light percussion with a fly swat. The treatment was applied twice daily on weekdays for the three-week period. Plant growth was measured by height of the longest stem at the beginning and end of the experiment. The results showed that when artificial physical stimulus was applied to leafy vegetable plants their growth was significantly lower in comparison to both the plants receiving no physical stimulus and the plants receiving naturally occurring physical stimulus.

## Literature review

The post-harvest treatment and handling of leafy horticultural crops is integral to the quality of the crop and thus how much it is worth. Leafy plants such as kale, spinach, silverbeet, and lettuce have fragile leaves which can be easily snapped or bruised during transport and storage (Thompson 2003). It is reasonable to assume that plant handling techniques that occur during the growth phase, either through management practices or due to people or animals moving through the crop, will similarly affect the growth of plants, however this is an under-researched area of plant science.

Some researchers have looked at the effect of natural touch stimuli, for example, wind or spray (Braam & Davis 1990) on plant growth. The response of plants accustomed to touch stimuli is known as thigmomorphogenesis. This term was coined by Jaffe (1973), who described that “mechanical stimulation also affected aspects of growth and development other than stem elongation” Thigmomorphogenesis causes changes to plant’s growth such as stem retardation, and the permanent distortion of the stem and/or other parts of the affected plant.

In terms of how physical stimuli affect growing plants, Eisinger (1983, as cited by Braam & Davis 1990) noted “the morphogenic changes in plants that occur following

mechanical stimulation resemble the decrease in elongation and the radial expansion observed following ethylene exposure”. This indicates that plants normal physiology is altered in an adverse way when stimulation is applied. This is one of the main points on which I have based my scientific hypothesis.

The effect of physical touch has most commonly been explored by research into transplanting stress or shock which affects the roots (Leskovar & Cantliffe 1991), however the application of a stimulus to the vegetative growth of the plant (i.e. on the above ground part where the roots remain undamaged) is likely to be quite different.

There is evidence that handling adversely effects the growth of other agricultural crops such as cotton (Frizzell et al. 1960) and maize (Beardsell 1977). This research instead explores the effects of handling on crops which consumers buy as a raw product, hence, the use of leafy horticultural crops as opposed to cereals, oilseeds, or fibre crops.

Other researchers have established the significance of other factors on quality assurance of plants pre-harvest. These things include the presence of macronutrients in the soil (and their availability), day length, light intensity, and temperature (Thompson 2003). Current

agricultural and horticultural practices have a deep understanding of these factors, and practically apply them to plant production to achieve optimum results. Much of the research in this area is older, and this research aims to fill the gap in modern understanding and applications of plants' responses to physical stimulus.

### Scientific research question

What is the effect of physical touch on the growth of leafy vegetable crops?

### Scientific hypothesis

When plants are exposed to non-naturally occurring physical stimulus, their growth will be adversely affected (ie the growth will be lower than the control).

H<sub>0</sub>: Non-naturally occurring physical stimulus will result in Group A's average growth being less than Group B and Group C's average growth

H<sub>a</sub>: Non-naturally occurring physical stimulus will result in group A's average growth being greater than or equal to Group B and Group C's average growth

### Methodology

Three trays, each comprising of 24 individual planting cells were potted with commercially prepared Rainbow Silverbeet seedlings. The trays were labelled with the letters A, B and C.

Three seedling trays were filled with seedling potting mix (Osmocote Premium Potting Mix). Six store bought punnets of 'Easy Grow Silverbeet Rainbow Mix' (Rainbow Silverbeet) were gently split into individuals or small groups at the roots. Before planting the seedlings, the seedling trays were all sprayed lightly with water spray bottle until they were all moist. A pen was pushed into the middle of each section of each seedling tray and spun around to make a small circular hole. This was done in every cell of all three trays to minimise root disturbance during transplanting. Each tray was labelled with its group number and type of stimulus. In each tray, all columns were labelled A-D, and each row labelled 1-6 with sticky dots. This ensured that data could be reliably collected from each cell. The individual plants/groups of plants were gently dropped into each hole, ensuring that the tap root of each was deep in the hole. Additional potting mix was added to each cell to ensure that the roots were covered and that the plants were supported. Each tray was placed into a lining tray containing 100mL of tap water.

A clear ruler was held touching the soil in each cell of all three trays. The longest leaf in each cell was measured at eye level and recorded the day of planting to establish a baseline of data. All trays were left undisturbed under grow lights for 48 hours to recover from transplant disturbance.

The three seedling trays were each put on a bench underneath the growing light. The plants were kept in an indoor growing facility to protect from frost and remove the chance of pest disturbance. The seedling trays were rotated one position every week day to ensure that they received the same amount of light.

The initial experimental design prescribed that plants received equal water (10 ml every second day) which was to be delivered carefully using a syringe to the base of the plant to ensure no additional stimulation was applied.

Instead, for logistical reasons, (access to the building), watering was not able to take place at the same time of day or on second daily interval. Instead water was applied by syringe to the base of plant on an ad hoc basis – basically using visual perception to determine whether the soil was dry and whether watering was required. When watering took place, the water was applied identically to the whole group. In this way the water variable was still standardised and an equal amount of water was applied to all plants at the same time for all groups. Each time the plants were watered, a 12mL syringe was used to ensure accurate watering (as seen in Figure 1). One day after planting, each cell was given 10mL of a water and nitrogen-rich fertiliser solution (Nitrosol Liquid Plant Food).



Figure 1 – An example of how the plants were watered

Group A received artificial physical stimulus in the form of gentle brushing with a fly swat (a fly swat was chosen to ensure that no sweat or oils produced by human skin would affect the plants and skew the experiments results). Group B received an approximation of naturally occurring physical stimulus (a fan). Group C, the control group, received no physical stimulus.

The treatment was applied to Groups A and B on weekdays only for three and a half weeks. For the first week the treatment was applied twice daily but after some plants began to look very damaged, treatment was reduced to once per day after the first week. When the plants were being treated, the growing lights were turned off. The fan was placed next to one of the short ends of the Group B tray. The fan was left on for two minutes, and then the seedling tray was turned 180°. The fan was left on for two more minutes. During these four minutes, a clean, dry, fly-swat was brushed along the Group A plants (as seen in Figure 2). For two minutes, the plants were brushed one way, two rows at a time, ensuring every plant received equal touch. For the next two minutes, the plants were brushed in the opposite direction.



Figure 2 – Group A being treated with a fly swat)

Plant growth was measured using a ruler to find the height of the tallest plant in each cell at the beginning and end of the experiment. The starting height of each cell’s plant was deducted from its finishing height. A mean growth was then calculated for each group by averaging over the 24 cells, and an ANOVA was performed with a post-hoc Tukey HSD test.

**Results**

All measurements were taken in millimetres and rounded to three decimal places. The average growth of the group receiving artificial touch (Group A) was

31.542mm, the average growth of the group receiving naturally occurring stimulus (Group B) was 60.6mm, and the average growth of the control group (Group C) was 63.3mm.

It was observed that the average growth of Group A plants was significantly lower than the growth of both Groups A and B.

An ANOVA test was conducted to determine whether or not the differences in the groups’ means were statistically significant. The *p*-value came out as <0.00001, which shows that the result is significant at *p* <0.01.

The post-hoc Tukey HSD results concluded that the difference in results between the means of Groups A and B and the difference between the means of Groups A and C were statistically significant. The results also showed that the difference between the means of Groups B and C were not statistically significant (*p*-value is <0.00001).

Table measurements are given in millimetres, and averages are shown as 5 significant figures.

Table 1 – A table showing the average growth of Group A which were treated with the fly swat (mm)

FLY SWAT				
Growth height for each planting cell (mm)				
	A	B	C	D
1	49	21	41	52
2	50	50	48	9
3	46	32	41	28
4	0	34	20	22
5	5	42	27	22
6	31	39	27	21
Average = 31.5mm				

Table 2 – A table showing the average growth of Group B which were treated with the fan (mm)

FAN				
Growth height for each planting cell (mm)				
	A	B	C	D
1	51	95	72	63
2	76	60	60	84
3	78	40	60	50
4	42	51	29	72
5	60	49	76	56
6	43	79	52	57
Average = 60.6mm				

Table 3 – A table showing the average growth of Group C which was the control group (mm)

CONTROL				
Growth height for each planting cell (mm)				
	A	B	C	D
1	52	95	72	63
2	76	60	60	84
3	78	40	60	50
4	42	51	29	72
5	60	49	76	56
6	43	79	52	57
Average = 63.3mm				

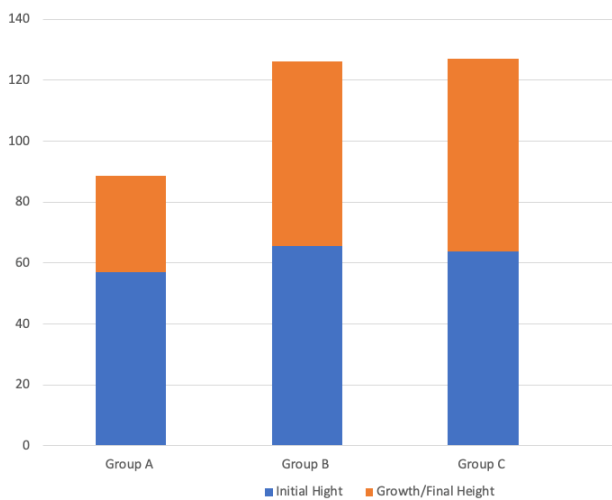


Figure 3 – Average initial height and average height gained by the three groups over the course of the experiment

### Discussion

An ANOVA revealed that there was a significant difference in growth height for at least two of the groups ( $F = 27.00164, p < 0.00001$ ). Table 4 shows the results of a Tukey post hoc test.

Table 4 – Tukey HSD results indicating significance

Treatments pair	Tukey HSD Q statistic	Tukey HSC p-value	Tukey HSD inference
A vs B	8.5810	0.0010053	p<0.01
A vs C	9.3678	0.0010053	p<0.01
B vs C	0.7868	0.8260369	insignificant

The results demonstrated that when the plants were exposed to artificial physical stimulus (Group A), their growth was adversely affected in comparison to both the natural wind stimulus (Groups B) and no stimulus (Group C). This can be seen in Table 4, with a significant difference ( $p$ -value:  $<0.00001$ ) in the mean of Group A from the means of both Groups B and C.

As the difference in the means of groups B and C, were not statistically significant, there is no evidence that the naturally occurring physical stimulus of wind (the fan)

had any effect on the growth of the Group B plants. This means that the null hypothesis cannot be rejected. The wind (fan) stimulus was shown to have no effect on the growth of plants and this requires further investigation to determine whether a stronger fan could have produced results that were significant. It is possible that stronger winds would have a similar effect to the artificial stimulus. This indicates that (gentle) wind does not have an adverse effect on the growth of horticultural crops, and changes do not need to be made regarding light winds in horticultural production areas (such as the use of fans in greenhouses).

These results should be further investigated and other experiments performed to understand whether the conclusion that my research has come to could have a practical application on the pre-harvest handling of leafy horticultural crops.

In regard to the watering of the plants, due to the restricted access of the building in which the plants were being grown, watering was irregular. Although the plants were watered irregularly, each planting cell of each group was given the same amount of water during each watering session, with minimal disruption to the body of the plant due to the use of a small syringe. The irregular nature of the plants' access to water may have been a contributing factor to the results of the experiment. For example, if the Group A plants were provided with water at regular intervals immediately after stimulation, they may have better recovered from being touched. This regular, reliable watering system could be achieved by using an automated system, for example, an accurate drip irrigator set with a timer to ensure that water availability was standardised and available to the plant at all times. A hydroponic design may offer another alternative.

Silverbeet plants were used as they are relatively fast growing, and are a suitable model which should represent a large number of other leafy horticultural crops, such as spinach, kale, and lettuce. The experiment could be repeated using different types of leafy crops such as the ones mentioned to ensure consistent results across the spectrum.

It was previously known that post-harvest handling was a major factor in the quality and profitability of horticultural plants. In regard to real life application of these results, it is useful for farmers/producers of leafy horticultural crops to understand the significance and negative implications of stimulus to their growing plants. In greenhouse situations, the removal of loose pieces of plastic or any material which could be

brushing past plants could increase their overall yield and the profit gained from their product. The results would also indicate that humans and machinery moving between or over rows of plants (for example, to apply pesticides) in a greenhouse or field situation could reduce the yield of individual plants and thus the yield of sellable product per hectare.

Further research into this area could have significant implications on how horticultural plants are produced on the farm, and could increase the amount of sellable plants being produced (and therefore profit), and thus minimise food waste. Furthermore it is an important consideration for the design of emerging robotic technologies which are being developed for use in horticultural settings.

### Conclusion

Non-naturally occurring physical stimulus was demonstrated to have an adverse effect on the growth of plants. The use of a small fan to replicate naturally occurring physical stimulus (wind) did not have a significant effect on the growth of plants. Although the results regarding the average growth of the group receiving artificial stimulus compared to the other two groups were statistically significant, the difference between the average growth of the group being treated and the control group was not. This research demonstrates the adverse impact of artificial stimulus on leafy plants and has serious implications for agricultural production techniques due to its potential to increase the profitability and quality of the crop.

### Acknowledgements

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# The intention experiment: The effect of intention on the growth of cherry radish seeds

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How can the scientific method be applied to measure the effect of intention given to the growth of a plant? This investigation shows the scientific approach on a novel idea: intention. Intention is a conscious mental state that purposely gives orders to carry out an action or actions in the future. It is a mental movement such as inner-thought and planning. This blinded design study gathered a group of eight people and also one individual to give their collective intention to cherry radish seeds. After ten days, the height of the plants was measured and an ANOVA with a *post hoc* test was conducted. The data showed that group 8 and group 1 in trials 2 and 3 were significantly taller than the others, with p values of 0.0292 and 0.0125 respectively; however, further research is needed to conclude whether there was a positive effect of intention on plant growth.

## Literature review

Intention is a conscious mental state that purposely gives orders to carry out an action or actions in the future. It is a mental movement such as inner-thought and planning. There have been many areas of study in this field of 'mind over matter'. This research project explores the impact of intentional thinking on the growth of plants. Existing research in this field of intention includes work from reading plants' 'feelings' (Backster 1968) to observing the effects humans have on electronic machinery (Jahn 1979). Intention is a major section of parapsychology, which is the study of mental phenomena that are excluded from or inexplicable by orthodox scientific psychology (Broughton 1991).

### *Existing Intention Research*

Lynne McTaggart's research is the most influential in this area (McTaggart 2007). Her investigation: 'the intention experiment' was a global 'laboratory' involving thousands of readers around the world testing the power of group thoughts to heal the world (McTaggart n.d.). Lynne McTaggart's research spawned from research published by Cleve Backster, Robert Jahn and others. The experiment detailed in this report has been designed to apply the scientific method and further explore and refine the research conducted by the research team at Arizona University.

Cleve Backster was a German physicist that worked with a lie detector to investigate the energy given off by

plants in certain scenarios. In the 1960s, Backster used a lie detector attached to a plant to infer that the leaf registered a stimulus when a lit match was brought towards it. 'The plants had felt a disturbance in the force,' he said (McTaggart 2017). Published in 1973, "The Secret Life of Plants", immediately sparked the interest of amateurs and scientists, who attempted to replicate what was known as the 'Backster effect' (Rein 1996 p7), testing whether or not there is a plant response to human actions, especially actions that were aimed to harm the plant. This early research sparked the use of the scientific approach on areas most commonly categorised as pseudoscience. The results across the spectrum were mixed but Cleve Backster's experiment allowed for Lynne McTaggart to propose her experiment of healing powers and intention.

Another investigation that sparked the use of the scientific method on eccentric concepts was the work of Robert Jahn and Princeton University, (Jahn 1979). Their experiment investigated the effect of the human intention on machinery by having university students seek to change the machinery showing a 50/50 ratio of electronic photos of cowboys and Indians to favour Indians. This research was highly significant in the field of human bio-fielding and pseudoscience. Their use of mass sample size and selection allowed for very little gaps in their research, running over a 25-year period. Their research resulted in an effect size of 52% for these experiments; in comparison, aspirin's effect size is 10 times smaller.

### *Lynne McTaggart's Investigation Results*

McTaggart and colleagues' Germination Intention Experiments were conducted to investigate the effect of intention on the height of plants. Their experiment differs slightly in that their goal was to maximise the number of participants giving intention (but this current experiment looked into the effect of no intention versus 1 person's intention versus the group intention (8 people) and seeing how these differ from one another). There have been 6 germination intention experiments conducted by the Arizona research team:

- One via the Internet
- Sydney, Australia (600 participants)
- Palm Springs, California (130 participants)
- Rheinbeck, New York (100 participants)
- Hilton Head, North Carolina (500 participants)
- Austin, Texas (120 participants)

These experiments were all trials of the Germination Experiment and the results supported their hypothesis that intention had a positive effect on plant growth. It was shown that the seeds that received intention grew on average 8mm higher than the control seeds. The effect was statistically significant ( $p < 0.007$ ), meaning that there was only a 0.7% possibility that the results were simply by chance. These results allowed McTaggart and the research team to investigate bigger issues and how intention can be used to 'heal' the problem areas of the world.

'Mind over matter' has been a contested area of science for years. This research seeks to construct a methodology that uses the scientific method to test the effect of intention on the growth of cherry radish plants. Using a blind format, six groups of fifteen cherry radish seedlings were "given intention" by nine adult participants (one group of eight participants and one single participant). The intention participants gave to selected seedlings was that "the plant will grow 7 centimetres by the 10<sup>th</sup> day after germination".

### *Purpose*

The purpose of this experiment and research paper is to contribute to the novel side of scientific research. The scientific approach allows the idea of human bio-fielding and intention to be seen as valid in science. Having a scientific methodology allows for replication of the experiment. The idea of intention having an external effect is novel in science. Therefore, to make this experiment scientific and true to the format of an investigation it is needed to make the intention precise and reproducible. Using the same people for each trial and controlling all other aspects of the experiment will increase the chances of it being a valid investigation.

### **Aim**

The aim of this research is to scientifically investigate the effect of intention on plant growth by developing a methodology to test a theory that may be considered 'unscientific' by conventional scientists. It seems unlikely that active intentional thought could improve the growth of plants. If this were to be true it would have massive ramifications for agricultural productivity and food security such as social and economic benefits and farming practices.

### **Scientific research question**

The research poses two research questions as follows:

- 1) How can the scientific method be applied to measure the effect of intention given to the growth of a plant?
- 2) What is the effect of "giving intention" to the growth of cherry radish seedlings?

### **Scientific hypothesis**

Null hypothesis: That the increase in intention given will not result in an increase in plant growth.

Alternate hypothesis: That as the number of people giving intention increases, the plant growth will increase.

### **Methodology**

Six groups of 15 cherry radish seeds (*Raphanus raphanistrum* subsp. *Sativus*) were placed in packets. 8 adults from different cultural and religious backgrounds, were recruited (All were known to the researcher) to the study and met on three occasions throughout the year to give intention to prepared and separated seeds. They were instructed on how to give intention to the seeds using a prepared video used by Lynne McTaggart for her experiment (Appendix C). After the instructions were given, the researcher left the room and the participants took two packs of seeds and gave their collective intention. For two minutes timed, the group all collectively gave intention only on their respective seeds while the others were put away to not alter the results, the intention was given whilst mentally/physically holding hands. The intention was "that the plant will grow 7 centimetres by the 10<sup>th</sup> day" after germination. This was repeated with a single individual who gave intention to two further packets of seeds also for two minutes. The final two packets of seeds received no intention and these were the control group. A relative of the researcher was asked to maintain the double-blind key to ensure that the researcher did not know the identity of the groups.



After the intention was done, all six sets of fifteen seeds were collected and immediately planted in their respective, labelled, pots (A1, A2, B1, B2, C1, C2).

Each pot was filled with 500g of soil each and made fifteen divots in the soil one inch deep (note: preferably two inches apart). All 90 seed were placed and cover with surround soil. Then a mixture of 5mL of liquid fertiliser and 1L of water was made and 160mL cup of fertiliser solution was poured into each pot. All pots were plated in a sunny area and watered daily with 120mL of water. Every second day, the pots were rotated around to even out sunlight distribution. After 10 days the plants were gently pulled out and measured from the start of the plants; growth (not including the roots) in centimetres and tabulated.

The experiment was repeated twice in its entirety with the same individuals.

Prior to the experiment taking place, a consent form was sent to all participants outlining what was included in the experiment, the purpose and benefits of the experiment and their right to withdraw at any moment with no consequences. This was sent out 7 days before the first experiment took place to allow the individuals to review the experiment and come to a decision prior to the commencing of the investigation (Appendix B). As a part of the Science Extension guidelines that operate at Barker College, the project proposal containing detailed assessments of ethical considerations was submitted to the Director of Research in Learning, Dr Matthew Hill, for approval.

**Results**

The results of the experiment appear below as Tables 1-3 along with Figures 1-3. The statistical analysis data is shown below in Table 4-8. Figure 1 illustrates the relationship between intention and height of the plants after 10 days obtained in trial. The raw data has been averaged and can be seen in Appendix A(i). Figure 2 illustrates the relationship between intention and height of the plants after 10 days obtained in trial 2. The raw data has been averaged and can be seen in Appendix A(ii). Figure 3 illustrates the relationship between intention and height of the plants after 10 days obtained in trial 3. The raw data has been averaged and can be seen in Appendix A(iii).

**TRIAL 1**

Table 1 – The effect of intention on plant height after 10 days

# of people giving intention	Pot number	Average height – pot (cm)	Average height – intentions group (cm)
8	A1	3.456	4.251
	A2	3.847	
1	B1	4.200	
	B2	3.946	
0	C1	3.636	
	C2	4.236	

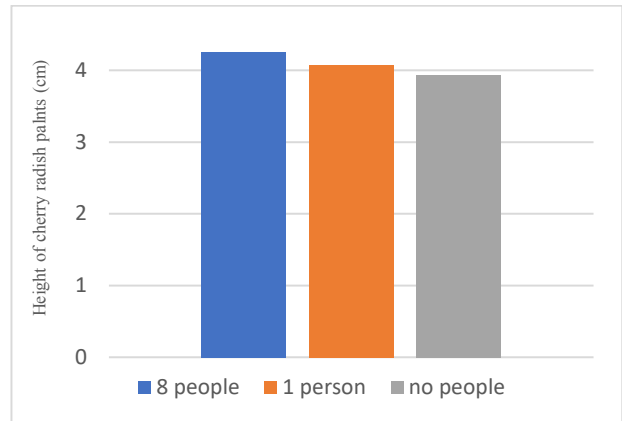


Figure 1: Trial 1 - Average height after 10 days

**TRIAL 2**

Table 2 - The effect of intention on plant height after 10 days

# of people giving intention	Pot number	Average height – pot (cm)	Average height – intentions group (cm)
8	A1	3.923	3.895
	A2	3.862	
1	B1	4.553	
	B2	3.756	
0	C1	3.862	
	C2	3.182	

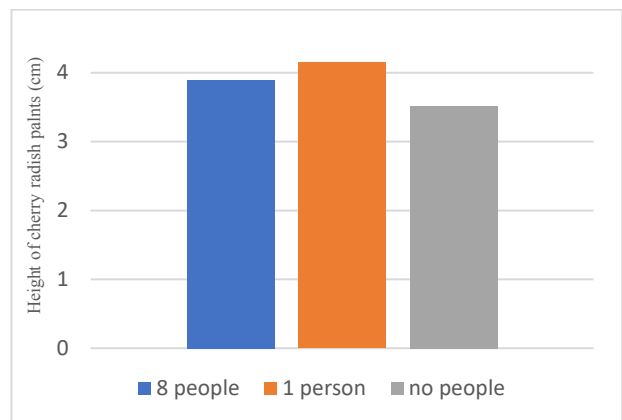


Figure 2: Trial 2 - Average Height after 10 days

**TRIAL 3**

Table 3 - The effect of intention on plant height after 10 days

# of people giving intention	Pot number	Average height – pot (cm)	Average height – intentions group (cm)
8	A1	4.207	4.073
	A2	3.938	
1	B1	4.511	3.745
	B2	2.979	
0	C1	3.655	3.511
	C2	3.367	

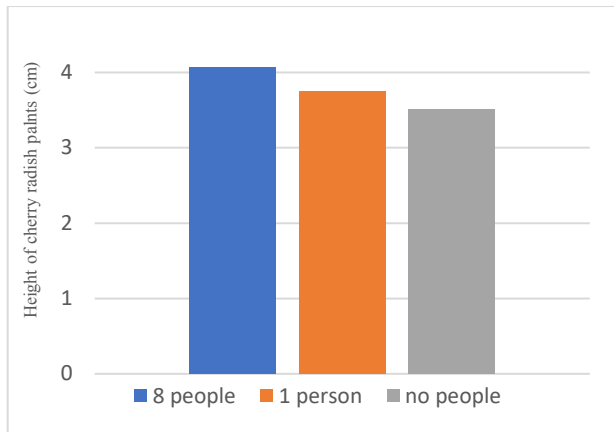


Figure 3: Trial 3 - Average Height after 10 days

**Statistical Analysis**

The statistical analysis was used to look at each individual trial, obtaining the 3 groups, no people, 1 person and 8 person intention. This included an ANOVA with post hoc Tukey tests.

**TRIAL 1:**

*Null and Alternate Hypothesis:*

Ho:  $\mu_1 = \mu_2 = \mu_3$

Ha: Not all means are equal

Table 4 – ANOVA testing key information in relation to the effect of intention in trial 1

Number of people giving intention	8	1	0
Average height (cm)	4.150	4.078	3.972
Standard Deviation	0.992	0.736	0.810
F value		0.274	
Fcrit		3.122	
Relationship	F = 0.274 ≤ Fc = 3.122		
Alpha Value	0.05		
P value	0.7608		

Since it is observed that  $F = 0.274 \leq F_c = 3.122$ , it is then concluded that the null hypothesis is not rejected and there is no significant difference between the groups ( $p = 0.7608 \geq 0.05$ ).

**TRIAL 2:**

*Null and Alternate Hypothesis:*

Ho:  $\mu_1 = \mu_2 = \mu_3$

Ha: Not all means are equal

Table 5 - ANOVA testing key information in relation to the effect of intention in trial 2

Number of people giving intention	8	1	0
Average	3.892	4.254	3.468
Standard Deviation	0.757	1.005	1.065
F value		3.731	
Fcrit		3.136	
Relationship	F = 3.731 > Fc = 3.136		
Alpha Value	0.05		
P value	0.0292		

Since it is observed that  $F = 3.731 > F_c = 3.136$ , it is then concluded that the null hypothesis is rejected and there is a significant difference between the means of at least two of the groups ( $p = 0.0292 < 0.05$ ).

**Post Hoc Tukey Test:**

Table 6 – The comparison of the 3 groups in trial 2

Treatment Pairs	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSC analysis
8 people v. 1 person	1.9295	0.366	Insignificant
8 people v. no people	2.1199	0.298	Insignificant
1 person v. no people	3.8622	0.021	Significant (p < 0.05)

**TRIAL 3:**

*Null and Alternate Hypothesis:*

Ho:  $\mu_1 = \mu_2 = \mu_3$

Ha: Not all means are equal

Table 7 - ANOVA testing key information in relation to the effect of intention in trial 3

Number of people giving intention	8	1	0
Average	4.082	3.982	3.504
Standard Deviation	0.424	0.951	0.698
F value		4.669	
Fcrit		3.128	
Relationship	F = 4.669 > Fc = 3.128		
Alpha Value	0.05		
P value	0.0125		

Since it is observed that  $F = 4.669 > F_c = 3.128$ , it is then concluded that the null hypothesis is rejected and there is a significant difference between the means of at least two of the groups ( $p = 0.0125 < 0.05$ ).

*Post Hoc Tukey Test:*

Table 8 - The comparison of the 3 groups inn trial 3

Treatment Pairs	Tukey HSD statistic	Tukey Q	HSD p-value	Tukey analysis	HSC
8 people v. 1 person	0.7087		0.8573789	Insignificant	
8 people v. no people	4.1323		0.0128305	Significant ( $p < 0.05$ )	
1 person v. no people	3.2223		0.0655620	Insignificant	

**Discussion**

From the three trials, there are a variety of results to be explored. Over the 10 days, the cumulative average height growth of all plants was 3.9cm. This average height demonstrates the investigation was replicable in all trials as consistent results were obtained in each trial. It suggests that variables were successfully controlled within the experimental design.

The key research question was to investigate the effect of intention on plant growth. During each trial, there were four different pots of plants that received intention (two pots with a single person offering intention; two pots with eight people) which were compared to two control pots that had no intentions applied. Testing the hypothesis – that as the number of people giving intention increases, the plant growth will increase – would suggest that, if any of the intention pots had significantly greater height growth, then intention can be seen to have a positive effect on growth, and would require more exploration in this field of science.

The first trial showed no significant differences between any of the three groups (eight people, one person and no people offering intention) which supported the null hypothesis. The ANOVA test showed that none of the three groups were significantly different to the others even though from initial data collection, it did show that the plants with intention from eight people were, on average, taller in height (4.25cm) than both the one person and no people (4.07cm and 3.94cm respectively). This observation did not turn out to have a measurable statistical significance in the data analysis.

The second trial showed some promising results, with the group receiving intention from one person being significantly different to the control group. As seen in Table 5. having a p value  $< 0.05$  allows for data to

support the alternate hypothesis: that as the number of people giving intention increases, the plant growth increases. Although having a p value of 0.05 or less is universally used as the threshold for statistical analysis, given that intention is such a novel concept, it would be ideal to use a p value of around 0.01 or lower to provide statistical certainty.

In trial 3, only one group differed from the rest. The intention from eight people was seen to have a significant statistical difference from the control group, with a p value of 0.013 less than the alpha value, 0.05. Although this can support the conclusion of intention having an effect, due to only one group being different and not having a significant difference between all three groups, further investigations and research is needed to support the positive impact of intention in this field.

These results are in agreement to those of Lynne McTaggart (2007) and contributes to the growing body of research in this area of science. Her investigation of plant growth with intention was conducted by the method of using the largest group they could find. This investigation looked at the difference of the size of group giving the intention – either one person or eight people.

It is evident that the more trials conducted, the use of more people and better resources allowed the Arizona research team to effectively collect data that supported the existing hypothesis, having a p value less than 0.007.

In support of this intention theory, there were some instances where a group of plants with the intention applied did grow more than the ones without. However, clearly this cannot be claimed as a universal rule from this data, especially because there was no consistency as to which groups grew the most. Furthermore, in the first trial there was no group that appeared to be have any beneficial effect. There is much more study needed to make any firm conclusions around this data.

In future studies, the environment should be as controlled as possible, ideally in a laboratory glasshouse where temperature, moisture in the air and water distribution are all consistent during each trial. However, on a high school level, this is difficult to achieve, but the plants in each trial were all exposed to the same environment and water distribution was kept consistent (with the plants being watered with 120mL of water daily).

Three trials is insufficient to make conclusions on intention. In addition, a larger sample size than 270

plants, ideally around 200 plants in each trial would increase the sample size significantly to confidently support or reject the hypothesis. The broader question regarding the effect of intention on living and non-living bodies still comes into play and further research is needed, including investigation of intention on non-plants, such as animals.

## Conclusion

Overall, the results obtained showed promise in a scientific approach to measuring the effect of intention. The project has tested the first research question in proposing a scientific approach and methodology to unpack with some scientific certainty the impact of intention. In trial 1, the averaged data between all of the three groups was not significant; however, in trial 2 and 3, one of the three groups in each trial showed to have a significant difference, with trial 2 having a difference between one and no people and trial 3 having a difference between eight and no people. The overall findings are not sufficient to conclude that there is a positive effect of intention on plant growth, and the field needs further research with new variables to support the hypothesis that as the number of people giving intention increases, the plant growth will increase.

## Acknowledgements

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# Contralateral vs Ipsilateral in free throw performance

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The ability for individuals to shoot drastically differs, even at a professional level. This study set out to explain whether there's a biological advantage or influence that some individuals have over others. The aim of this paper is to determine whether contralateral eye-hand dominance positively impacts free-throw performance in basketball. The first task was to gather students who were willing to participate and agreed to shoot free throws under exam conditions. Over the course of 2 weeks, 28 students from Barker College attempted sets of 10 free throws. At the conclusion of the data collection, each participant disclosed their hand dominance and determined their ocular dominance through a standard, manual test. A t-test was conducted on the shooting percentages of the contralateral vs the ipsilateral groups and revealed that the results were not significant ( $t = -0.95289$ ,  $p = 0.34479$ ). Conclusions were that further testing is needed with a larger sample size and further control amongst the variables.

## Literature review

Basketball is a team sport played and enjoyed across the world with players ranging from junior years to a professional stage. Mastery levels are partly dependent on the dedication of the player to practice key skills of shooting, dribbling and passing the ball. Additionally, their skill level extends to their ability to perform within a team environment and to serve their purpose within their role. The point guard and shooting guard are players who are generally smaller and to compensate they train their shooting ability so they can score at greater distances from the ring. However, at the professional level, individuals have practised for an extensive amount of time so that their ability to shoot, dribble and pass is the best that it can be. Amongst professional players, there's still variation in the consistency of free throws despite having no pressure from a defending player or time urgency from the shot clock. For example, commonly available NBA statistics show that Stephen Curry has a 90.5% free throw percentage within his 10-year professional career within the NBA whilst Rajon Rondo has a 60.5% free throw percentage within his 13-year career with both of them being point guards who shoot with their right hand. The question arises as to why some players are able to shoot with a higher percentage than others. This paper attempts to determine whether there is a biological advantage that results in a higher shooting percentage.

## Hand dominance, eye dominance, and crossed eye-hand dominance

Hand dominance is the preference of one hand over the other to perform fine and gross motor tasks, this includes activities such as writing, catching and throwing a ball (Morin 2009). Most people have become familiar with their hand dominance through childhood. There are four main types of handedness: Right-handedness, left-handedness, mixed-handedness and ambidexterity. (Mastin 2012). Right-handedness is when people are more dextrous with their right hand and it is their preferred hand for everyday tasks. Approximately 70%-90% of the world is right-handed, making it the most dominant handedness preference in the world. In contrast, only 10%-12% of people are left-handed. Mixed handedness is when an individual prefers to perform different tasks with different hands. Such people could, for example, prefer to write using their right hand whilst throw a ball with their left hand. Ambidexterity is the ability for people to equally be able to use both their hands. Approximately 1% of the population are ambidextrous (Mwaniki 2018).

Ocular dominance is the preferred visual input from one eye rather than from the other. The brain processes and builds images using slightly different views from the right or left eye. Most people tend to have a dominant eye so that even when both eyes are open, one visually processes more information than the other. (Eyeque 2017). Approximately 67% of people are right eye

dominant which can be measured using a manual, non-evasive field test (Heiting 2017).

Whilst ocular dominance and hand dominance aren't directly related, there are correlations within these traits (Heiting 2017). Contralateral eye-hand dominance is the biological tendency to prefer visual input from one eye and to prefer to use the hand from the opposite side of the body, whilst ipsilateral eye-hand dominance is the preference to use the hand from the same side of the body. Scientists believe that 85-90 per cent of the world is right-hand dominant however only 2/3 of the population is right-eye dominant (Heiting 2017). The nature of contralateral eye-hand dominance opens investigations into whether it plays a major role within our lives.

#### *Studies into the effects of contralateral eye-hand dominance*

There has been a range of studies that have investigated how contralateral dominance affects performance on physical activities. Research in tennis showed that contralateral individuals were more likely to get a serve in on both sides of the court whilst the ipsilateral group could only achieve accuracy on the advantage side (the left side of the court from each player's perspective), which is the left side of the tennis court from each (Ziagkas & Mavvidis 2018). Within the field of darts and biathlons, the interaction between eye-hand dominance and performance was not significant (Razeghi et al. 2011; Nosek et al. 2018), and interesting research into baseball has found a lot of variation in preferences. It turns out pitchers who are ipsilateral eye-hand dominant found more success whilst batters generally display contralateral eye-hand dominance (Portal 1998).

#### *Contralateral eye-hand dominance in basketball*

On the basis of these findings, it is proposed that some skills in basketball may be affected by contralateral dominance, but other skills may be less affected due to the different skills involved within the game. Some aspects that may affect a person's ability to shoot free throws include appropriate depth perception and throwing ability which correlates negatively with contralateral eye-hand dominance (Portal 1998). Therefore, while the literature is ambiguous about what may be best for free throws, it seems likely that contralateral eye-hand dominance will negatively affect the accuracy of free throws.

### **Scientific research question**

To determine whether contralateral eye-hand dominance positively impacts free-throw performance

in basketball when compared with ipsilateral eye-hand dominance.

### **Scientific hypothesis**

If an individual is contralateral eye-hand dominant, then their free throw percentage will be lower than ipsilateral eye-hand dominant individuals.

### **Methodology**

#### *Preparation*

A group of 30 male students, from the senior years of Barker College, a co-educational school in Sydney, Australia, were asked to participate as subjects to shoot free throws. Groups of 3-4 were assigned to a standard 10 ft indoor basketball hoop.

#### *Collecting Data*

Participants were given 5 minutes to warm up, to stretch and to shoot 10 practice free throws. They then shot a set of 10 consecutive free throws and their shooting percentage was recorded. Participants attempted 1-5 sets over a period of 2 weeks. 15 contralateral sets and 43 ipsilateral sets were recorded. Each individual's ocular dominance was tested using standardised methods (described below) and their dominant hand was recorded.

#### *How to test for ocular dominance*

Ocular dominance was found by asking the individual to open both eyes and fixate their eyes on something at a distance away. They brought their hands to the same level of the object and slowly brought their hands closer together till only the object can be seen within the triangle formed by their hands. Then the individual closed their left eye to see if the object was still within the frame of the triangle, then closed their right eye and opened their left eye. Whichever eye the object could still be seen within the frame of the triangle was the dominant eye.

#### *Analysing data*

A two-tailed t-test was conducted to see if the difference between the two means of ipsilateral and contralateral eye-hand dominance was significant at  $\alpha < 0.05$ .

**Results**

Table 1: Shooting percentage for contralateral sets.

<b>Contralateral</b>		
Set number	Number of Successful shots (out of 10)	Successful shot percentage (%)
1	5	50
2	4	40
3	3	30
4	4	40
5	3	30
6	7	70
7	6	60
8	6	60
9	4	40
10	8	80
11	7	70
12	4	40
13	5	50
14	9	90
15	2	20
<b>Average successful shot percentage (%) =</b>		<b>51.33</b>

Table 2: Shooting percentage for ipsilateral sets

<b>Ipsilateral</b>		
Set number	Number of Successful shots (out of 10)	Successful shot percentage (%)
1	6	60
2	8	80
3	8	80
4	7	70
5	6	60
6	6	60
7	8	80
8	8	80
9	9	90
10	4	40
11	5	50
12	3	30
13	5	50
14	2	20
15	2	20
16	9	90
17	8	80
18	10	100
19	5	50
20	4	40
21	4	40
22	6	60
23	6	60
24	8	80
25	4	40
26	6	60
27	8	80
28	8	80
29	7	70
30	1	10
31	4	40
32	6	60
33	3	30
34	4	40
35	3	30
36	3	30
37	3	30
38	6	60
39	6	60
40	6	60
41	8	80
42	7	70
43	7	70
<b>Average successful shot percentage (%) =</b>		<b>57.44</b>

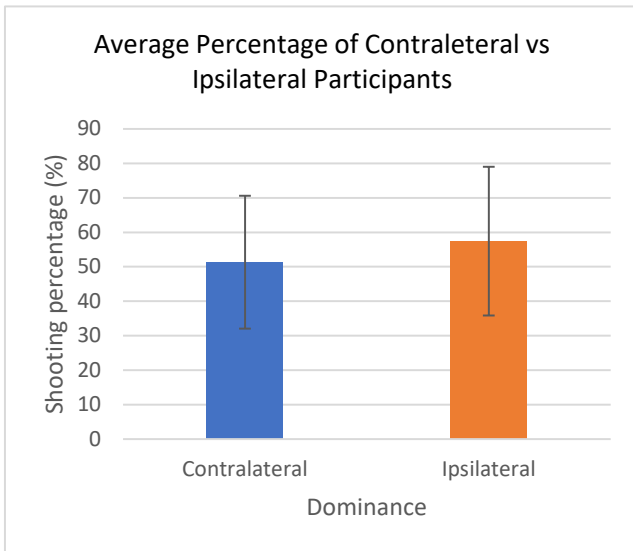


Figure 1: Means of contraleateral and ipsilateral shooting percentage with one standard deviation error bars

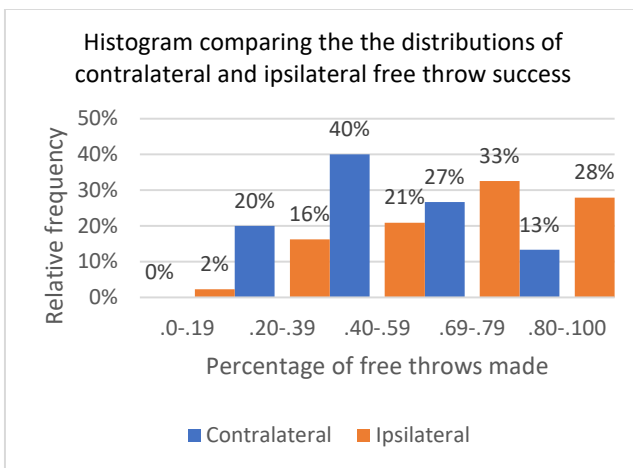


Figure 2: The difference in free throw success between contralateral and ipsilateral. It can be seen that ipsilateral participants were more likely to shoot at higher percentages than contralateral participants.

## Discussion

A two-tailed t-test was conducted with an alpha value of 0.05. The results showed that the contralateral performance on average was less than the ipsilateral performance however the test did not find a significant difference between the two means ( $t = -0.95289$ ,  $p = 0.34479$ ). Therefore, this experiment has not been able to find any significant difference in free throw ability for people who are contralateral or ipsilateral.

It is possible that this is the correct result and that there is no difference. It is also possible that this was a false negative and through a variety of improvements or areas of further research, the true result can be confirmed.

## Implications for further research

### Sample size

Increasing the overall sample size would allow for a much larger scope and valid representation of the capabilities of both contralateral and ipsilateral groups. Within this experiment, there was a limited number of participants and a limited number of sets attempted because it was difficult to recruit willing participants (students and teachers) to voluntarily give their time to take free throws under test conditions (test conditions involves removing distractions such as noise, visual stimulants). Within the experiments mentioned within the literature review, the study involving dart skill, baseball, biathlons, and tennis contained a sample size of 12, 25, 37, 36 respectively (Razeghi et al. 2011; Portal 1998; Nosek et al. 2018; Ziagkas & Mavvidis 2018). This suggests that the sample size used in this experiment (28 people contributing a total of 58 data points) is not unreasonable, however, more participants would lead to more confidence in the generalisability of the results. 100 people contributing 5 sets of 10 free throws each would be more appropriate.

### Skill level

Another aspect which should be implemented in the future is to account for the variance of the skill level of the participants as skill level is a large factor that outweighs the potential of contralateral eye-hand dominance. This could be controlled by categorising the participants into three skill levels to minimise the variance between the skill levels. Initially, the methodology was to categorise the cohort into three skill levels and analyse the difference of the means between contralateral and ipsilateral individuals within the categorised group. Within the experiment, there were 8 contralateral individuals which meant that dividing the cohort into three would mean that only one or two contralateral individuals would reside within the groups which are insufficient to validly test the difference of means.

### A consistent number of sets per person

Furthermore, for each participant, they shot different amounts of sets with some shooting one set with other shooting five sets and as such, each set was treated as an independent result. Within the experiment, there were difficulties in having willing participants to regularly take the time to assist in shooting free throws in exam conditions. Some participants were more compliant than others which resulted in some individuals attempting more sets. However, this is another variable that should be controlled in the future for optimal validity as individuals may have an “off day” which affects their performance and if that individual only attempted one set, the results incorrectly represent the individual’s performance. Optimally each individual shoot 5 sets of 10 and the average is taken. This allows for larger



sample size and allows consistency across the participants.

#### *A similar number of people who are contralateral and ipsilateral*

Moreover, there were a different number of contralateral participants compared to ipsilateral. Within the experiment, there were 15 sets from the ipsilateral cohort whilst there were 43 sets from the contralateral cohort. This was due to the participants disclosing their ocular and hand dominance at the conclusion of the experiment, so the amount of contralateral eye-hand dominant participants was unknown at the start of the project which resulted in the disparate numbers between the two groups. The test for ocular dominance was released to all the participants at the start of the experiment however there were difficulties in obtaining the participant's ocular dominance due to non-compliance from the participants. The limited attempts from the ipsilateral cohort restrict the scope of valid experimentation.

#### *Suggestions for the future*

The suggested methodology of an expanded study might include having 4 groups of 25 people who are categorised into skill level who conduct 5 sets of 10 shots, with one set a day, for five subsequent days inside an indoor court on a standard 10ft hoop. 50 of the participants are to be ipsilateral whilst the others are contralateral. The averages of each individual's 5 sets are to be recorded and contralateral and ipsilateral groups separated.

### **Conclusion**

The investigation into whether contralateral eye-hand dominance positively impacts free-throw performance in basketball resulted in an inconclusive result. Although the data suggest that the contralateral group have a lower scoring percentage compared to the ipsilateral group, the t-test has clarified that the result is not significant ( $t = -0.95289$ ,  $p = 0.34479$ ). This means that ambiguity still resides in whether contralateral eye-hand dominance affects free throws, and this should be further researched in the future.

### **Acknowledgements**

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# The relationship between age and infection rate of Invasive Meningococcal Disease

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This study investigated the relationship between the infection rate of Invasive Meningococcal Disease (IMD) and the varying age among the population of Australia, specifically at the spike seen in adolescents (15-19 years of age). The data was collected from the Australian National Notifiable Surveillance System between the years 1999 to 2018. The data was collected for all age groups between 0-85+. This data was then analysed and manipulated through both a One Way ANOVA and Post-Hoc test to determine whether it was statistically significant. It found to be significant and thus shows that IMD did indeed have the second highest notification rate per 100,000 people for the adolescent age bracket (15-19 years old) within Australia. Conclusively depicting Australia's population and its relationship to Invasive Meningococcal Disease across the last 20 years amongst all age groups, and specifically looking at how it interacts with the increased sociability between adolescents.

## Literature review

IMD, otherwise referred to as Invasive Meningococcal Disease, is an infection caused by *Neisseria meningitidis* contaminating an individual. IMD can result in a multitude of symptoms, such as blood infection (septicaemia) or inflammation of the membranes of the brain or spinal cord (meningitis), which can consequently result in amputation, brain damage, and potentially even death (Rosenstein et al. 2001). Whilst being uncommon, Meningococcal Disease is a serious consideration for populations to account for due to its severe characteristics. In a matter of hours, a simple fever can transition into a potentially lethal concoction of symptoms. The most prevalent strains within Australia are the B and W serogroups of Meningococcal. There are a total of 5 primary strains of the disease, which all have vaccinations currently available (Booy et al. 2007).

### *How It Spreads - Descriptive Epidemiology*

*Neisseria Meningitidis* spreads through close bodily contact in which carriers (individuals carrying the bacteria but not suffering the symptoms) or those contaminated transmit the disease through prolonged contact. Meningococcal bacteria are unable to live outside of a human host for more than a few seconds, hence why it spreads through close prolonged contact,

such as kissing or living within a close quarter environment with a carrier or infected individual (Campbell et al. 2017). As the Meningococcal bacteria thrives in dense clusters of people, it can be logically inferred that populations with generally more sociable characteristics are potentially more prone to infection as well as those with weakened immune systems (elderly and infants). This is apparent in the scientific papers included within this literature review.

### *Statistical Epidemiological Trends*

One particular study was conducted by MacLennan et al. in 1999 where approximately 14,000 teenagers had pharyngeal swabs taken to understand the prevalence of meningococcal in this age group. Through analysis, MacLennan et al. showed that of the 16.72% of the 14,000 that had *Neisseria Meningitidis* present (as carriers evidently), 32.8% of this population – who were carriers - were strongly associated with activities such as attendance at pubs and clubs, intimate kissing, and cigarette smoking in comparison to the 7.8% of those who did not participate in any of the listed activities, therefore indicating a link between sociability and infection rate of IMD. Furthermore, it has been noted that even prior to the 2003 introduction of Meningococcal vaccinations, the infection rate of IMD had already begun to decline in regions such as NSW

(Booy et al. 2007), thus accentuating the highly probably chance that increased socioeconomic status and herd immunity are significant factors to consider and this should be consistent within the data analysed.

#### *Conclusion in Regards to Scientific Papers and Present Trends*

In regards to the present trends and research from scientific papers, it can be concluded that there is a relationship between sociability and infection rate of IMD, and this is reflected in the increased proportion of teenagers who are affected within the population. This is most likely a reason for why the Australian Government body instituted vaccinations for adolescents to minimise infection rate and subsequently reduce impact for other age groups due to herd immunity.

#### *Contribution and Focus*

Studies in this area tend to focus on a particular small population group that are geographically or logistically grouped (MacLennan et al. 2006).

There are three categories of studies that are conducted in this field of research. Small scale studies take a localised group of people (e.g. the students at a university) and survey them regarding their history of IMD and various behavioural traits including social interaction (For example, the Meningococcal Risk Study For Adolescents 1999-2000 looked at 144 cases of infection). Other researchers have taken once off snapshots of a large scale population such as 1400 teenagers in the UK during 1999. There are limited studies that analyse health data on a national or international level. One study in Australia (Booy et al. 2007) used health data in NSW to determine variation by age and changes in the notification rate over time. This third category is under-researched and is the focus of this research report exploring IMD notification rate exclusively in Australia, how it varies by age group, and most importantly, how this variation has changed over 20 years of data collection. The 20 years of historical data ensure unique outlying years will not lead to false conclusions, and allows investigation of how trends change over time.

This research report focuses on the prevalence of Meningococcal among age groups, and specifically its interactions with adolescents over the previous 20 years. This will provide further insight into how this bacteria functions within Australian society despite the introduction of vaccinations and through societal progression, therefore examining if this disease could potentially fluctuate in infection rate among the age

groups and if this impacted the state of Australia's standings with IMD (specifically the teenage population).

#### **Scientific research question**

How does age relate to infection rate of IMD (Invasive Meningococcal Disease)?

#### **Scientific hypothesis**

That Australians aged 15-19 form the age group with the second highest notification rate per 100,000 of IMD (Invasive Meningococcal Disease) than any other age group in Australia.

#### **Methodology**

A suitable dataset that represented the infection rate of meningococcal across a range of ages was needed for this experiment. Thus, it was essential to find a reliable and expansive dataset from a national perspective, which is publicly available as a government-funded source of information. From an ethical standpoint, this methodology does not violate any specified guidelines and only provides the notification rate without infringing on any individual's privacy.

The Australian National Notifiable Disease Surveillance System publishes publicly available data on various diseases in Australia. Data on IMD included notification rates sorted by age group, gender, state or territory, each year for over 20 years. Therefore this data was considered most appropriate for this study.

Using the Australian National Notifiable Disease Surveillance System website, summary tables were created using the tool describing 'Notifications of a SELECTED DISEASE by Age Group and Sex'. By selecting 'Notification Rate' and 'Meningococcal Disease (Invasive)', data could be extracted individually for each year from 1999 to 2018.

The data from each year from 1999 to 2018 was extracted and tabulated. This table presented the Australian notification rate per 100,000 people for each 5 year age group for that given year.

Descriptive statistics were calculated along with an ANOVA to consider the long-term averages for each age group 0-4, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, 75-79, 80-84, and 85+.

#### **Results**

The Table 1 depicts the national notification rate per 100,000 individuals within Australia between the years

Table 1: Notification rate by age group for each year.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0 to 4	16.1	16.0	16.8	14.2	12.7	10.2	10.1	8.7	8.1	7.2	6.2	5.8	4.9	4.6	3.0	3.3	2.9	3.4	5.5	4.6
5 to 9	3.1	3.2	5.2	4.2	2.8	1.9	2.3	1.7	1.2	0.8	1.3	1.1	1.0	0.8	0.4	0.6	0.3	0.5	1.2	0.6
10 to 4	2.7	2.9	2.9	3.4	2.5	1.2	1.6	0.6	1.2	1.4	1.2	0.9	0.8	0.5	0.6	0.4	0.2	0.1	0.6	0.2
15 to 9	8.4	8.7	7.7	10.5	7.1	4.8	3.9	3.9	4.2	3.8	3.4	2.5	2.9	2.2	1.8	2.1	2.6	2.5	2.8	2.6
20 to 4	4.4	6.0	5.1	5.8	5.2	2.7	2.6	2.1	2.3	1.3	1.3	1.1	1.6	1.6	0.9	1.4	1.1	1.9	2.2	1.3
25 to 9	1.7	2.0	2.3	2.0	1.5	1.2	0.8	1.2	0.7	0.7	0.8	0.4	0.5	0.8	0.3	0.2	0.2	0.9	1.1	0.8
30 to 4	0.4	0.9	2.0	1.9	1.3	1.0	1.1	0.7	0.5	0.8	0.6	0.3	0.3	0.4	0.2	0.2	0.2	0.3	0.4	0.7
35 to 9	1.2	1.2	1.5	1.2	1.2	0.7	0.4	0.9	0.3	0.4	0.6	0.2	0.1	0.3	0.2	0.1	0.3	0.4	0.6	0.5
40 to 4	1.1	1.0	1.3	1.4	0.6	0.4	1.0	0.3	0.3	0.7	0.5	0.5	0.3	0.2	0.1	0.4	0.1	0.2	0.4	0.3
45 to 9	1.1	1.4	1.0	0.9	0.7	1.0	1.0	0.7	0.4	1.0	0.1	0.5	0.7	1.0	0.4	0.2	0.4	0.4	0.6	0.4
50 to 4	0.7	1.3	1.5	1.5	1.7	1.2	0.9	0.5	0.5	0.7	0.6	0.3	0.7	0.3	0.3	0.2	0.6	0.6	1.6	0.8
55 to 59	1.0	1.0	0.9	1.4	0.7	1.1	1.2	0.3	0.6	0.4	0.3	0.5	0.6	0.4	0.3	0.4	0.3	0.5	1.1	0.9
60 to 64	1.0	0.9	0.7	1.2	1.2	1.3	0.6	0.5	0.6	0.3	0.3	0.6	0.4	0.7	0.5	0.3	0.4	0.9	1.5	1.4
65 to 69	0.9	0.6	0.6	0.9	1.5	0.5	0.4	0.6	0.2	0.2	0.0	0.3	0.7	0.4	0.3	0.3	0.7	1.3	0.9	1.0
70 to 74	1.4	0.5	2.7	1.6	0.8	1.1	1.1	0.2	0.6	0.3	0.1	0.6	1.2	0.5	0.3	0.5	0.9	1.6	1.6	0.9
75 to 79	0.8	0.4	0.4	0.2	0.9	1.3	0.5	0.2	0.7	0.4	0.5	0.0	0.2	0.2	0.3	0.8	1.0	0.9	2.7	1.2
80 to 84	1.4	0.3	0.9	1.2	1.4	0.8	1.3	0.2	0.7	0.5	0.2	0.9	0.9	0.4	0.0	0.4	1.1	1.3	2.6	1.5
85+	0.8	2.0	2.3	1.1	1.1	0.7	0.7	1.6	0.6	0.3	0.5	0.8	0.2	1.4	1.1	1.1	1.5	1.7	2.4	1.2
Total	3.1	3.2	3.5	3.5	2.8	2.0	1.9	1.5	1.5	1.3	1.2	1.0	1.1	1.0	0.6	0.7	0.8	1.0	1.5	1.1

1999 to 2018. Through the progression of the data over the years it can be seen that there has been a decrease overall in terms of notification rate, aligning with the improved medical care in conjunction with the introduction of vaccines in 2003.

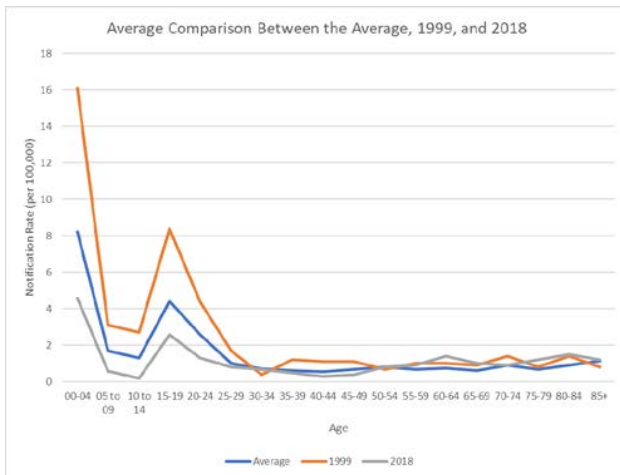


Figure 1: The notification rate by age group comparing the 1999 distribution to the 2018 distribution (and the average across the 20 years).

Figure 1 compares the Notification Rate of IMD across the previously specified ages with three trend lines representing all the years averaged, the year 1999, and the year 2018. This will shed further light into the progression of the notification rate across the 20 years that have been examined throughout this study. The

trends remain proportionally consistent between the different lines, therefore indicating that IMD has managed to – in relation to the age groups – retain similar trends between 1999 and 2018.

Figure 2 is a direct representation of the previously listed tables. Present among the trends is that of the adolescent group spiking in notification rate, which aligns with that of the hypothesis written for this study – yet this can only be verified through statistical analysis whether or not the data is indeed significant. Furthermore, as specified in the literature review, the insight into sociability and its relationship to infection rate is reinforced by the given spike in adolescents. Through comparative examination between the years, it is evident that the general notification rate is decreasing. Additionally, for each age group, it is relatively consistent that there is a decrease in notification rate per 100,000 as age approaches the elderly. The only abnormality – other than that of adolescents – is the minor fluctuation in the elderly group, however, this correlates to that of the weakening of the immune system among older individuals.

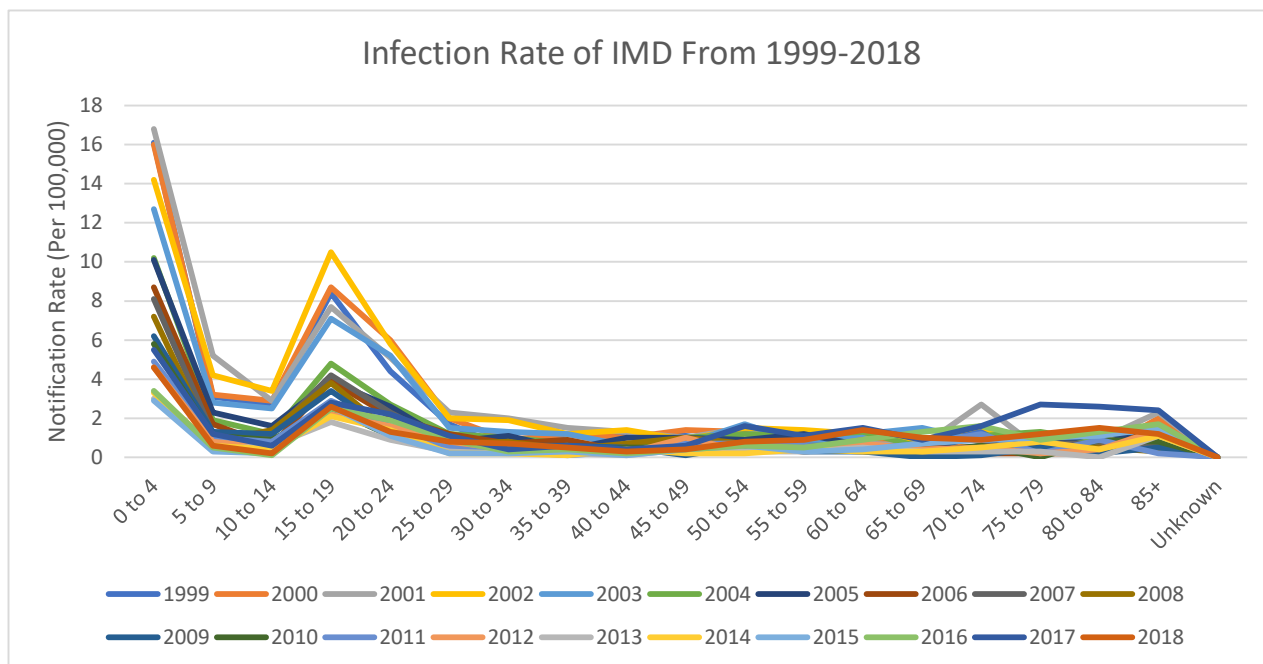


Figure 2: The notification rate by age group for each year from 1999-2018.

**Discussion**

A one way ANOVA was performed on the averages across the 20 years. The results showed that there was a significant difference between at least two of the age groups (F-Statistic = 34.6734). Table 1 presents the P-values for a Tukey HSD test (post hoc analysis) revealing which groups had a significant difference between their means. Only 0 to 4, 15 to 1 and 20 to 24 exhibited a significant difference.

	0 to 4	15 to 19	20 to 24
0 to 4	----	<0.00001	<0.00001
5 to 9	<0.00001	<0.00001	----
10 to 14	<0.00001	<0.00001	----
15 to 19	<0.00001	----	0.01009
20 to 24	<0.00001	0.01009	----
25 to 29	<0.00001	<0.00001	0.05771
30 to 34	<0.00001	<0.00001	0.00614
35 to 39	<0.00001	<0.00001	0.00269
40 to 44	<0.00001	<0.00001	0.00156
45 to 49	<0.00001	<0.00001	0.00541
50 to 54	<0.00001	<0.00001	0.01563
55 to 59	<0.00001	<0.00001	0.00541
60 to 64	<0.00001	<0.00001	0.00969
65 to 69	<0.00001	<0.00001	0.00269
70 to 74	<0.00001	<0.00001	0.03311
75 to 79	<0.00001	<0.00001	0.00475
80 to 84	<0.00001	<0.00001	0.02760
85+	<0.00001	<0.00001	----

Table 2: P-values for the difference between means of various groups determined using Tukey HSD post hoc analysis.

The F-Statistic of 34.6734 in conjunction with the P-value of 0 indicate that there is a statistical significance present as a result of the One Way ANOVA test – due to  $P < F$ -Statistic. The table above is comparing the age groups and their associated p-values between each other as an outcome of the ANOVA and Post-Hoc test. As the p-value approaches zero, the significance in terms of statistics between the groups is more distinct. For example, the 0-4 age bracket has a 0.00000 p-value with every other relevant age group, therefore indicating it is statistically significant, and subsequently greater than every other age group in terms of notification rate of Invasive Meningococcal Disease.

This study is concerning primarily the adolescent age bracket (15-19 years of age) and whether they were the second highest group in terms of notification rate per 100,000 for IMD. As observed in both the trends within the graphs (the sudden spike in notification rate for this age group) and visibly here in the Post-Hoc test, there is significant data in support of the hypothesis. While infants (0-5 year olds) remain the group in which IMD is most prevalent, the 15-19 year old age group being statistically significant and greater in comparison to every other group (apart from 0-5 year olds), it can hereby be stated that the hypothesis has been accepted, and ultimately it can be concluded that across a 20 year time span that adolescents (15-19 year olds) are indeed the age bracket that are the second most affected in terms of notification rate per 100,000 of Invasive Meningococcal Disease.

This is closely linked to the previously specified scientific articles where sociability was linked to the increased notification rate present among adolescents - which is reflected in the data analysed (MacLennan et al. 2006). This indication, correlated to the previously found literature and research, in collaboration with the data across the last 20 years, the nature of IMD and the environment in which it thrives (close prolonged contact amongst a social community – Campbell et al. 2017). This data provides more insight into which age groups are most affected, and subsequently where Meningococcal Disease tends to thrive, and thus could assist in implementing a multitude of varying systems (For example, targeted vaccinations) to reduce the presence of IMD throughout Australia.

While sociability has been linked to a higher infection rate of IMD, this area could benefit from further study, and as observed within this study, the adolescent age group is one of the most affected portions of society within Australia, and it could be useful to establish a more well-founded understanding in how IMD directly navigates and spreads through this social component of Australia's population.

## **Conclusion**

Overall, it can be stated that the 15-19 year old division of the Australian population is the second highest group in terms of notification rate per 100,000 of Invasive Meningococcal Disease across the last 20 years. This reinforces the previously researched literature of sociability and its relevance to that of adolescence, and thereupon indicates the critical areas that should be investigated – these being the analysed spike in the 15-19 year old group – to further improve the state of Australia's medical system and in regards to Meningococcal's characteristics within society, and thus the implementation of targeted vaccination and/or the development of a more informed community to the symptoms of the disease.

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# The effect of solution concentration on maximum height of capillary rise, with specific reference to the fertilizer Ammonium Dihydrogen Orthophosphate

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Fertiliser is typically seen as a beneficial factor in plant growth. This experiment aims to determine whether it is possible that the increase in concentration of a solution (of a fertiliser compound) could decrease the ability for that solution to be absorbed by the plant, or capillary in this case. By creating solutions of specific concentrations and using a capillary to measure the maximum height of travel for each solution, an average height of capillary rise can be obtained. Graphs of these results show a strong negative correlation. While the data gained in this experiment did agree with this strong negative linear correlation after analysis, more data points could affect the trend towards inverse proportionality rather than linear.

## Literature review

Fertilisers are chemical compounds designed to maintain soil fertility and to enhance crop production (Koloman et al. 2018). Fertilisers contain essential chemical elements required for plant growth (Science Learning Hub, 2013). Nitrogen and phosphorous are the two major plant-growth limiting nutrients, leading to their use in modern fertilisers (Gyaneshwar et al. 2002; Chapin & Stuart, 1980). Hydrogen also makes up the building blocks for plant growth (Crop Nutrition, 2019). The compound ammonium dihydrogen orthophosphate ( $\text{NH}_4\text{H}_2\text{PO}_4$  – hereafter ADO) is a common compound in many plant fertilisers. Ammonium phosphates are highly soluble in water and form an important base for many compound fertilisers (Chemical Book, 2019). Plants can utilise their xylem in order to absorb the high-nutrient water solution in the soil and transport it up to their leaves, where the nutrients are used in plant cell creation (dummies, 2019). Plant xylem, in turn, utilise capillary action, or the transport of liquids through thin ‘straws’ or capillaries, to move around this nutrient rich solution (Biology 1520 - Georgia Tech Biological Sciences, 2016).

Capillary action occurs when the adhesive force (between a solution and the walls of its vessel) is strong enough to overcome the weight force by dragging liquid up the sides of a vessel and causes a net upwards force (United States Geological Survey, 2018). Cohesion is an attractive force between like molecules, such as the

hydrogen-bonding interaction between water molecules that causes high surface tension, menisci formation and the beading of water on hydrophobic surfaces (Helmenstine, 2019). Hydrogen bonds are the strongest intermolecular forces which can occur between covalent molecules (Ashenhurst, 2019). Hydrogen bonding occurs when hydrogen is attached to nitrogen, oxygen or fluorine, each having very high electronegativities. These high electronegativities mean that in the covalent bond pair, the nitrogen, oxygen or fluorine will attract the electron pair significantly more than the hydrogen will. This leads to a small local area of positive charge on the hydrogen, and a small local area of negative charge on the nitrogen, oxygen or fluorine, called a bond dipole (Khan Academy, 2019). These small areas of local positive and negative charge between different molecules are strongly attracted due to the electrostatic force, as they essentially act as positive and negative charges. Water molecules are very good at adhesion, primarily due to their ability to form hydrogen bonds with other molecules containing hydrogen, nitrogen, oxygen or fluorine (Exploring our Fluid Earth, 2019). This strong force explains the high surface tension of water, where each molecule of water would much rather stick to another molecule of water than an oxygen molecule, and in turn forms more intermolecular forces with other molecules of water.

In the case of very thin glass ‘straws’ or capillaries, the cohesion to adhesion ratio is minimised by having a

smaller diameter for the capillary width, meaning that when a tube of a larger radii is compared to a tube of a smaller radii, the smaller tube will have a smaller cohesion to adhesion ratio, which is beneficial for capillary action. This is shown in Figure 1 on the right, which demonstrates how the radius of a capillary affects the ratio of cohesion bonds to adhesion bonds. In the figure, blue lines/text represent cohesion forces while green lines/text represent adhesion forces. Hence, the capillary action (or the maximum height of capillary rise) significantly increases as the radius of a capillary decreases.

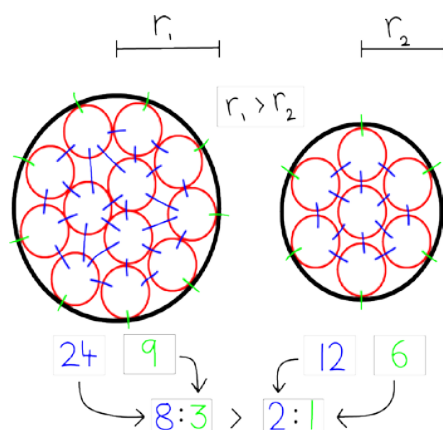


Figure 1 shows tubes of different radii, and their cohesion + adhesion forces

When ADO is added to water, it is dissolved into an anion and a cation -  $\text{NH}_4^+$  and  $\text{H}_2\text{PO}_4^-$  (Crop Nutrition, 2019). A polar molecule has regions of positive charge and regions of negative charge within the molecule. A non-polar molecule has no regions of positive or negative charge within the molecule (Helmenstine, 2019). In terms of the adhesion forces, this means that these ions can't adhere to the glass walls of the capillary. In relation to cohesion; the ions in the solution will gain hydration shells either by bonding the oxygen in water molecules to the cation, or the hydrogen in water molecules to the anion (Phys Org, 2018). The bonds found in hydration shells are strong enough for it to be stable in an undisturbed environment, hence allowing the entire hydration shell to function like a molecule with a large molecular weight.

As nitrogen, hydrogen and phosphorous are essential nutrients for plant growth, ADO was chosen as a suitable solute for the experiment which sought to relate the concentration of ADO with the maximum height of capillary rise. The hypothesis based on existing literature was that increasing the concentration of ADO will decrease the maximum height of capillary rise in a linear relationship.

The addition of ions will solely increase the cohesion forces, and not increase the adhesion forces. This is due to the hydration shells that form around ions in solution. Any dissolution in water works off of the principle that the solute is a polar substance, and the strongly polar water will form strong intermolecular forces with the solid as it enters the water. Due to the strength of the water's polarity (much stronger than most molecules) the solute finds it easier to break the bond between its cation and anion, and instead bond with the water molecules. Once the cation and anion are separated, the water molecules form a hydration shell or a spherical latticework around the new ion in solution, as the negatively and positively charged ions have a stronger electrostatic attraction to the hydrogen and oxygen atoms in a water molecule respectively.

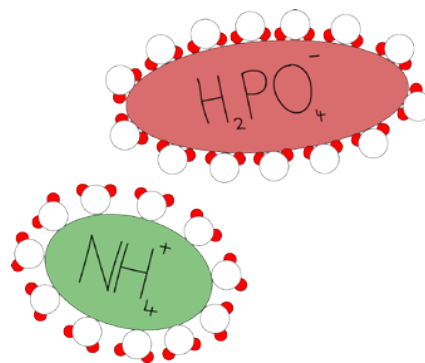


Figure 2: Representation of hydration shells

Figure 2 shows a simplified representation of hydration shells on a 2D plane around the ions formed from ADO in solution. The white balls represent oxygen and the red balls represent hydrogen. The hydrogens local positive charge is attracted to the dihydrogen phosphate's negative charge and the oxygen's local negative charge is attracted to the ammonium's positive charge. In both cases electrostatic intermolecular forces are the cause of the attraction.

Essentially each ion will have its own hydration shell, and due to the hydration shell, no ion will ever be contacting the glass. This essentially means that the adhesion forces between the glass walls and the water molecules are effectively the same as before the solute was added. However, when the cohesion forces are examined, these large hydration shells are already keeping the big 'compound molecules' together. This leads to an increase in cohesive forces compared to before the solute was added. In addition, the hydration shells can also form intermolecular forces with each other more strongly than the water molecules originally. They have essentially the same hydrogen bonds,

however due to the large organised structure of the hydration shells, the water molecules in each hydration shell can line up to connect hydration shells with multiple hydrogen bonds each. The two hydration shells combined could have many times more hydrogen bonds connecting it, whereas the water molecules before the solute was added had a limit of 4 hydrogen bonds. This makes it increasingly more difficult to separate these hydration shells, effectively increasing the cohesion significantly as soon as any solute enters the water. As the adhesion is not increasing, and the cohesion is being increased, the cohesion to adhesion ratio is getting bigger.

The impact of this scientific research project is that it could significantly affect the way that nutrient concentrations (fertiliser use) are managed in the agricultural industry due to possible repercussions of using excessive amounts of fertiliser, in turn reducing the maximum height of capillary rise in plants and crops.

### Scientific research question:

What is the effect of increasing the concentration of an ammonium dihydrogen orthophosphate solution on its maximum height of capillary rise?

### Scientific hypothesis:

That as the concentration of ammonium dihydrogen orthophosphate in water increases, the maximum height of capillary rise will decrease in a linear relationship.

### Methodology:

#### *Rinsing/Drying*

All glassware was rinsed out three times with distilled water, in an attempt to remove all impurities or residue from previous tests. The glassware rinsed included: a 20 mL volumetric flask, a volumetric flask stopper, a 10 mL measuring cylinder, two small 20 mL beakers and a glass funnel. The beaker was dried with a clean tea towel (that has only been used to dry glassware rinsed with distilled H<sub>2</sub>O).

#### *Making the solution*

Ammonium dihydrogen orthophosphate (hereafter referred to as ADO - 0.288g, 0.0025moles) was accurately weighed into a clean and dry beaker using an analytical balance. A small amount of distilled water was added to the beaker to dissolve the ADO and the resulting solution was accurately transferred to a 20 mL volumetric flask, ensuring that no solution was lost during the transfer. The beaker and funnel were rinsed several times during this process to ensure accuracy. The volumetric flask was shaken vigorously to ensure

complete dissolution of ADO. The resulting concentration of this solution is 0.125M.

#### *Creating the capillary tubes*

A 5mL glass pipette was heated over a Bunsen burner while being rotated. When the glass was started to collapse inwards, the glass was pulled out of the flame and stretched outwards as it cooled. The glass formed a thin, long capillary with a uniform central section. The capillary was broken into short uniform lengths. The now-jagged edges the capillaries were filed straight. A tape-tag was attached to each capillary (see Figure 3 on the right)  $\sim \frac{1}{4}$  of the way down. The tape tag allows for easier handling of the capillary, reduces chance of breakage, and reminds the experimenter which side of the capillary is being used at any given time.

#### *Calibrating the capillary tube*

The capillary tube was calibrated with distilled water before each test. A 20 mL beaker was filled with distilled water. The capillary was held with the tape-tag on the higher end of the capillary. The bottom of the capillary was placed 1cm under the surface of the distilled water and held vertically. The capillary was held there until the water stopped travelling up the capillary for 3 seconds (indicating the maximum height of capillary rise). The grip on the capillary was shifted to  $\frac{3}{4}$  of the way down the capillary (to reduce chance of breakage), then the tip was pressed onto a tissue to draw the water out. The capillary was rinsed 3 times from each end of the capillary tube.

#### *Measuring maximum rate of capillary rise:*

A clean pipette was used to transfer 2 mL of the ADO solution from the volumetric flask into a 10 mL measuring cylinder. The measuring cylinder was rinsed thoroughly with this solution. The solution was removed by inverting the measuring cylinder. The same pipette was used to transfer 10 mL of the ADO solution into the measuring cylinder, ensuring that the bottom of the meniscus lines up with the 10 mL mark. The calibrated capillary was then inserted vertically into the solution,  $\sim 1$  cm under the surface of the solution in the measuring cylinder and held by the tape-tag  $\frac{1}{4}$  of the way down the capillary. The solution was allowed to rise up the capillary tube until it reached its maximum height of capillary rise (when the solution stops rising for at least 3 seconds). The capillary was carefully moved to a horizontal position on a flat surface. A ruler (that measures to the nearest millimetre) was used to measure the height of capillary rise up the tube, to the nearest half millimetre, ensuring to view from directly above to avoid parallax error. This measurement was recorded as

a value for the 0.125M ADO solution. The solution was blotted out on tissue. Once the capillary was empty, the measurement/blotting process was repeated. It is important to note that it is very likely that meniscus/invisible remnants of distilled water will be trapped in the tube, increasing the maximum height of capillary rise. These will get rinsed out over the next 0 to 5 readings but will increase the intended results up until this point. As the experiment is not controlled until the maximum height of capillary rise being measured is solely due to the solution, these results are discarded. This trend was noticed in all preliminary result tests and affected anywhere from 1 to 10 results for each different solution before the results became similar with each test, indicating that the tube was thoroughly standardised with the solution being tested. This means that all results must be discarded until they fall within a consistent range of  $\pm 5\%$ . This was repeated for concentrations up to 1.250M, in steps of 0.125M each.

**Results:**

Table 1 contains the maximum height for capillary rise for the five trials for each concentration from 0.125M through 1.250M, as well as the average result for each concentration, and the inverse of each average result.

Table 1: Capillary rise for various concentrations.

ADO Concentration (M)	Maximum height of capillary rise (mm)					Mean	1 / Mean
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
0.125	77.0	77.0	76.5	76.5	76.0	76.6	0.013
0.250	60.5	60.5	60.0	60.0	59.5	60.1	0.017
0.375	58.5	58.0	57.5	57.5	57.5	57.8	0.017
0.500	52.5	53.0	54.0	54.0	52.5	53.2	0.019
0.625	52.5	52.5	52.0	52.0	51.0	52.0	0.019
0.750	50.5	50.5	50.5	50.5	50.0	50.4	0.020
0.875	49.5	49.5	49.5	49.5	49.5	49.5	0.020
1.000	48.5	49.0	49.0	48.0	48.5	48.6	0.021
1.125	48.0	47.0	47.5	48.0	47.5	47.6	0.021
1.250	47.5	47.0	47.0	47.0	47.0	47.1	0.021

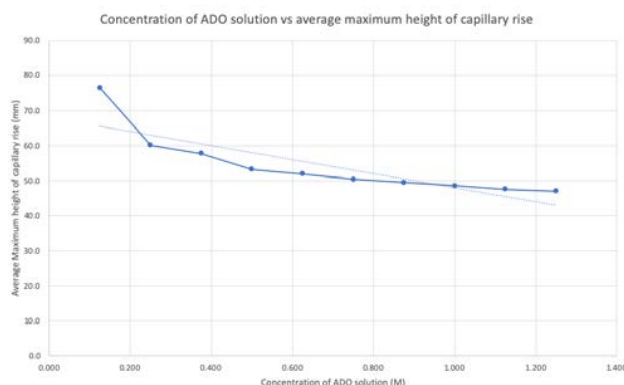


Figure 3: Average maximum height of capillary rise vs concentration of ADO solution.

Figure 3 shows a graphical representation of this data without manipulation with a linear trendline, indicating

a trend that is unclear whether it is inversely proportional or linear.

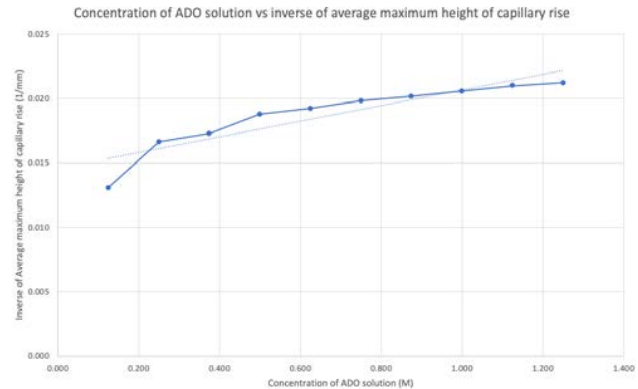


Figure 4: Inverse of average maximum height of capillary rise vs concentration of ADO solution.

Figure 4 shows a graphical representation of this data, instead plotting the concentration against the inverse of the maximum height of capillary rise. This is done to analyse whether the original graph is inversely proportional or linear.

**Discussion:**

In order to interpret the data in a way such that it can either agree or disagree with the hypothesis, certain data analysis must be completed. As the hypothesis is predicting a linear relationship with a negative gradient, a Pearson’s correlation coefficient test will produce a valuable indication of the strength of the linear relationship..

Table 2: Pearson’s R correlation test results for each graph

	Average vs concentration	Inverse average vs concentration
R coefficient	-0.8463	0.9133
R <sup>2</sup> coefficient	0.7162	0.8341
$\alpha$	0.05	0.05
p value	0.0020	0.0002

Table 2 shows the results of the Pearson’s correlation coefficient test for the two sets of data.

For the unaltered data, the P value is lower than the alpha value, so it can be concluded that there is a significant negative linear correlation between the concentration of an ADO solution and its maximum height of capillary rise.

This does satisfy the hypothesis, but it has been noted that the original graph resembles an inverse proportional relationship between concentration and maximum rise.

Table 2 also shows the results of the Pearson’s correlation coefficient test for the inverse dataset.

This graph also passed the Pearson's correlation test showing a strong positive correlation, with a higher R-value than the other graph. Both p-values are significantly lower than the alpha value.

It is also important to bring up the distinction that the data set available from the experiment does not disprove either trend. It could be a linear relationship or a gradual inverse proportional graph, and the current data points aren't widespread enough to provide a specific answer to this question yet. The best plan to proceed onwards is to get more data around the points of contingency around 0.125M. Additionally, taking a reading of distilled water by itself would be valuable into interpreting the shape of the graph. While less important than the previous steps, continuing the data past 1.250M would also help to explain the trend of the data.

Limitations in this experiment included:

- Ambiguous trend line – could be either linear or inverse proportional
- Not a wide enough range of data to have a fully conclusive report
- Hypothesis initially made too narrow with the 'linear' component limiting the scientific process

### Conclusion:

In conclusion, the findings of this research determined that there is a clear negative correlation between the concentration of a solution of ADO and the maximum height of capillary rise, reinforced with a Pearson's correlation coefficient. However, there are two possible trendlines of that relationship that both can't be disproven with the current data. With the current data there is enough information to claim that there could be a significant negative linear correlation between the independent and dependent variable or a significant inverse proportional relationship. This indicates that the sample size is not large enough to cover the whole range of the graph and should be extended to include smaller concentrations than 0.125M. A good starting point would be to use smaller increments in these areas that are more impactful than 0.375M – 1.250M.

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# Physics

Physics is perhaps the most fundamental of all the scientific disciplines, seeking to explain the physical behaviour of matter and the universe.

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All of our Science Extension researchers have enjoyed the process of learning and understanding the history of the great traditions of Science, and through that, some of the greatest scientific discoveries and how they came to be made. Alex used an engineering approach to consider the effect of ducting on propellers and used his technical skills to 3D print a ducted propeller to test his model. Akilan proposed an interesting mathematical approach to determine the randomness of cards through different techniques. Nick's project explored the motivation of students in the secondary Physics classroom in an enlightening project that paves the way for future students to develop his findings. Duncan's curiosity about frisbee ricochets intrigued us all. He developed a method to record, calculate and test his hypothesis about the equality of initial and resultant angles.

The Physics projects for our inaugural 2019 Science Extension cohort are extraordinary in their creative approaches to real world problems. We commend these projects to you.





# The efficiency of ducted propellers

Alexander Marlin

Barker College

To determine how the introduction of a duct influences the efficiency of a drone propeller, 3D models were designed and tested, both computationally and practically. Computational results revealed that the ducted propeller has a significantly greater flux ratio (the chosen measure of efficiency) than the non-ducted propeller ( $t=4.877$ ,  $p=0.0003$ ). Computationally generated velocity heat maps showed clear evidence of the elimination of wingtip vortices, proving the efficacy of the duct. Finally, the practical test of the 3D printed duct was consistent with the computational results, at least for rotational speeds under approximately 9500 RPM. A drone with a ducted propeller will operate with a greater efficiency, allowing for a longer flight time as well as lowering the rotational speed required for lift thus reducing noise.

## Literature review

### *Theoretical Principles:*

Propeller mechanics is inherently linked to fluid dynamics, the study of the motion and flow of fluids. Although it could be assumed that fluids only refer to the liquid state of matter, in fact fluids also include the gaseous state. Thus, the motion of air in the atmosphere can be explained using fluid dynamics. The study of fluid dynamics is regularly used in the fields of car and ship design, aircraft efficiency and in the study of propellers (Blazek 2015).

All the equations and laws of fluid dynamics are derived from the laws of conservation of energy (Blazek 2015). A fundamental principle of fluid dynamics is the Venturi effect which states that as a fluid flows through a constrained section of a pipe (tighter) the fluid's pressure will decrease (Kalsi & Balani 2016). Another fundamental principle in fluid dynamics is Bernoulli's principle which is that "an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy" (Clancy 2006, p97). This means that as a fluid's velocity increases it will have a relative decrease in pressure. This is important to propellers as blades are not flat and of constant thickness, but are designed in a similar manner to aircraft wings which utilise these fluid dynamics principles.

Fluid flows can be generally categorised as either laminar or turbulent. Laminar flow is defined as when the fluid particles move in smooth paths, with a uniform velocity and there are no cross-currents or eddies

(swirls) of fluids (Christie, John & Geankoplis 2003). Turbulent flow is much less uniform (Christie, John & Geankoplis 2003). A propeller with a more laminar flow will produce less eddies, and as a result less drag, than a propeller with a more turbulent flow.

### *Propeller Theory:*

A propeller is essentially a rotating wing, where the wing's lift is applied as thrust (Sforza 2017). A wing generates its lift as a consequence of Newton's 3rd Law and Bernoulli's principle. Due to the curved shape of the top of a wing, the air moving across the top will move at a greater velocity and thus have a lower pressure than the air moving below the wing (Deshpande & Sivapragasam 2017). The relative high pressure on the bottom of the wing will push towards the low pressure above the wing, thus generating an upwards force known as lift (Deshpande & Sivapragasam 2017). This phenomenon also applies to the rotating blades of propellers. The propeller's diameter, pitch, rake angle and angle of attack are all factors that will influence the lift and thrust created (Santhosh & Padmanabhan 2017).

When the high and low-pressure air flows off the end of the propeller (due to Newton's 1<sup>st</sup> Law), the air combines and creates a turbulent flow in the form of a vortex, known as a wingtip vortex (Clancy 2006). Wingtip vortices subsequently create a drag on the propeller (Wald 2017). Due to the conservation of energy, it can be assumed that when drag is created by a propeller, energy is being allocated away from thrust, reducing efficiency.

*Duct Theory:*

Wing designers combat the formation of wingtip vortices with what is known as passive flow control. This involves geometric modifications to an aerofoil to influence flow (Findanis 2017). Winglets (such as a flick or endplate) on the end of a wing, influence the flow of air off the end of a wing by creating a laminar flow between the high and low-pressure air. This result is a "significant improvement in aerodynamic efficiency" and reduces induced drag and downwash (Findanis 2017, p583).

Applying the design principles of a wing to a propeller are key to improving efficiency (Sforza 2017). A duct, similar to a winglet, works by significantly limiting the ability for high and low-pressure air to combine at the end of the propeller. By placing a barrier at the end of the propeller blade and providing that the blade tips are as close as possible to the inside of the duct, tip losses may be reduced (Sforza 2017). Furthermore, if the leading edge (front edge) of the duct is curved to direct flow into the propeller, the Venturi effect will cause the fluid's pressure to decrease and because of Bernoulli's principle the fluid velocity will increase. As a result, more thrust will be generated, particularly at lower rotational speeds (Sforza 2017).

In marine applications, it has been found that when compared to an open/non-ducted propeller, a ducted propeller "performs a more laminar flow" in open water conditions (Santhosh & Padmanabhan 2017, p4996). Thus, the ducted propeller provides a greater thrust at a lower rotational speed than the non-ducted propeller (Santhosh & Padmanabhan 2017).

*Computational Data Collection:*

Due to the nature of conservation laws, the easiest way to mathematically calculate and model the behavior of a fluid, is to split fluid up into a number of volumes and model these as a series of finite regions (Blazek 2015). This method of calculation is based on Newton's calculus principles and is the way computational software is able to determine the behavior of a fluid within a simulated environment.

When setting up the simulation it is imperative that the initial conditions (air velocity, temperature, compressible/incompressible flow) are as close to the real conditions the propeller will operate in, in order to receive an accurate result (Blazek 2015).

The amount of fluid that crosses a certain boundary is known as *flux* (Blazek 2015). The flux in and out of the simulation region can be calculated within the software.

To provide an accurate determination of efficiency the flux ratio can be calculated (Flux Out/In). If the flux ratio of a region is 1, it is perfectly efficient.

**Scientific research question**

How does the introduction of a duct influence the efficiency of a drone propeller?

**Scientific hypothesis**

That a ducted propeller will be more efficient than a non-ducted propeller as measured by producing a greater flux ratio.

**Methodology**

*Preliminary:*

The propeller and duct were designed in the CAD (Computer Aided Design) program Fusion 360, which is made by Autodesk. The outline of the propeller shape is drawn in the xy plane and then 'extruded'. The extrusion is then manipulated in the 'patch' section of the program to create the 3D shape of the propeller. The duct was created by drawing a cross section of the duct and using the revolve tool to create the 3D shape. Figures 1 and 2 show the two products, a ducted and a non-ducted (but otherwise identical) propeller.

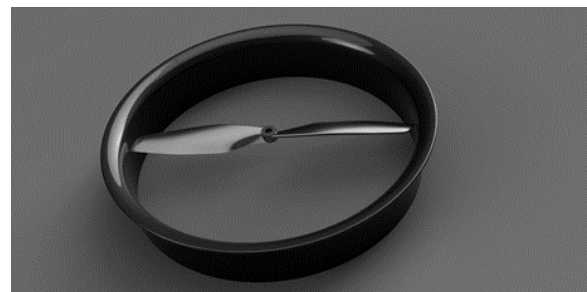


Figure 1: Propeller with Duct

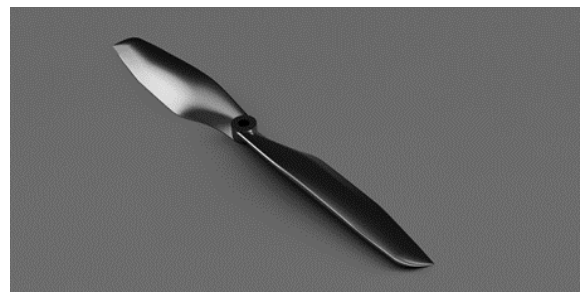


Figure 2: Propeller without duct

*Part 1: Computational quantitative determination of flux ratio*

In the first part of the experiment, results were found using Computational Fluid Dynamics (CFD) software, made by Autodesk. The propeller and duct that were designed in CAD (Computer Aided Design) were

imported into the software as a 3D geometry file. The boundary conditions were set so that the initial fluid velocity was 10m/s, the flow was compressible, and the temperature was 20°C. The experimental parameters were set so that the software would record the *flux* in and out of the boundary region as well as recording the maximum fluid velocity during the simulation. These parameters were recorded at 3000, 4000, 5000, 6000 & 7000 RPM for both the ducted and non-ducted propeller. There was no need for multiple recordings to be taken of the same RPM as the software produces identical results when the conditions and parameters are the same. With the computational data collected, the flux ratio was calculated (out/in) and a graph was produced, and a t-test was performed.

*Part 2: Computational qualitative determination of fluid velocity*

In the second part of the experiment, the fluid velocity of the ducted and non-ducted propeller was visually compared using the CFD software. An inspection plane was setup in the software so the fluid velocity would show up as a heat map. The visual comparison between the ducted and non-ducted propeller was used to explain the data collected in Part 1 and to predict the results that would be collected in Part 3.

*Part 3: Practical quantitative determination of fluid velocity using 3D printed models*

In the final part of the experiment, the computational results collected in Parts 1 and 2 were validated in real life. The propeller and duct were 3D printed using the same files that were used during the CFD simulations using a maker bot Replicator 2. The propeller was attached to a dremel and the dremel was mounted on a retort stand (Figure 3). The duct was also positioned in a retort stand so that the propeller (now attached to the dremel) was 2cm from the front of the duct. The speed of the propeller was set using the speed control on the dremel and an optical tachometer was used to record the RPM. Due to the difficult nature of recording flux, the physical experiment was modified to only measure the fluid velocity. Though a different variable was recorded, the relationship between the two sets of data should remain the same. The air velocity was recorded 2, 4 & 6cm behind the duct with an anemometer. The rotational speed of the propeller increased by approximately 500 RPM every recording via the free moving speed controller on the dremel. The air velocity was subsequently recorded again, a total of 10 times. Once all the data was collected with the duct attached, the duct was removed and all the data collecting steps were repeated.

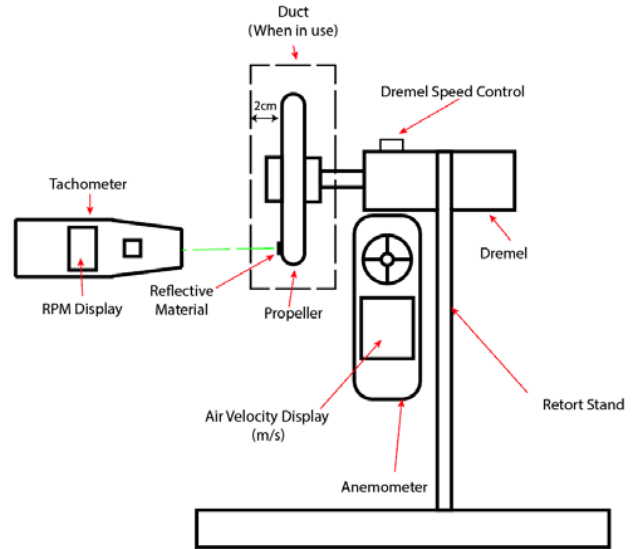


Figure 3: Scientific diagram of equipment set-up

**Results**

*Part 1: Computational quantitative determination of flux ratio*

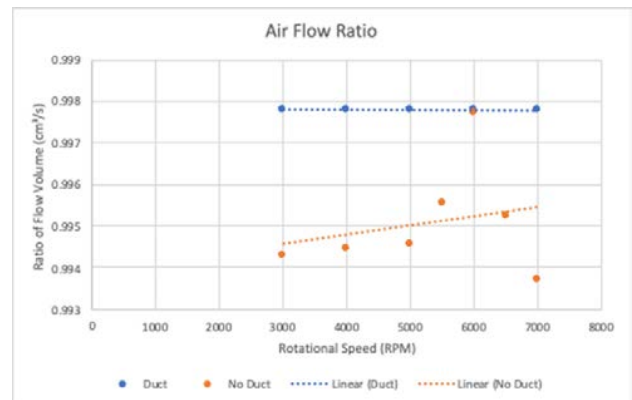


Figure 4: Computational results were collected in Autodesk CFD, recording volume of flow in and out of the selected region at a specific rotational speed.

*Statistical Analysis:*

Ducted propeller Airflow Ratio ( $\mu_1$ )

- Mean = 0.99778666
- Standard Deviation =  $8.45639 \times 10^{-6}$

Non-ducted propeller Airflow Ratio ( $\mu_2$ )

- Mean = 0.995077954
- Standard Deviation =  $1.224493 \times 10^{-3}$

Completing a t-test:

$H_0$ = The ducted propeller has less than or equal flux ratio than the non-ducted propeller ( $\mu_1 \leq \mu_2$ )  
 $H_1$ = The ducted propeller has a greater flux ratio than the non-ducted propeller ( $\mu_1 > \mu_2$ )

The value  $\alpha=0.01$  was chosen as it reduces the risk of a false positive by establishing a higher threshold over the commonly used value 0.05.

Since  $t(4.877) > t_c(2.764)$  and  $p=0.0003 < 0.01$  the Null Hypothesis is rejected, and we can accept that  $\mu_1 > \mu_2$  at the 0.01 significance level. Therefore, based on the computational results we can confirm that a ducted propeller is significantly more efficient than a non-ducted propeller ( $t=4.877$ ,  $p=0.0003$ ).

At 6000 RPM there is an unexpected increase in the air flow ratio for the non-ducted propeller (clearly seen in Figure 4). To ensure that this was not an error related to inputs, the simulation was repeated for smaller RPM intervals (5500 RPM and 6500 RPM) on either side of the anomalous value. This was able to validate the accuracy of the spike. It is likely that the design the propeller was modelled off was engineered to operate at 6000 RPM, where it would be at its most efficient. At this particular RPM it makes no difference whether or not there is a duct. It is clear that the duct shows a higher efficiency for varying RPM.

*Part 2: Computational qualitative determination of fluid velocity*

Velocity heat maps (Figure 5) are visualisations of the characteristics of the flow over a 2D surface which, as the propellers are rotationally symmetrical, can be extrapolated to 3D space. Looking at these two velocity heat maps (both at 5000RPM) a clear difference in the fluid flow can be seen. In particular, the wingtip vortices can be faintly seen coming off the end of the propeller without the duct (circled). Comparing this with the ducted propeller heat map, no vortices appear in the area behind the duct, demonstrating that the duct is effective in deterring wingtip vortices. From the background research, this may be a key reason for the increase in efficiency as measured by the flux ratio (Santhosh & Padmanabhan 2017).

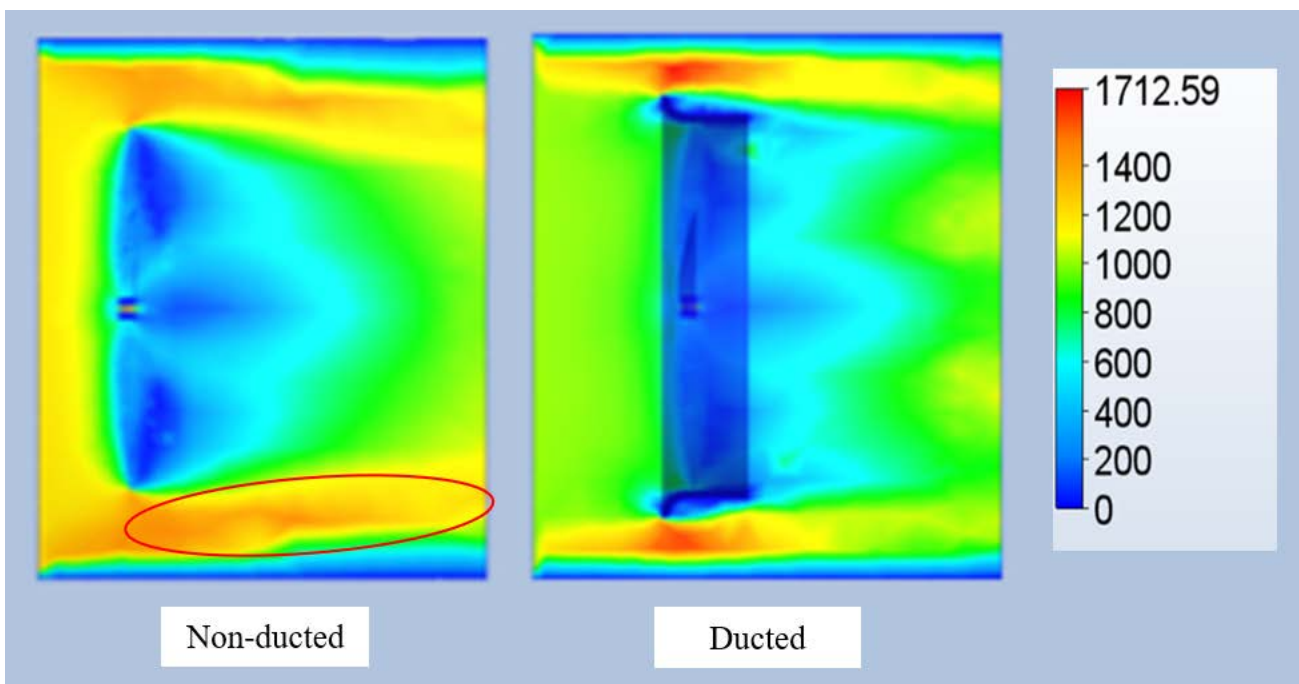


Figure 5: Fluid (Air) Velocity Heat Map of propeller without a duct

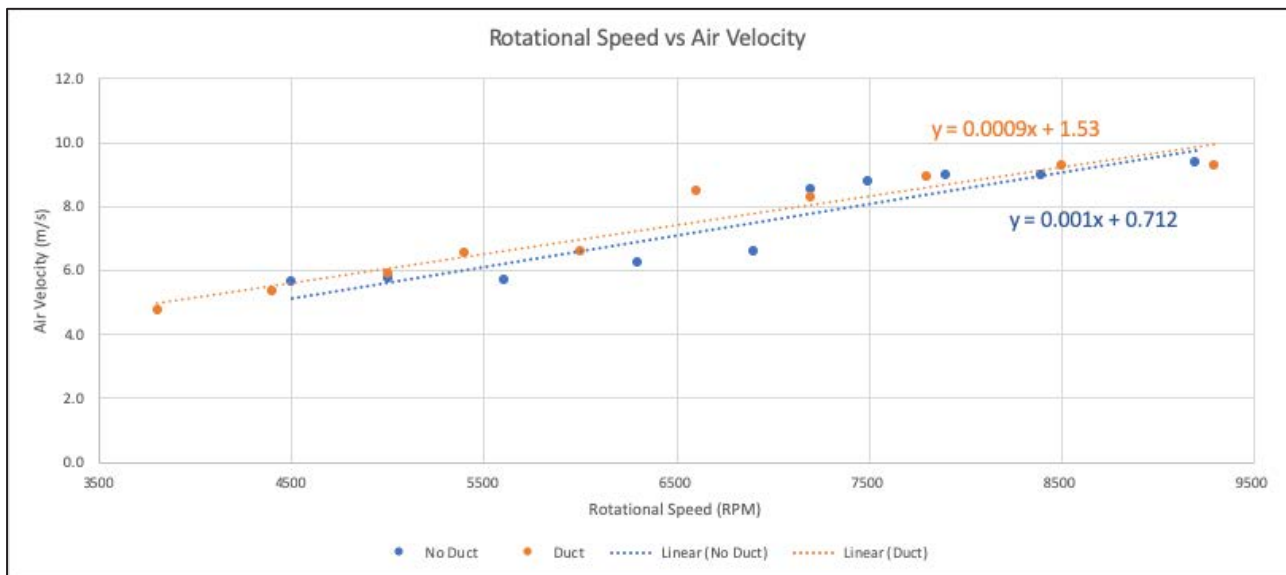


Figure 6: Air velocity vs rotational speed for 3D printed ducted and non-ducted propellers.

### Part 3: Practical quantitative determination of fluid velocity using 3D printed models

The air velocity results recorded in the graph for Part 3 (Figure 6) are averages of the air velocities recorded at 2, 4 & 6cm behind the duct (Appendix A). Since the ducted and non-ducted propellers produce a different air flow (different velocities in different places), an average ensures consistency across the two tests. At lower RPMs there is a greater fluid velocity produced on the ducted propeller (suggesting a higher flux ratio and therefore higher efficiency) however, by extrapolating the lines of best fit, at around 9500RPM the lines of best fit will cross over and the non-ducted propeller will produce a greater fluid velocity (suggesting higher efficiency). Though the literature is ambiguous on the efficiency at higher RPM's, it is clear that the ducted propeller should be more efficient, particularly at lower RPM's (Sforza 2017). This is consistent with the experimental findings in Figure 6.

### Discussion

Part 1 of the experiment found that the ducted propeller produced a significantly greater flux ratio than the non-ducted propeller. This demonstrated that the ducted propeller has a greater efficiency than the non-ducted propeller, confirming the hypothesis which was consistent with the findings of the literature review. It is proposed that the reason for this was because the introduction of the passive flow device (the duct) reduces tip losses and thus increases the efficiency of the propeller (Sforza 2017). As discussed, there is large spike in the flux ratio of the non-ducted propeller at 6000 RPM. This could be fully explained if the propeller the design was modelled off was built to perform with its optimum efficiency at 6000 RPM. However, this still

does not explain why the ducted propeller did not also have an increase in efficiency at 6000RPM as the propellers from both simulations are both identical. Further research into the phenomenon is required.

As predicted from the results of Part 1, the images of Part 2 (Figure 5) demonstrated how wingtip vortices can be clearly seen on the non-ducted propeller (Clancy 2006), whilst the ducted propeller shows no obvious wingtip vortices. Substantial turbulence can be seen on the leading outermost edge of the duct. This is likely due to poor duct design, but it was unlikely to have any effect on the variables being tested. For commercial applications this problem could be solved by increasing the length of the duct's edge allowing the air to have a more laminar flow off the edge of the duct. This solution could then be retested computationally (in CFD) and practically.

Part 3's practical experiment showed that up until a point, the ducted propeller produced a greater fluid velocity than the non-ducted propeller and thus was more efficient. This result is consistent with literature findings that a ducted propeller should produce more thrust than a non-ducted propeller, particularly at lower rotational speeds (Sforza 2017; Santhosh & Padmanabhan 2017). The results from Part 3 possess a degree of uncertainty due to the difficult nature of recording air velocity in 3D space, though they served their purpose of validating the findings of Parts 1 and 2.

This experiment is successful in proving the accuracy of the theoretical (Computational) concepts and practical applications of propeller theory. Therefore, this result is relevant for various future commercial applications of ducted propellers. Drones have low speed motors and

rarely fly for more than 20 minutes on a single charge. Thus a ducted propeller that is able to increase the efficiency of such a drone could increase flight time, reduce the size of motors needed (hence reducing weight and decreasing charge time), as well as reducing the rotational speed needed to produce the same amount of thrust, therefore allowing for quieter drones.

There is room for further study and improvement in a number of aspects of the research. In Part 1 of the research there is a very small chance of a type I error in the statistical analysis. A wider set of data points may be taken to further increase the reliability of the data, however as the p value is already incredibly low (0.0003), the likelihood of a false positive is incredibly small. The equipment design could be made more reliable by use of a wind tunnel with highly accurate anemometers. This would increase the accuracy of the results and make them more comparable to the conditions experienced by a duct on a drone.

Further testing could be conducted to determine the cause of the spike in efficiency of the non-ducted propeller, particularly because the ducted propeller did not also have the same spike. Furthermore, it would be interesting to design and test other passive flow control devices that would eliminate tip vortices and to compare them against the efficiency of a duct.

## Conclusion

The results were consistent with existing research and between the computational and practical aspects of the experiment. The null hypothesis was rejected, accepting the alternate hypothesis, that the ducted propeller has a greater flux ratio than the non-ducted propeller ( $t=4.877$ ,  $p= 0.0003$ ) and therefore is more efficient. This efficiency result was further explored and verified

through the velocity heat map and the practical test using the 3D printed propellers.

## Acknowledgments

I wish to thank Dr Hill for assisting me with developing the experiment and reviewing various iterations of the report. I wish to thank my Mum and Dad for assisting me with data collection. Finally, I wish to thank Dr Gates for proof reading my research report.

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# The casino's gambit: The randomness of three different manual shuffling practices

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This research tests how effective three different card shuffling techniques are at randomizing a deck of cards. In order to achieve this one must be able to have a scalar value of randomness as well as precisely define randomness. Seven participants used a set of 26 cards with no duplicates to shuffle and record the Overhand [OS], Riffle [RS] and Smooshing shuffle [SS] for fifteen seconds each and an equal amount of times for each shuffle. By creating a frequency of occurrence vs card position change, a completely random shuffle would start to converge on a histogram with a straight line at three occurrences (as there would be an equal chance for the card to end up in all 26 positions) for each final position. The actual histogram was compared to the theoretical situation of each card position moving to all different card position three times. The difference in means of the sum of error from three suggested Overhand was the most effective shuffle followed by Smooshing and Riffle shuffle. A one-way ANOVA test revealed that there was no significant difference between the mean randomness value of any of the three shuffles ( $f=1.367$ ,  $p=0.201$ ). Casinos can use the method from this study to give a more practical means of testing how effective their current shuffling technique is in randomizing a deck of cards.

## Literature review

For casinos, being able to effectively randomise a deck of cards is the difference between immense prosperity or bankruptcy. People like Edward Thorpe or the infamous MIT Blackjack team were able to capitalise on a casino's inability to effectively randomize cards to make obscene profits of close to one million dollars in a single weekend in games like blackjack and baccarat (Kendal and Smith 2003). To some extent, these concerns can be mitigated using automatic shuffling devices (Diaconis et al. 2013; Armstrong et al. 2016), however these can be expensive and are not mandatory nor used in all casinos.

The experiment detailed in this report tests how effective 3 different card shuffling techniques. The three techniques are showed in figure one and explained in figure two. In order to achieve this one must be able to have a scalar value of randomness as well as precisely define randomness. In the case of this experiment, complete randomness within a shuffle would mean all variations in the change of the order of the deck of cards are equally likely. No randomness would mean that the change of the order of the deck of cards is completely predictable.

According to existing literature, the three most common shuffling techniques would have different effectiveness in randomising the deck. The most random would be the Smooshing shuffle followed by the overhand then the riffle shuffle. By mathematical definition the riffle shuffle only requires 7 moves to randomize a deck of cards, whereas the overhand shuffle requires 10,000 moves explained in the research paper "*shuffling cards and stopping times*" by Perci Diaconis. However, when asking a human to complete the riffle shuffle, the results would narrow compared to the broad spectrum of what classifies as a riffle shuffle. In other words, humans are not very random at completing a riffle shuffle. This leads to the hypothesis that the overhand shuffle is more effective than the riffle shuffle in the 15 seconds the participant must shuffle.



Figure 1: The Three shuffling methods (Griffiths, S. (2019). The best way to shuffle cards revealed. [online] Mail Online. Available at: <https://www.dailymail.co.uk/sciencetech/article-3011046/How-shuffle-cards-like-pro-Mathematician-shows-riffle-technique-effective-flashy-overhand.html> [Accessed 22 Aug. 2019].)

**CARD SHUFFLING METHODS EXPLAINED**

**RIFFLE METHOD**

**Technique:** Cutting a pack of cards in half and quickly shuffling them into each other.

**Efficiency:** A dealer needs to repeat the process seven times to randomise the pack and this can be done in less than 30 seconds.

**OVERHAND METHOD**

**Technique:** Quickly inserting chunks of cards from one hand into the majority of the deck of cards held in the other.

**Efficiency:** A dealer needs to do this 10,000 times to achieve similar results.

**SMOOSHING METHOD**

**Technique:** Randomly laying the cards face down on a table and messing them up with the hands over and over again.

**Efficiency:** One minute of smooshing guarantees a random pack of cards.

**SIMPLE METHOD**

**What:** Taking one card from the top of a deck and inserting it at random.

**Efficiency:** It takes 200 or so 'pokes' to randomise a deck, making progress slow.

Figure 2: Shuffling methods (Griffiths, S. (2019). The best way to shuffle cards revealed. [online] Mail Online. Available at: <https://www.dailymail.co.uk/sciencetech/article-3011046/How-shuffle-cards-like-pro-Mathematician-shows-riffle-technique-effective-flashy-overhand.html> [Accessed 22 Aug. 2019].)

**Scientific research question**

Which manual shuffling technique out of the three shuffles: overhand, riffle and smooshing shuffle results in the greatest randomization of the card deck?

**Scientific hypothesis**

Null hypothesis: that there is no difference in the effectiveness of randomising the deck for each shuffling technique

Alternative hypothesis: the smooshing shuffle will be the most effective at randomising the cards followed by the overhand then the riffle shuffle.

**Methodology**

Each participant (shuffler) gave full consent to shuffle and for their results to be recorded. No force was used or threatened to encourage the participant to shuffle a deck of cards and record it. As a part of the research process the project proposal outlining consent and the

method for dealing with participant data was sent to the Director of Research at Barker College, Dr Matthew Hill.

Seven participants used a set of 26 cards with no duplicates to shuffle and record the Overhand [OS], Riffle [RS] and Smooshing shuffle [SS] for fifteen seconds each and an equal amount of times for each shuffle, until a total of 78 card shuffles were completed. The raw data consisted of lists of cards in the order that they lay before and after shuffling.

After each shuffle, the numerical position of the card that was previously first in the deck was recorded. For each type of shuffle, this resulted in 78 different numbers, which could be distributed anywhere from 1-26, which showed the numerical position of the card that was first before each shuffling event.

In theory, if a shuffle is truly random, there is an equal percentage chance that the first card will end up in any of the 26 positions. Therefore, for the 78 different final positions of the first card, on average we might expect that each position occurred 3 times after shuffling (as it is just as likely to be first, as it is ninth or 26<sup>th</sup> for example).

Therefore, the frequency of the first card being found in each position was recorded, and a histogram was produced (for each type of shuffle).

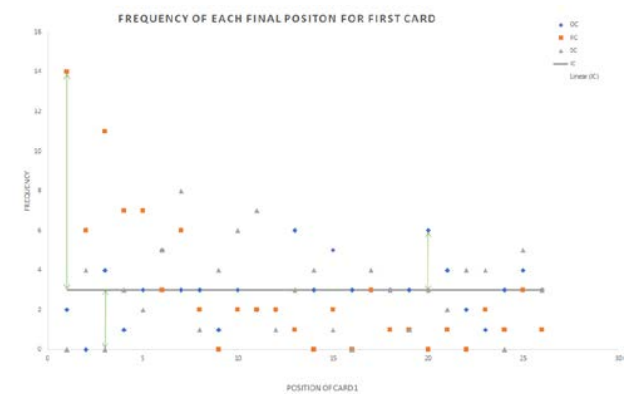


Figure 3: Histogram for 1<sup>st</sup> card for each type of shuffle. The data set that is best represented by a straight line at a constant frequency of 3 can be considered the most random shuffling method for distributing the first card in the deck. This can then be repeated for all 26 cards.

As a random shuffle would start to converge on a histogram with a straight line at 3 occurrences for each final position, the actual histogram can be compared to this theoretical situation. This can be quantified by finding the absolute error (difference between actual frequency compared to ideal frequency of 3). Adding



these over the 26 data points representing each position gives a number, where the lower the number indicates the better fit to the model of 3 occurrences per position.

For the case of the cards that were originally in position 1, the sum of the difference in each of the points from the model of 3 per position for the overhand, riffle and smooshing was respectively 26,66,44.

This process was repeated for cards initially in each other position 2-26, and the results are in the table below.

**Results**

In order to compare the randomness of each type of shuffle, the following analysis methodology is proposed.

If all cards are shuffled and many change places, except the first card remains the first card consistently then this shuffle has a low level of effectiveness of randomising the first card. Ideally there should be an even chance that the first card could end up in any of the 26 position. Therefore, one can give a score for a type of shuffle's ability to randomise each card individually. These scores can then be combined to give an overall measure of randomness.

For example, take the first initial card position for the overhand shuffle as having a degree of randomness value of 26. This value came about by first taking the change in position of the first card:

Table 1: final position of the first card after 15 seconds of shuffling

14	15	5	20	22	20	15	13	7
3	16	19	19	5	12	25	14	26
21	17	5	14	6	10	15	23	20
1	3	24	21	16	22	18	18	13
8	19	20	25	16	1	15	12	17
7	20	10	18	8	6	15	25	6
11	3	3	20	13	8	6	4	21
17	11	24	7	6	13	9	24	13
13	10	26	25	26	21			

What these numbers represent is the new position of the card that was initially in the 1st position. For example, 14 would mean the card in the 1st position just before the overhand shuffle moved to the 14th position. The new card in the 1st position will now be considered the

1st card in the next shuffle. The order of these numbers does not matter. Notice how the numbers range from 1-26, this is because there were 26 cards in the deck used to shuffle. Therefore, there are 26 new possible positions for the cards.

The frequency of how often the 1st card moved to each card position was then recorded as follows:

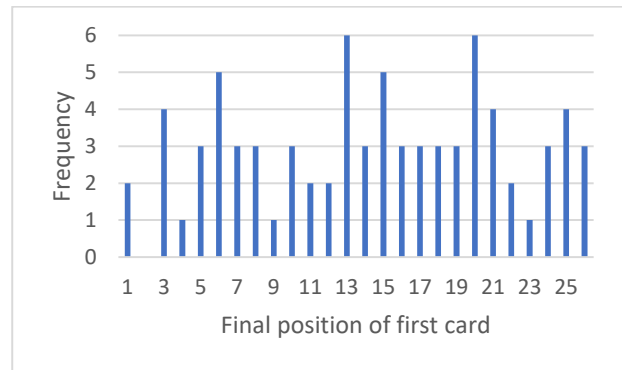


Figure 4: frequency of the position changes

For example, the first card remained in the first position twice, but moved to position 13 six times.

78 card shuffles were recorded for each shuffling method. Recall that there are 26 card positions that the first card (as well as the other 25 cards) can move to. For a perfectly random card shuffle, the first card (as well as the other 25 cards) would have an equal chance of moving to all 26 positions. Therefore, if the card shuffle was purely random, we would expect the first card (as well as the other 25 cards) to move to all the 26 positions three times (78 divided by 26). Therefore, theoretically the further the frequency is from three the less random our shuffles were. This magnitude of these differences can be added to produce a total value of randomness for that card position (the lower the value the more random and the larger the value the less random).

This process is then repeated with each individual card position and the average found to give a degree of randomness for the particular type of shuffle.

To further prove the effectiveness of this method, below is displayed the most and least random card position and shuffling technique and their randomness value.

Figure 5 shows the least random result (for an individual position) with a randomness value of 66.

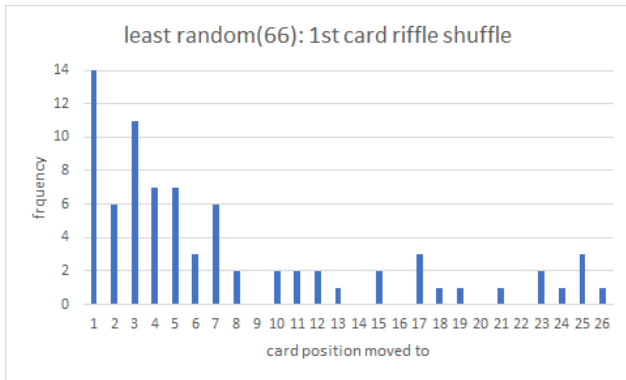


Figure 5: least random, 1<sup>st</sup> card riffle shuffle

Figure 6, shown below, is the most random result with a randomness value of 22.

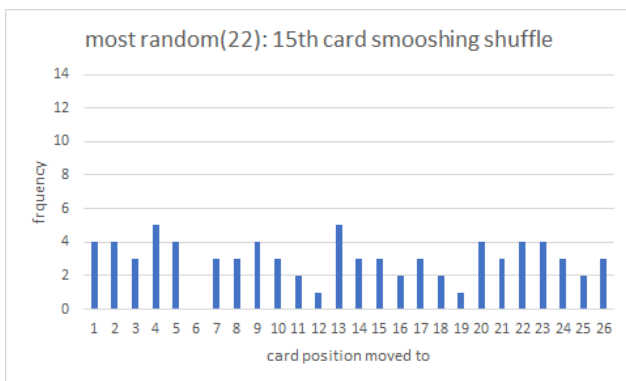


Figure 6: most random 15<sup>th</sup> card smooshing shuffle

The full data can be seen in Table 2 at the bottom of the page, this can be read in conjunction with visual representation of Figure 3 earlier in the paper. In order to test the statistical significance of the results an ANOVA test was completed standard  $p=0.05$  was used. The ANOVA reveals that there was no significant difference between the mean randomness value of any of the three shuffles ( $f=1.367, p=0.201$ ).

Therefore, the null hypothesis that the means are the same cannot be rejected.

### Discussion

These results indicate that the overhand shuffle was marginally better at randomizing the deck of cards when compared with the smooshing shuffle (the shuffle that was hypothesised to be better). As expected, the riffle shuffle was the least effective. This could be explained

by the fact that most participants would smooch shuffle cards using insufficient surface area. For the cards to move in position, the cards need to have enough space in order to separate so that they can clutter back together into a different position. The overhand shuffle however does not need a surface with large enough area as it can be done in the participant's hands. The riffle shuffle was expected to be least effective as most participants would riffle shuffle in a very similar way; i.e. split the cards roughly evenly and interweave the two parts with noticeable clumps. This meant that the cards on the top and bottom were less likely to move positions. These results do not confirm any hypothesis as a one-way ANOVA test indicated that the data collected was not statistically significant ( $P=0.201$ ).

Issues facing the experiment included the varying skill of the participants. This most, significantly impacted the results of the riffle shuffle due to it requiring the highest skill of the three shuffles to complete. As well as the varying surface area used in completing the smooshing shuffle which requires the most surface area of the three shuffles to be completed as previously explained. All participants faced no issue with the overhand shuffle method unlike the other two shuffling methods.

Probability testing of card shuffles can be furthered by changing the time interval which may change the ranking of the effectiveness of the card shuffles. Further experimenting can be done on the smooshing shuffle to see how surface area impacts the effectiveness of the smooshing shuffle.

Casinos currently use mathematical definitions and computer simulations to test the randomness of their card shuffling method, which the data indicates may not be practical possibly due to human card shuffling being often different to a computer. Casinos can follow the method of this study, using their dealers as participants, to detect whether there are any patterns in the change of order of their current card shuffling method that could be exploited to give the punters better odds of profiting.

### Conclusion

The aim of the experiment was to determine which of the three popular shuffling techniques would be most effective in randomizing a deck of cards in 15 seconds.

Table 2: Shuffling method VS. Degree of randomness

		Randomness score for each starting card position for each type of shuffle																											
Initial card position		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Average	StDev
Overhand		26	40	36	30	34	30	30	44	30	30	34	30	32	30	34	38	36	34	36	36	30	40	30	28	48	38	<b>33.8</b>	<b>5.09</b>
Riffle		66	40	34	36	22	32	40	36	40	38	30	36	32	32	40	34	34	34	38	28	34	32	36	28	54	56	<b>37.0</b>	<b>9.20</b>
Smooshing		44	32	38	26	44	42	38	36	28	34	40	28	32	34	22	34	44	30	36	32	28	28	32	34	38	34	<b>34.2</b>	<b>5.79</b>

It was hypothesised that the smooshing technique would be most effective followed by, overhand and then riffle shuffle. The data suggested the overhand shuffle was most effective followed by smooshing and riffle shuffle. However, the data was statistically insignificant with  $p=0.05$ . Therefore, we rejected the null hypothesis and the alternate hypothesis.

### Acknowledgements

I'd like to thank my mother for teaching how to use excel as well as the participants that shuffled the cards for me providing me data. I'd like to thank Dr Hill for showing me how to use a histogram to give a quantitative value to the randomness of card shuffle, as well as greatly helping me develop the methodology. and Dr Terrett and Dr Gates for proof reading and correcting my report.

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# Motivation style and the academic performance of Physics students

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This research aims to investigate the motivational styles of physics students and how it affects their performance in their physics course. Surveying 40 physics students to identify their motivational profile based on four areas (Curiosity, Conscientiousness, Sociability, Achievement) and their course rank, it was found that there was no correlation between performance (as measured by their course rank) and motivational style. It was also found that the number of sociable students was significantly greater than any other type ( $F=86.64$ ,  $p=0.000001$ ). It is theorised that the lack in relationship between correlation and performance comes as a result of students prioritising social affiliation over the need for academic performance.

## Literature review

Recent scientific efforts have investigated the factors that influence student's scientific academic results. While studies have investigated demographical factors, especially gender (Witkin & Goodenough 1977; Kelly 1988; Karaçam 2015) on performance, research focus has also highlighted cognitive influences on academic achievement. Cognitive factors include cognitive styles (Gardner & Hatch 1989; Armstrong 2000; Bahar & Hansell 2000), which relate to the way an individual thinks and perceives; for example Field Dependence/Interdependence (Witkin et al 1977) which regards whether an individual perceives and thinks based on their surroundings (field dependent), or think independently of their surroundings (field independent). Learning styles (Biggs 1987; Kolb 2011; Koçakoğlu 2010), are another cognitive factor and include the way students learn. Kolb (2011) draws upon experiential learning theory to outline a framework for the different ways students learn from experience, this concept is drawn from the idea knowledge is derived from experience. Another cognitive factor on student learning would include motivational styles; particular attention has been given to these motivational styles (Maslow 1943; Bahar 2002; Adar 1969; McClelland 1984; Ryan et al 2000; Karaçam 2015).

Several theories exist to describe the nature of motivation, however a common thread throughout all of them is that motivation exists to satisfy some needs. This includes Maslow (1943) who theories motivation as a hierarchy of needs; including the needs for basic

survival and extending to the needs for self fulfilment (see Figure 1). For example; when we are hungry, we are motivated by a need to eat, once we satisfy our basic needs, we then also desire to accomplish and fulfil ourselves, hence are motivated to do so.

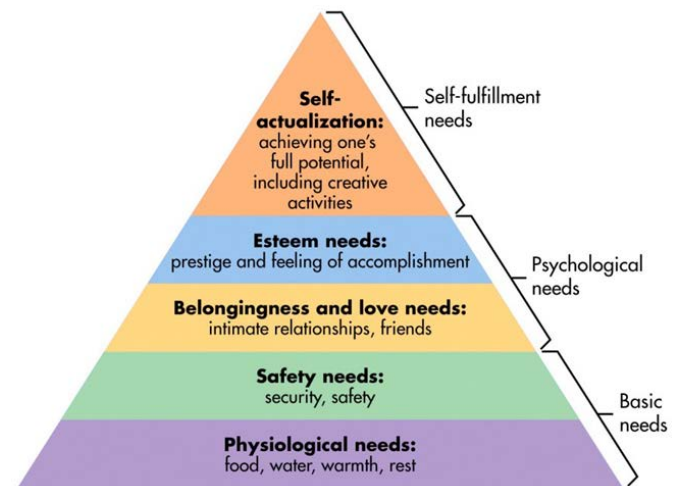


Figure 1 - Visualisation of Maslow's hierarchy of needs (Source: McLeod, 2018)

When considering motivation specific to education; Maslow's pyramid can be applied, however other frameworks and theories set this out in greater detail, such as McClelland (1984), who broadly theorised motivation to be the need to satisfy one's desire for achievement. As "Achievers like situations in which they take personal responsibility for finding solutions to problems" (McClelland 1984, p. 3) in order to fulfil their self esteem. Achievers are motivated through the affirmation and esteem gained from their achievement.

This is similar to the needs for esteem and self-fulfillment present in Maslow's framework.

Ryan and Deci (2000) would separate achievers into intrinsically and extrinsically motivated students. Intrinsic motivation would refer to the need for completing tasks to extend one's individual capacities and overall to benefit one's self. Non-intrinsic motivation or extrinsic motivation concerns acting in need to please something external to one's self. As an example; intrinsic motivation would include completing study and work out of enjoyment and interest, as opposed to completing it to avoid punishment or to achieve a higher mark in an external test, which would be extrinsic.

Another theory set out by Adar (1969), groups students into having four distinct motivational styles; Curiosity, Conscientiousness, Sociability and Achievement. Each of these styles satisfies a student's need for something. Curious students are defined to be motivated by the need to satisfy their personal interest in their work, Conscientious students are motivated by the need to discharge a duty, Achiever students are defined by being motivated through their need to achieve and Sociable students are motivated through their need for social affiliation.

Bahar (2002) found that biology students tend to be more sociable than any other motivational style.

Using this framework and Bahar's (2002) adapted questionnaire for determining motivational styles, Karaçam (2015), found that social physics students are less successful than other physics students when performing exams on direct current circuits, concluding this is probably due to exam environments being a non social environment.

Considering Adar's framework alongside Ryan and Deci's framework, one can see similarities between extrinsic students and students who are considered achiever or social students. Visualised in Figure 2, achiever and social students both strive to gain affirmation and interact with influences extrinsic to them, just like Ryan et al's Extrinsic students. Contrasting to this, conscientious and curious students both are motivated from internal influences in order to satisfy themselves, similar to Intrinsic students.

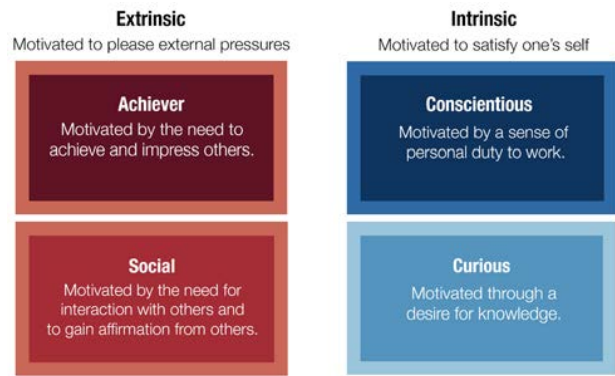


Figure 2 - A diagram comparing similarities in Adar's framework to Ryan and Deci's framework

From this; the achiever and social styles can actually be connected; bridging Adar's and Ryan et al's frameworks.

Some may argue that they are an achiever if they aim to achieve for personal gain; however these students would fit better into the conscientious category as the motivation for achievement is gained from self (Ryan et al 2000).

The instrument for measuring Adar's motivational styles used in this study, was adapted by Mr Dean Bunn, current high school teacher at Barker College in Sydney, Australia, which he based upon Bahar's (2002) questionnaire. Bahar based his questionnaire on work done by Adar's (1969) study and Hofstein and Kempa's (1985) study. It is designed to measure a student's scores in the four motivational styles (Curiosity, Conscientiousness, Sociability, Achievement) on a scale from -30 to 30. The survey has been tested and confirmed as valid.

The survey questions included Likert scale responses to agreement on a statement. Examples of questions and their corresponding motivational pattern follow (and the full survey may be found in appendix 1):

Social: "I enjoy practicals because I learn better with the help of others."

Curious: "As a child I remember always wanting to know how different things worked."

Conscientious: "When we get lots of problems to solve, I usually make sure that I complete every question thoroughly."

Achievement: "It is very important to me to get results that are better than my friends."

### Scientific research question

What are the motivational styles of physics students and how does this affect their performance in the course?

### Scientific hypothesis

The more varied the motivational style of two students, the more different their ranking in physics.

### Methodology

The year 12 physics cohort at Barker College was invited to complete the questionnaire, and also provide their ranking in the physics course from the previous year. This was done during their class time. The ranking was composite of a variety of assessments through the year. The students were informed of how to complete the questionnaire and asked not to distract or influence others during the test.

40 students completed the survey appropriately and their entries could be analysed (one student who did not include their rank was not included in analysis).

When analysing the data, the student's difference in motivational style (calculated as the Euclidean distance between each student, using their motivational style scores as coordinates on four dimensional axes. The formula is included in appendix 2 and ranking was calculated between each student and recorded. This was all done by software custom built and tested for this purpose. A download link for the software is included in appendix 3.

A Pearson correlation test was done on a plot of the difference in rank against the difference in motivational style. Similarly, a Pearson correlation test was also done on a plot of each student's corresponding rank against their unique motivational style score. An ANOVA, along with post-hoc tests were also performed on the motivational scores of the students.

The methodology of the study was conducted and created in consultation with the Director of Research in Learning, Barker College, which involved gaining ethical approval; and so risks included in collection and analysis of data have been foreseen and mitigated.

One mitigated risk was the privacy of the data being collected, as it is personal information that could be used against the participants. Firstly, the survey was optional and entirely explained to the students undertaking it. Also, data was collected anonymously to ensure confidentiality. If anyone was upset by the survey or the research, they would have access onsite to counselling at the school. As well as this, the data was not shared with anyone other than the Director of Research in Learning, Barker College.

### Results

When examining the motivational profiles of students, first it is seen that the average score for curiosity is much greater than the values for other styles, table 1 shows descriptive statistics for the motivational data of students, and it is visualised in Figure 3. Each motivational score is an integer varying between -30 and 30. A table of all the raw data can be seen in Appendix 5.

Table 1 - Descriptive statistics for each motivational style

	Mean	Standard Deviation
<b>Curiosity</b>	4.72	4.99
<b>Achievement</b>	4.84	4.37
<b>Sociable</b>	11.75	4.24
<b>Conscientious</b>	2.89	3.84

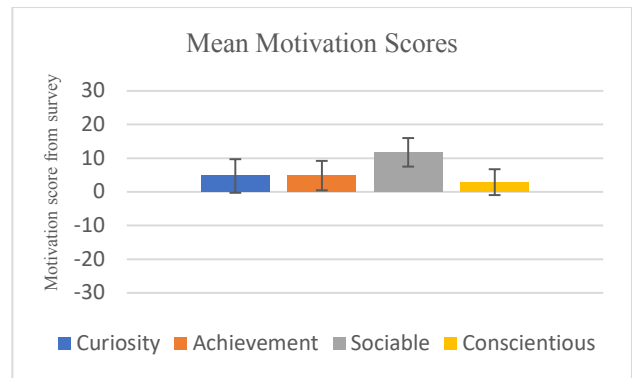


Figure 3 - A bar graph presenting the mean score for each motivational style, with bars representing the standard deviation of each mean. The vertical axis extends from -30 to 30 with higher positive values indicating a stronger association with that type of motivation.

An F-Test (or ANOVA) was performed and returned a significant result (with p value  $1 \times 10^{-16}$ , significant at  $p < 0.05$ ), F-stat = 86.6444, suggesting that one or more sample(s) are different. A post-hoc tukey test (results shown in table 2) revealed that of the four motivational styles (Curiosity [Cu], Conscientiousness [Co], Sociability [So], Achievement [Ac]), only Curiosity and Achievement were not significantly different, and that every other style was.

Table 2 - Results from post-hoc Tukey tests

treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD
Cu vs Ac	0.28	0.90	insignificant
Cu vs So	16.76	0.001	p<0.01
Cu vs Co	4.38	0.011	p<0.05
Ac vs So	16.47	0.001	p<0.01
Ac vs Co	4.66	0.005	p<0.01
So vs Co	21.13	0.001	p<0.01

When plotting rank against each motivational style, there is no significant result with  $p < 0.05$ . Each plot is shown in appendix 4.

When plotting the difference in motivational style (calculated by applying the Euclidean distance formula to student's motivational styles) against the difference in corresponding student's rank (Figure 4). Applying a Pearson correlation test gave an R-value of 0.074 suggesting there is no correlation with p value of 0.02, significant at  $p < 0.05$ .

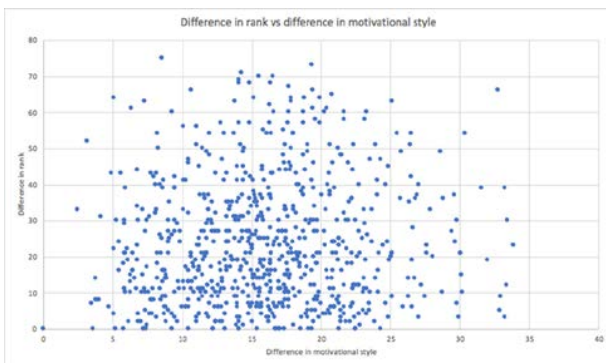


Figure 4 - Scatter plot of rank difference vs difference in motivational style between every student

## Discussion

It is visible that Barker Physics students show a more sociable motivational style, aligning with Bahar's (2002) findings that students tend to have more sociable patterns. However, unexpectedly, there is no correlation between any motivational style and performance. Furthermore, it is not seen that similarly motivated students tend to perform similarly, or vice versa (that differently motivated students are perform differently).

Examining these results in conjunction with the previously discussed motivational theories (Maslow 1943; McClelland 1984, Adar 1969; Ryans et al; 2000), the common concept throughout all of them is the idea

of satisfying a need. A simple explanation for the distinct lack of correlation between performance and motivational style could be simply that the students do not find a need for academic performance, and instead seek to satisfy their need for social interaction.

However, these findings still seem to contrast with the findings of other studies (Hofstein & Kempa 1985; Kempa & Diaz 1990; Johnstone & Al-Naeme, 1995; Bahar 2002) that stated that motivation is an important factor in student learning, however it is also important to consider that all these papers regard fields of study other than physics, such as Chemistry and Biology. This is important as subjects like Biology and Chemistry have a greater focus on conceptual, long response concepts as opposed to the numerical calculations that utilize formulas visible in physics. This is why it could be seen that in Karaçam's study (2015), which focuses on more conceptual questions that there is a significant difference in the scores of sociable students and other students.

Another important consideration would be regarding the various teachers for classes in the course. The teachers have varying levels of experience and so this would be a factor on the performance of students. As well as this, some teachers may teach with methods that appeal varyingly to different motivational profiles. This can skew results as this is spurious and not controlled.

It should also be understood that the physics ranking used in the study is the result of an entire year of assessment, which included a take home assignment, a written examination based on problem solving skills and conceptual knowledge, and several practical tests. This variety of assessment types can appeal varyingly to different motivational styles, meaning different styles perform in some areas better than others.

This result should not be entirely unexpected as no other study has been completed to suggest that motivation does actually influence the performance of physics students.

And so it can be seen that the way a student is motivated does not necessarily suggest the way that they perform; implying that this is not necessarily the most important factor in student motivation. Future study can be done to determine these other factors, perhaps investigating cognitive styles or learning styles and performance. Also, similar investigation can be done in other scientific subjects to determine if motivation correlates to performance in those fields.

Extending this; more studies similar to the one performed by Karaçam (2015) could be completed, investigating performance in specific tasks and relating



their performance in those specific tasks to their motivational style. By using a variety of questions, and focussing on more conceptual, or practical understandings of the content could reveal trends in performance of specifically motivated students according to certain styles of questions.

## Conclusion

It was found that Barker's year 12 physics cohort favours a mostly sociable student profile, aligning with the findings of previous studies on science students. It was also found that there is no significant relationship between a student's rank and motivational style, and so therefore we cannot accept our hypothesis that a more varied motivational style would result in a more varied ranking. In fact there is no found relationship between performance and motivational style.

This could be interpreted to see that students prioritise the need for social affiliation over other needs, and so therefore do not see the need for academic performance to be as important.

Further, it is suggested that further research should be done on the factors influencing student performance, as it does not appear as though motivation is an important factor. However this does not mean that motivation should be ignored as previous studies have all discussed the importance of motivation in the classroom environment (Hofstein & Kempa, 1985; Kempa & Diaz 1990; Johnstone & Al-Naeme, 1995; Bahar 2002).

## Acknowledgements

I would like to thank all the student participants, as without their honest and enthusiastic participation there would be no results. Thank you to the teachers, who were willing to sacrifice class time for students to complete the survey. Thank you to Dr Hill, who has put superhuman levels of effort into supporting us. Thank you to Mr Bunn, who provided crucial information regarding the project. Thank you to Ms Balarin, for her energy and advice throughout the study. And thank you to the rest of the Science Extension class, for their camaraderie and enthusiasm through the year.

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# The phenomenon of Frisbee ricochets

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Frisbees are a ubiquitous part of sports and entertainment culture, able to enamour many through its unique motion and capabilities that seem to defy gravity. Such extends to the phenomenon of Frisbee ricochets, whereby the throwing of a Frisbee to the floor can result in the Frisbee bouncing off the floor maintaining flight. This study compared the angle of between the floor and the Frisbee or Frisbee's trajectory before ricochet (initial angle) to the angle between the Frisbee or Frisbee's trajectory and floor after ricochet (resultant angle). Interestingly, the resultant angle of the Frisbee after it interaction with the floor, is less than the initial angle, due to the loss of velocity and spin as it hits the floor. This change affects its ability to maintain stable flight under Bernoulli's Principle of lift and gyroscopic inertia.

## Literature review

An investigation into a Frisbees flight and the dynamics of a Frisbee ricocheting off a surface, settles within the area of sports physics, mainly the field of object motion and reflection. For any sport, being able to understand and predict the outcome of objects ricocheting off a surface can be beneficial, such as predicting the placement of a tennis ball serve.

Thus, investigation into Frisbee flight dynamics has relevance in many fields, ranging from the sports-based physics concerning flying discs, and also wing structures and other fluid dynamics applications. (Lukes et al. 2014). The popularity of such sports is increasing, with Frisbee's being one of the most sold sports objects per year, highlighting the need for research.

Frisbees are able to achieve lift through their airfoil shape (Hummel 2003), utilizing Bernoulli's principle. Bernoulli's principle states that 'there is a relationship between the velocity, pressure and height of a fluid at any point on the same stream line... fluids flowing at a faster velocity have a lower pressure than fluids flowing at a slower velocity' (Morrison 2005, pp 3). The greater distance by the Frisbee's convex shape, causes the air on the top to be faster than the bottom (Baumback 2010). According to Bernoulli's Principle a pressure differential is created where the pressure on the top of the Frisbee is lower than the bottom due to difference in air velocity (See Figure 1) (Schultze 2009). This generates lift, as according to Newton's 3<sup>rd</sup> Law, the higher pressure on the bottom pushes the air downwards, pushing the Frisbee upwards (Hummel 2003). Thus, a Frisbee can overcome gravity as the lift

force generated can be greater than the weight force (Crowther & Potts 2007). However, when a Frisbee lifts, the oncoming air pushes the front of the Frisbee upwards, due to the angle of attack that the Frisbee makes with the streamline of air. This creates a torque upwards on the Frisbee and an axis of rotation across its length (Hummel 2003; Motoyama 2002). So, if a Frisbee was thrown without spin, it would flip backwards and falter. However, Frisbees are thrown with spin which resist the flipping because of gyroscopic inertia.

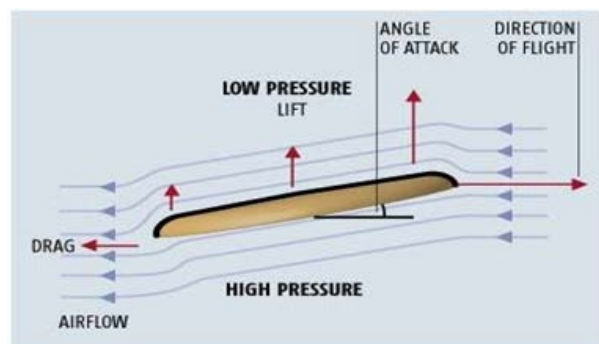


Figure 1: A diagram highlighting the difference in pressure on the Frisbee induced from Bernoulli's Principle.

Gyroscopic inertia is that an object 'rotating about its axis of symmetry tends to remain rotating about its axis of symmetry' (Motoyama 2002, pp 7). This means that the torque on the front of the Frisbee from the oncoming air is mitigated by the initial spin that is given to the Frisbee when thrown. This is due to the fact that spinning the Frisbee places its axis of rotation in center of the Frisbee, and when the torque occurs, where its axis is across the Frisbee, its angular momentum on its initial axis is greater than the torque, thus redirecting the

small torque (Morrison 2005). If spun clockwise, then the torque will be redirected to the right, the left if anticlockwise, which demonstrates why a Frisbee will veer to the right or left during its throw despite appearing to have a flat angle. Such an effect is known as the Magnus effect (Hummel 2003), which is evident in other sports involving rotating projectiles such as table tennis, where spin affects trajectory. Thus, from Gyroscopic Inertia, a Frisbee is able to maintain stability as the Frisbee resists major changes in its orientation, enabling it to sustain lift.

From understanding these principles, a theory on the phenomenon Frisbee ricochets can be made. Bernoulli's Principles suggest that a minimum initial velocity is required so that when the Frisbee ricochets off the floor, it has enough velocity to regain flight. Similarly, Gyroscopic Inertia suggests a minimum spin, so that the Frisbee has enough spin when ricocheted to have stable flight.

Similar research in ricochets in other sports also provides insight. An investigation into a skipping stone traversing over water through rebounds off the water provides comparable physics. Similarly to a Frisbee, 'the water surface exerts a reaction (lift) force on the stone, allowing it to rebound' (Bocquet 2002, pp.1) and thus continues its trajectory provided that the stone has enough velocity. However, a key difference between the ricochet processes is that the rebounding motion requires the leading face of the stone to be open and tilted upward whereas for Frisbees, the inverse is required, the leading edge is angled downwards so the edge contacts the surface first. What is also clear is that skipping stone 'ricochets are generally performed with a small tilt angle,  $\theta$ , and a small incidence angle,  $\beta$ ' (Bocquet 2002, pp.2). This suggests that similarly small angles should be the focus of this investigation into Frisbee ricochets.

Therefore, provided that the initial angle (in this paper defined as the angle between the angle between the trajectory and the ground) is sufficiently small, the velocity is sufficiently fast, and the rotation is sufficiently high, it can be predicted that a Frisbee will bounce off a flat surface and return to an airborne trajectory, but at what angle of inclination will the Frisbee bounce off the ground? In various physics collisions the initial angle will be equal to the angle of reflection. These situations include balls or pucks hitting and rebounding off a solid flat surface and waves (longitudinal and transverse) reflecting off an object (Diaz-Rubio et.al 2017). When a ball interacts with a surface perpendicular to its motion a compression will

occur so that it reflects off the surface in the same plane as its motion (Cross 2010). This is because of the law of conservation of energy, where the balls potential energy is converted to kinetic energy and then back again, losing some energy as heat (Chastaing et al. 2014), highlighting that the resultant velocity of the ball is less than the initial velocity due to the loss in energy. This reaffirms that a Frisbee will need a minimum threshold of velocity. Interestingly 'when a ball bounces at an oblique angle on a surface, it compresses vertically in the same way as it does when it is incident at right angles' (Cross 2006, pp. 5), however, the introduction of horizontal friction decreases the horizontal velocity and exerts a slight torque that alters the ball's spin. Whilst an alteration in spin affects the resultant angle of a ball, with a Frisbee, the spin is in the same plane as the surface that it is ricocheting off and so will not change the angle but rather (as shown through the Magnus Effect) may cause it to veer right or left. So it is hypothesized that a Frisbee will ricochet in a similar manner to a wave reflecting off a surface, or an unspinning pool ball of a cushion such that the result angle will be the same as the initial.

### Scientific research question

How can the resultant angle of a Frisbee ricocheting against the floor be determined provided that it has enough velocity and spin to do so?

### Scientific hypothesis

If a Frisbee is thrown towards the ground at angles between 10 and 30 degrees then the initial angle of the Frisbee ricochet will equal the resultant angle when the Frisbee ricochets off the ground (provided that the velocity and spin are sufficiently high to achieve a ricochet).

### Methodology

Note: initial angle is regarded as the angle between the Frisbee trajectory and floor, and resultant angle is angle between Frisbee trajectory and floor

Tape was placed to make a rectangle of dimensions 1.00 m x 0.50 m, with another strip of masking tape placed in the middle, parallel to the 1.00 m length of the rectangle (Figure 2).

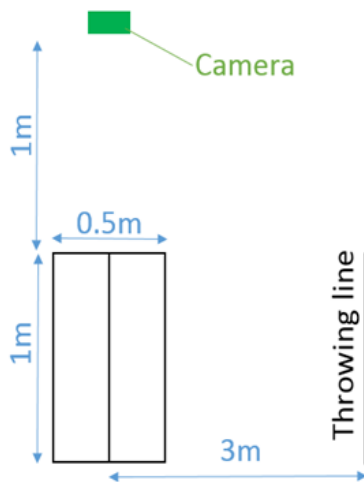


Figure 2: Diagram of experimental set up, view from above

Another tape strip was placed 3.00 m away from the rectangle, parallel to the rectangle to be the throwing line. A slow-motion camera of known frame rate (240 fps) was placed 1.00 m away from middle strip in the rectangle, so that the sight line of the camera aligns with the 1.00 m length of the strip. When recording, the thrower stood at the singular strip (throwing line) then aimed and threw the Frisbee at the rectangle attempting for the Frisbee to strike the ground at exactly the centre line of the rectangle. Thrower retrieved Frisbee and repeated, using the same throwing motion, throwing hand, type of throw, and holding technique for throw, only changing their aiming angle.

A total of 30 throws were attempted and through the video analysis 20 were determined to meet the criteria for a successful ricochet. The video of the successful attempts was uploaded to the video analysis software package Tracker (Tracker 2016). The following process was repeated for each ricochet. Using Tracker, a calibration stick was placed onto a nearby stationary object within the frame of known length (Figure 3). Calibration stick was set to that length. Calibration stick was placed onto red drink bottle and set to 26.8 cm.

In the first frame where the Frisbee was over 50% visible, a point mass was created to represent the Frisbee. The point mass was placed at the lowest point on the side of the Frisbee approaching the ground. This was consistently performed until that point was out of frame. A screenshot of the Frisbee in its last frame within the video was taken, with the trajectory of the Frisbee visible via the point mass trail (Figure 3).



Figure 3: Snapshot of the tracker, process, where the blue bar indicates the calibration stick, and the red points represent the point mass location of the Frisbee at each frame

Screenshot was uploaded to an online protractor program, and the initial angle and resultant angle as showcased by the trajectory was measured and tabulated (Figures 4 and 5).

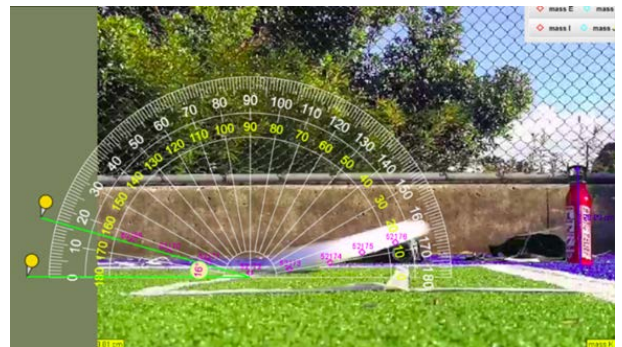


Figure 4: A snapshot of the Frisbee trajectory via the point mass trail was uploaded to an online protractor program, where the angle between the point mass trajectory and the floor was measured.

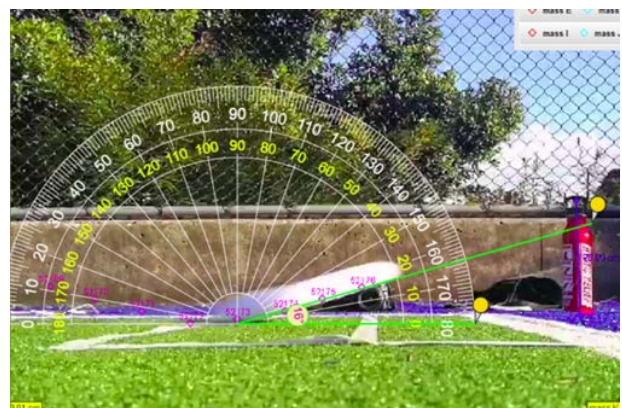


Figure 5: A snapshot of the Frisbee in that frame after it leaves the floor was uploaded to an online protractor program measuring the angle between the base of the Frisbee against the floor.

A second method of analysis involved taking a still image of the point immediately before the Frisbee hit

the ground and immediately after. Still image angle measuring was performed by screenshotting the closest frame where the front side of the Frisbee was initially interacting with the ground, and checking the angle made with the same protractor program, ensuring that the protractor line was aligned with the visible bottom edge of the Frisbee and the floor. This was then repeated in the closest frame where the Frisbee was just leaving the floor, in which the resultant angle was measured via the same method (Figure 5). Results were tabulated.

**Results**

The following table are the angles results from both methods, and the two graphs are scatter charts of the Trajectory results and Still Image results respectively

Table 1: Initial and Resultant angles for the trajectory and still image methods.

Frisbee Bounce No.	Trajectory		Still Image	
	Initial Angle (degrees)	Resultant Angle (degrees)	Initial Angle (degrees)	Resultant Angle (degrees)
1	17	15	12	11
2	19	14	14	11
3	15	14	12	11
4	15	13	15	14
5	19	13	18	11
6	16	14	11	15
7	15	13	12	10
8	12	10	10	11
9	14	12	8	11
10	16	14	13	13
11	17	15	15	14
12	12	10	12	11
13	13	12	10	11
14	15	14	12	16
15	10	12	10	11
16	11	11	11	13
17	11	12	8	6
18	11	10	13	12
19	13	9	14	10
20	14	10	13	10

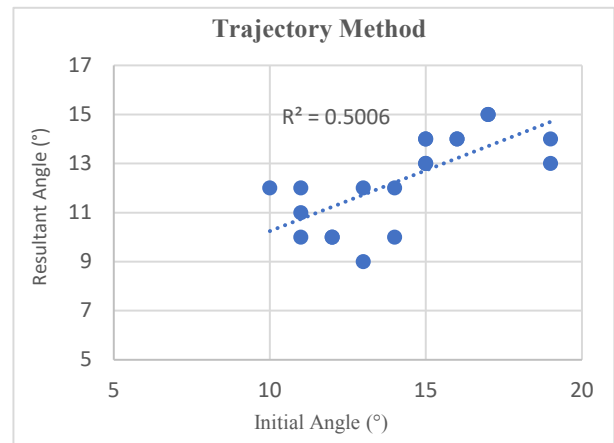


Figure 6: The results from the Trajectory method on a scatter chart, highlighting the relationship between the dependent variable, resultant angle, and the independent variable, initial angle. R value of 0.7075 was found via Pearson's Coefficient Calculator

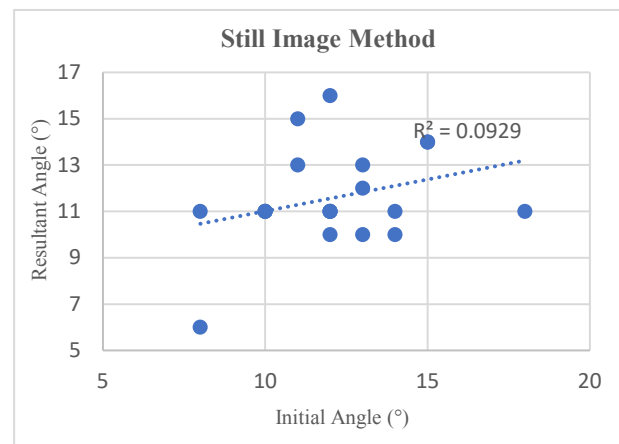


Figure 7: The results from the Still Image method on a scatter chart, highlighting the relationship between the dependent variable, resultant angle, and the independent variable, initial angle. R value of 0.3048 was found via Pearson's Coefficient Calculator.

**Discussion**

The trajectory analysis treated the Frisbee as a point mass and compared the angles associated with the path of the mass. The still-image analysis considered the pitch of the Frisbee itself, how the plane of the Frisbee was angled immediately before and after contact with the ground. Such was done due to the angle in which the Frisbee makes when interacting with the floor as with some trajectory images, the Frisbee crossed the trajectory path, indicating a discrepancy between the trajectory and the bottom lip of the Frisbee and the floor (Figure 8).



Figure 8: A snapshot of one of the Frisbee throws where the trajectory of the Frisbee crossed the Frisbee itself, highlighting the need for two methods of analysis.

In both, the initial angle can be compared to the final angle using a correlation analysis. Pearson’s R correlation was used where the R value determines the strength of the correlation (with absolute values between 0 and 1). Visual inspection of the graphs reveal that the trajectory method as resulted in a stronger correlation and this is supported by the Pearson’s R test. For the Trajectory method (Figure 6), the R value of 0.7075 ( $p=0.000484$ ), indicates a strong positive (and significant) correlation, and an  $R^2$  value of 0.5006 which means that approximately 50% of the variance in the resultant angle can be explained by the variance in the initial angle. The Still Image results (Figure 7) determined an insignificant correlation ( $p=0.191317$ ), and the R value was much smaller ( $R=0.3048$ ) which is a weak positive correlation, and an  $R^2$  value of 0.0929 meaning that only 9.29% of the variance in the resultant angle can be explained by the variance in the initial angle.

There is clearly a positive correlation between initial and resultant angle, though this correlation is stronger when considering the trajectory rather than pitch angle of the Frisbee itself. Therefore, on average as the initial angle increases the resultant angle also increases. This result is like one of a skipping stone (Bocquet 2002), where the velocity of the throw is redirected upwards in its interaction with the floor, allowing it to regain flight. However, the hypothesis was that for the Frisbee, these angles would be equal and this will be the subject of the ongoing discussion.

Evaluating the data, the resultant angle seems to have both cases where it is increased from the initial angle or decreased from the initial angle, the greatest disparity being  $6^\circ$  (Table 1), however the majority of the throws resulted in a resultant angle that was lower than initial. This is reflected in the gradient of the regression line produced as part of the correlation analysis being less than the predicted value of  $m=1$  (trajectory:  $m=0.4953$ , still image:  $m=0.2732$ ).

It was identified through the tracker analysis (Tracker 2019) that some spin is lost during ricochet, highlighting it’s increased instability after ricocheting as the torque

vector reappears (Hummel 2003), however, the remaining velocity and spin and the resultant angle is enough to regain lift through Bernoulli’s Principle (Morrison 2005; Baumbach 2010) as it has sufficient velocity to create a pressure differential (Scultze 2009; Hummel 2003) and enough spin to maintain gyroscopic inertia (Motoyama 2002; Morrison 2005). The resultant angle therefore, is dependent on the initial angle and also the loss of spin and velocity during its interaction with the floor, whereby its resultant angle is decreased due to such loss.

When comparing the two methods of analysis, the Trajectory analytical method seems to be a more valid in its approach. This aligns logically with the ricocheting phenomenon of the Frisbee, as the trajectory of the entire Frisbee’s flight before and after its ricochet would seem to provide a more valid data set than the arbitrary angle the Frisbee makes the floor the instance before and after its interaction, which is affected and limited by both the uncertainty in the Frisbees instability and also the random frame rate in which the camera captures the image of the Frisbee, in which the time between the capture and the Frisbee actually interacting with the floor can vary greatly between each measured throw. Thus the trajectory analysis method proves to be a more suitable method.

Key limitations in the analysis arise in the stability of the Frisbee during its flight due to the secondary angle that it makes with the floor in the third axis (Hummel 2003). Analysis was completed considering the z and x axis of the Frisbees flight, whereas the y axis which was neglected (Figure 9).

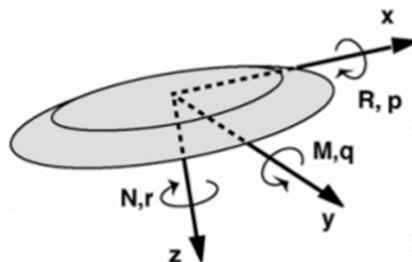


Figure 9: A photo of a Frisbee and its 3 axes from Hummel 2003

The angle the Frisbee makes with floor on the y axis subsequently affects it trajectory, as if looking from above, a y axis angle between the Frisbees right side and the floor would results in the resultant trajectory after its interaction with the floor to veer to the left as its bottom face is now directing the induced lift at an angle. Thus with a bottom face at an angle to the floor, the lift achieved by Bernoulli’s principle as discussed by Morrison and Hummel, would cause a divergence in trajectory, affecting the results seen on the x and z axis. Indeed, the y angle arises from the Magnus effect

(Hummel 2003), whereby the counter clockwise spin from the forehand throw imparts a torque on the Frisbee during flight and when it interacts with the floor (Morrison 2005), but furthermore, it is mainly due to the throwing technique, whereby the plane of the Frisbee during its release from the throwers hand is not parallel to the floor. Such can be seen in the comparison of the analysed throws (Figure 10 & 11)

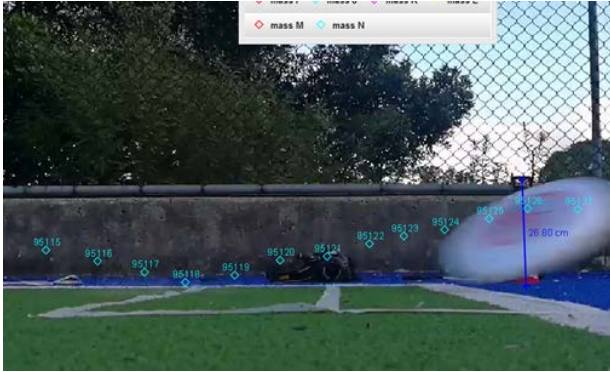


Figure 8: A snapshot of a Frisbee throw where the Frisbee's top can be seen, indicating a large  $y$  angle that affected its motion



Figure 9: A snapshot of a Frisbee where the side of the Frisbee is clearly shown, highlighting a small  $y$  axis.

#### Recommendations for further research:

First recommendation is to increase the sample size by completing more throws. The time that it would take to perform and analyse additional throws did not allow for this to be in the scope of the current project, however a larger data set would help make the relationships clearer and better allow for identification of anomalous data. Furthermore, considerations would be taken in addressing key limitations; the  $y$  axis angle would be analysed to understand the severity in which it affects the trajectory seen on the  $z$  and  $x$  axis. This can be achieved through a three dimensional analysis method. Such would require a secondary video, where it can record the angle on the  $y$  axis that the Frisbee makes. A camera placed before the target box where the Frisbee lands would be sufficient to measure the required angle. Then particular samples can be excluded if the angle in the  $z$  direction exceeded a given value.

## Conclusion

In this investigation the initial and resultant angle of a Frisbee ricocheting off the ground were compared using two analysis methods. The trajectory method (considering the Frisbee as a point charge) revealed a strong correlation ( $R = 0.7075$ ) whereas the still image method (considering the angle between the plane of rotation of the Frisbee and the ground) showed a weak correlation ( $R = 0.3048$ ). In both instances the regression analysis revealed that in general the resultant angle was less than the initial angle which means that the hypothesis that these angles are the same is not supported. It is proposed that this may be due to the loss of velocity and spin during its ricocheting interaction against the floor.

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